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# Improving the throughput of plasticating extruders : manufacture of non-circular pellets, measurement of their interparticulate friction coefficient, and implications for screw design

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# Improving the throughput of plasticating extruders: Manufacture of non-circular pellets, measurement of their interparticulate friction coefficient, and implications for screw design

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New Jersey Institute of Technology, 1992

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# IMPROVING THE THROUGHPUT OF PLASTICATING EXTRUDERS: MANUFACTURE OF NON-CIRCULAR PELLETS, MEASUREMENT OF THEIR INTERPARTICULATE FRICTION COEFFICIENT, AND IMPLICATIONS FOR SCREW DESIGN

by

**Chia-Ying Liu**

A Dissertation
Submitted to the Faculty of the Graduate Division of the
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy
Department of Mechanical and Industrial Engineering
January 1992

# APPROVAL SHEET

Title of Dissertation : Improving the Throughput of Plasticating Extruders: Manufacture of Non Circular Pellets, Measurement of their Interparticulate Friction Coefficient, and Implications for Screw Design.

Name of the Candidate : Chia-Ying Liu
Doctor of Philosophy in Mechanical Engineering, 1992

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# ABSTRACT

Title of Dissertation : Improving the Throughput of Plasticating Extruders:
Manufacture of Non Circular Pellets, Measurement
of their Interparticulate Friction Coefficient, and
Implications for Screw Design.

Chia-Ying Liu : Doctor of Philosophy in Mechanical Engineering, 1992

Dissertation Directed by: Dr. Keith T. O'Brien Keith T. O'Brien
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This dissertation addresses the hypothesis that the interparticulate friction coefficient of a bed of polymeric particulates is a function of the cross-section of the pellets. Most pellets have a circular cross-section especially those that are strand cut. But when such pellets constitute a particulate bed there are few restrictions to adjacent pellets turning with respect to each other, or of the beds rupturing under shear load. This rupture can occur in plasticating extrusion, and it results in a poorly mixed melt with an inhomogeneous temperature distribution. The temperature fluctuations cause viscosity fluctuations which in turn cause pressure fluctuations. The pressure fluctuations cause throughput variations which lead to thickness variations in the product. That results in poor quality product. This sequence of events is termed surging. If the rupture of the solid bed can be prevented then surging can be curtailed.

An increase in the interparticulate friction coefficient is expected to reduce solid bed rupturing. And the interparticulate friction coefficient can be increased if pellets with non-circular cross-section constitute it. Due to the fact that trilobal fibers

are used to provide interlocking in the textile industry, the trilobal cross-section was first tested. This led to tests on bilobal and quadrilobal cross-sections as well.

However, prior to testing the pellets required manufacture. Since bilobal, trilobal and quadrilobal cross-sections are different profile cross-sections, it was first necessary to design and build a series of profile extrusion dies. Each die was capable of producing a variety of pellet cross-sections if the material was changed, or if the throughput rate was varied. So many pellet geometries could be readily produced. Each variation of material and geometry was tested independently in a direct shear cell to measure the interparticulate friction coefficient. It was clearly found that the highest interparticulate friction coefficients occurred with pellets of bilobal cross-section, a 31% to 81% increase over pellets with circular cross-section. In addition pellets with trilobal and quadrilobal cross-section exhibited an improved interparticulate friction coefficient, a 20% to 34% increase compared to pellets with circular cross-sections. Consolidation pressure and time had minimal effects whereas agitation caused interparticulate friction coefficient increases from 51% to 89%. The effect of additives in the particulate continuum on the interparticulate friction coefficient was also studied.

Since production runs could not be made to test if surging could in fact be reduced, due to the vast amounts of feedstock required, resort was made to numerical experimentation. An existing software package was modified to allow study of the transport of a portion of the solid bed. In this way rupture could be predicted based on the value of the interparticulate friction coefficient. Thus it could be inferred that surging would be reduced.

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**This dissertation is dedicated to**
**my beloved parents**
**Ning-Ming Liu and Yang Yin-Dien Liu**
**my wife**
**Chiu-Hui Tu**
**and**
**my son**
**Kevin Liu**

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| | |
|---|---|
| $A$ | area, $in^2$ |
| $B$ | bound limit |
| $C_f$ | channel flight width, in |
| $C_c$ | channel flight clearance, in |
| $C_{ps}$ | specific heat of the solid, Btu/lb °F |
| $C_{pm}$ | specific heat of the melt, Btu/lb °F |
| $D_B$ | barrel Diameter, in |
| $D_c$ | channel depth, in |
| $F_c$ | channel flight clearance, in |
| $F_h$ | horizontal friction force, N |
| $F_v$ | vertical contact force, N |
| $G$ | mass flow rate through the extruder, lb/hr |
| $K$ | stress factor dependent on the particle shape |
| $F_d$ | screw flight diameter, in |
| $L$ | length of the extruder, in |
| $L_f$ | length of feed zone, in |
| $L_s$ | length of each geometrical section, in |
| $N$ | normal force, N |
| $N_s$ | frequency of screw rotation, rpm |
| $N_c$ | packing coordination |
| $N_t$ | number of channels (threads) in parallel |
| $P_o$ | pressure at entrance of feed zone, psi |
| $P_s$ | pressure at solid conveying zone, psi |
| $S$ | shear force, N |
| $S_l$ | screw lead, in |

| | |
|---|---|
| $S_n$ | number of geometries sections on the screw |
| T | total externally applied hirizontal force, N |
| $T_b$ | barrel temperature of the polymer, °F |
| $T_m$ | melting temperature of the polymer, °F |
| $T_{av}$ | average temperature of the polymer in the film, °F |
| V | velocity, ft/sec |
| $V_{bx}$ | velocitycomponent in the x direction of the inner surface of the barrel relative to screw, in/sec |
| $W_r$ | vertical force due to weight of ring, N |
| $W_r$ | friction force between ring and material, N |
| X | solid bed width, in |
| $X_i$ | solid bed width at the entrance of each axial increment, in |
| $X_o$ | solid bed width at the exit of each axial increment, in |
| $Z_F$ | power for feed zone, HP |
| a | constant |
| f | fractional density |
| $f_s$ | screw friction, |
| $f_b$ | barrel friction, |
| $k_m$ | thermal conductivity of the melt, Btu/hr |
| m | mean value, |
| n | parameter in the "power law" model |
| r | radius of orifice, |
| x,y,z | co-ordinate directionns |
| $\Phi$ | dimensionless constant |
| $\delta$ | thickness of the melt film, in |
| $\dot{\gamma}$ | shear rate, $s^{-1}$ |
| $\lambda$ | heat of fusion, Btu/lb |

| | |
|---|---|
| $\mu$ | interparticulate friction coefficient |
| $\psi$ | angle of internal friction |
| $\theta$ | angle of movement of the outer surface of the solid plug, radians |
| $\rho_m$ | density of melt, lb/ft$^3$ |
| $\sigma_c$ | tensile strength, psi |
| $\tau$ | characteristic relaxation time, sec |
| $\phi_s$ | helix angle at the screw root, degrees |
| $\phi_a$ | helix angle of screw at the average depth of the screw channel, degrees |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introductory Comments

The classical solids conveying and melting mechanism models for plasticating extrusion, reciprocating-screw injection molding, and extrusion blow molding assume that the solids bed remains intact. During solids conveying the particulates, are initially loosely packed and then, as the pressure is generated by the rotation of the plasticating screw, the particulates pack tightly into a solid bed. This mechanism of conveying was first presented by Darnell and Mol [16], and expanded upon by Tadmor and Klein [49].

The melting mechanism which occurs in plasticating extrusion, reciprocating-screw injection molding and extrusion blow molding, was first explained by Maddock [27] and was also expanded upon by Tadmor, Duvdevani and Klein [47]. Cross-sections of the polymer in the extruder channel are shown in Figure 1.1 in schematic form, for the solids conveying and the melting situations. In the solids conveying zone the solids become tightly packed into a solid bed continuum. As it melts from the surface in contact with the barrel, a melt film forms. The melt film grows until it is thick enough to be scraped from the barrel surface by the rotating screw flight. Then it collects in a recirculating melt pool in front of the screw flight. At this time the solids bed starts to melt from this second solid-melt interface, and consequentially develops a non-rigid side. This allows the possibility of solid bed fracture, since the bed is no longer contained by metallic walls. Gradually, all of the solids melt and the melting process is completed.

Most often this is exactly what happens in single screw plasticating extrusion. However, it is also known that the solid bed can fracture, and a discontinuity in the continuum will result. When fracture of the solid bed, or solid bed break-up, occurs it is frequently accompanied by surging of the output. The melting discontinuity resulting from the fracture precipitates a temperature non-homogeneity, which leads to a pressure variation at the die, and subsequently throughput variations, or surges. Tadmor and Klein [49] reported that for many materials, under various operating conditions, solid bed break-up can be observed. They also related solid bed break-up to the temperature fluctuations observed by Marshall, Klein and Uhl [30]. Under certain conditions, the solid bed break-up so that it fills up the channel with solids leaving no room for the melt to pass. When this happens the melt accumulating behind the solid plug occasionally breaks through causing a sudden increase in production rate and associated drop in pressure. Such a fluctuation in production rate and pressure is called surging. When surging occurs, the manufacturing system can become unstable, and low quality product can be produced. The product can even fail quality specifications and be rejected altogether. Therefore, surging is considered undesirable, and manufacturing units are frequently slowed down, or stabilized, until the surging is arrested. The causes and effects of surging have been reported by Tadmor and Klein [49]. The plane of fracture is clearly the weakest plane in the solid bed as shown in Figure 1.2. If the forces involved in the fracture are tensile, then the only methods available to maintain the integrity of the solid bed are to eliminate the tensile forces or increase the agglomeration forces of the polymer. However, tensile forces should not occur in a well designed plasticating screw since the solid bed is compressed and shear. If, however, the solid bed fractures as a result of shear loading, then an increase in the resistance of the solid bed to shear will clearly reduce, or eliminate, the solid bed break-up. Although not proven, it seems likely that the curvature of the channel may be responsible for the solid bed break-up since it may place the solid bed in a bending mode. This is illustrated in Figure 1.3. In this circumstance, tensile fracture near the barrel is possible. However, the positive pressure gradient in the screw channel should inhibit this action. Although not proven, it seems more likely that fracture would occur by the action of shear forces since the external loading is by torsional shear. Thus, if the resistance to the shear forces can be increased, then, solid bed break-up will be reduced. If the solid bed remains intact cold spots due to solids broken up on the melt cannot cause temperature variations in the melt at the die and so viscosity will not occur, therefore pressure variations and output variations will not occur. Clearly, the resistance to any applied shear force will be increased in proportion to the interparticulate friction coefficient. Hence, the onset off surging may be postponed.

## 1.2 Previous Studies

Although the interparticulate friction coefficient has not been extensively studied, the friction coefficient between polymeric particulates and various metals has received extensive attention. This is due to its importance in solids conveying calculations for the design of plasticating screws for extrusion, injection molding and blow molding, and the need to accurately know the friction coefficients between the metal surfaces and the polymeric particulates. The interparticulate friction coefficient, by contrast, is not measured, but is assumed to be great enough to maintain the integrity of the solid bed.

Schneider [41] was the first to measure the coefficients of friction between metal surfaces and polymeric particulates, noting its dependence on temperature, normal load and relative sliding velocity. Evans [18] confirmed the findings of Schneider in a more sophisticated apparatus. Finally, Huxtable, Cogswell and Wriggles [23] developed an apparatus which accounted for the above effects, as well as channel depth and particulate location. These authors provided extremely accurate, and extensive, results for several polymers. However, no additional results have been reported for the interparticulate friction coefficient since Jenike [25].

Thus, the assumption has always been made that the solid bed remains intact, and that the metal-polymer friction coefficients dominate the solids conveying in plasticating extruders, reciprocating-screw injection molding machines, and extrusion blow molding machines.

Subsequently the development of the barrier screws by Maillefer [29], where the solid and melt fractions are separated, and the many derivatives which followed [4], have provided a way to maintain the integrity of the solid bed, as well as to hasten melting. However, the designs are more complex, the screws more costly, and output is not necessarily increased. In addition, these designs have not penetrated the reciprocating-screw injection molding machine market, or the extrusion blow molding machine market. Yet, solid bed break-up can cause severe aberrations in these processes.

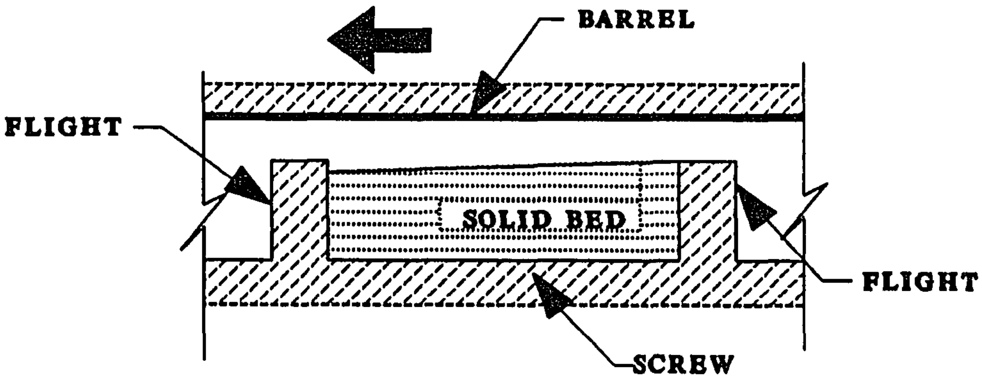
Clearly there is a strong motivation to maintain the production unit close to surging conditions in order to maximize the throughput, but it is taken at the risk of quality diminution. If the throughput could be increased, without the occurrence of surging, the resultant cost benefits would be significant. In fact, only a 5% increase in extruder throughputs would result in billion dollar savings to the industry.

### 1.3 Scope of the Present Work

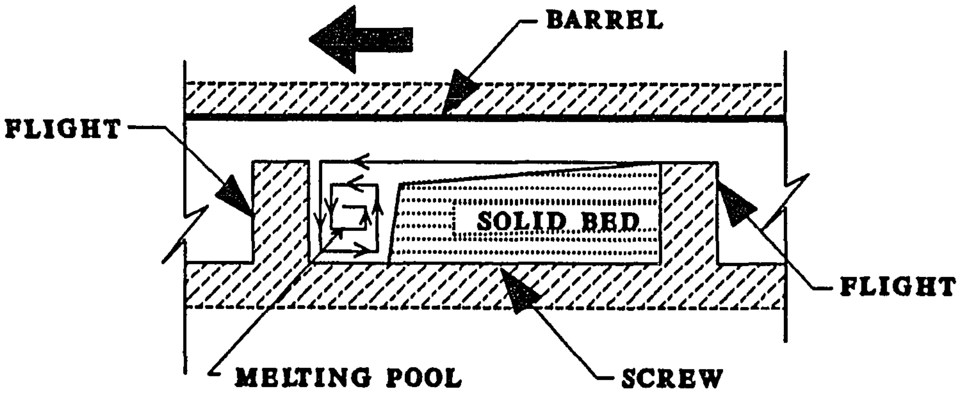
In this work, the hypothesis that increasing the interparticulate friction coefficients reduces the likelihood of solid bed fracture is tested. The resistance of the solid bed under shear loading is increased if the interparticulate friction coefficient is increased. The increases of interparticulate friction coefficient are expected if the polymeric particulates can be made to interlock. This action is further hypothesized if the traditional pellets of circular cross-section are replaced by pellets with more complex geometries which allow interlocking to occur. Some examples of pellet geometries which allow interlocking are shown in Figure 1.4 (a) and the methods by which they may interlock are shown in Figure 1.4 (b). There are many ways that pellets can rest against adjacent pellets, and the real system will involve a statistical combination of all of them. The manner in which they touch directly affects the interparticulate friction coefficient of the particulate continuum, and this coefficient will be utilized as a measure of the behavior of the particulate continuum without studying the explicit details of the situation. Although the interparticulate friction coefficient has not been extensively studied, the friction coefficient between polymeric particulates and various metals has received extensive attention. This is due to its importance in solids conveying.

In this study, the concentration has been placed upon pellets with multi-lobal cross-sections such as the bilobal, the trilobal and the quadrilobal as shown in figure 1.4 (c). The fabrication of pellets with multi-lobal cross-sections is presented in chapter three and four, including the task of designing, constructing and operating a profile die which produces consistently shaped pellets, during extrusion. The measurement of the interparticulate friction coefficient was first presented by Jenike [25], in his classic work on soil mechanics. For polymers, however, scant data is available [48]. The experimental apparatus, known as a direct shear cell, used for these measurements is described in chapter six and the experimental results are presented in chapter seven.

The simulation for the plasticating extrusion process is illustrated in chapter nine, in order to justify the performance of the screw extruder, to accomplish the optimum conditions for the extrusion process.



(a) Solids Conveying Zone



(b) Melting Zone

Figure 1.1 Solids Bed in Plasticating Screws, (a) Solids Conveying Zone, (b) Melting Zone.

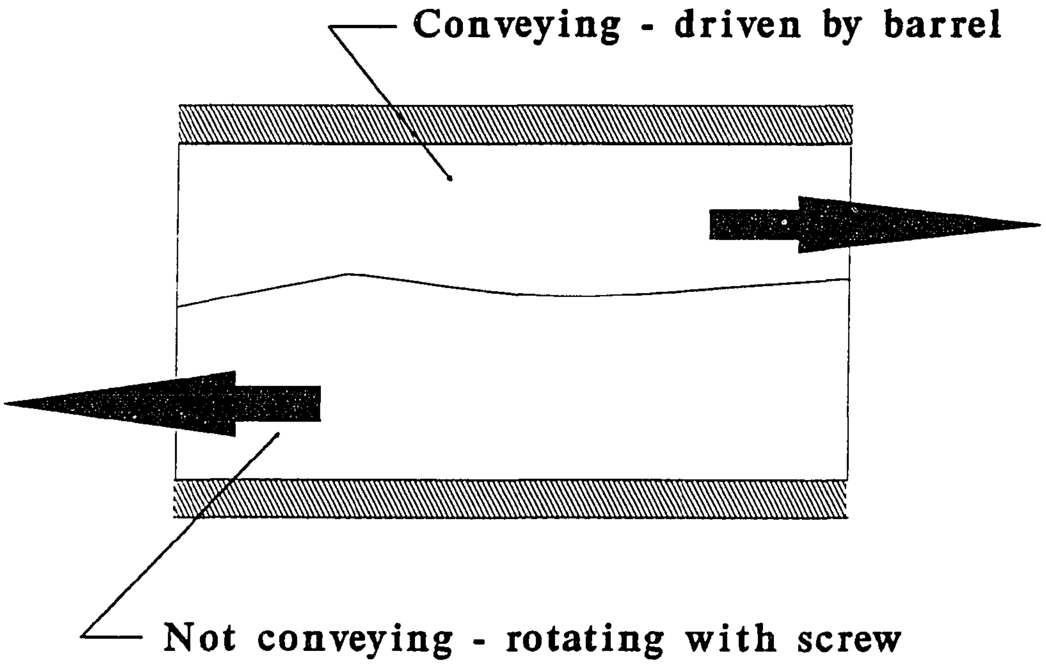


Figure 1.2 The Fracture Plane on Solid Bed.

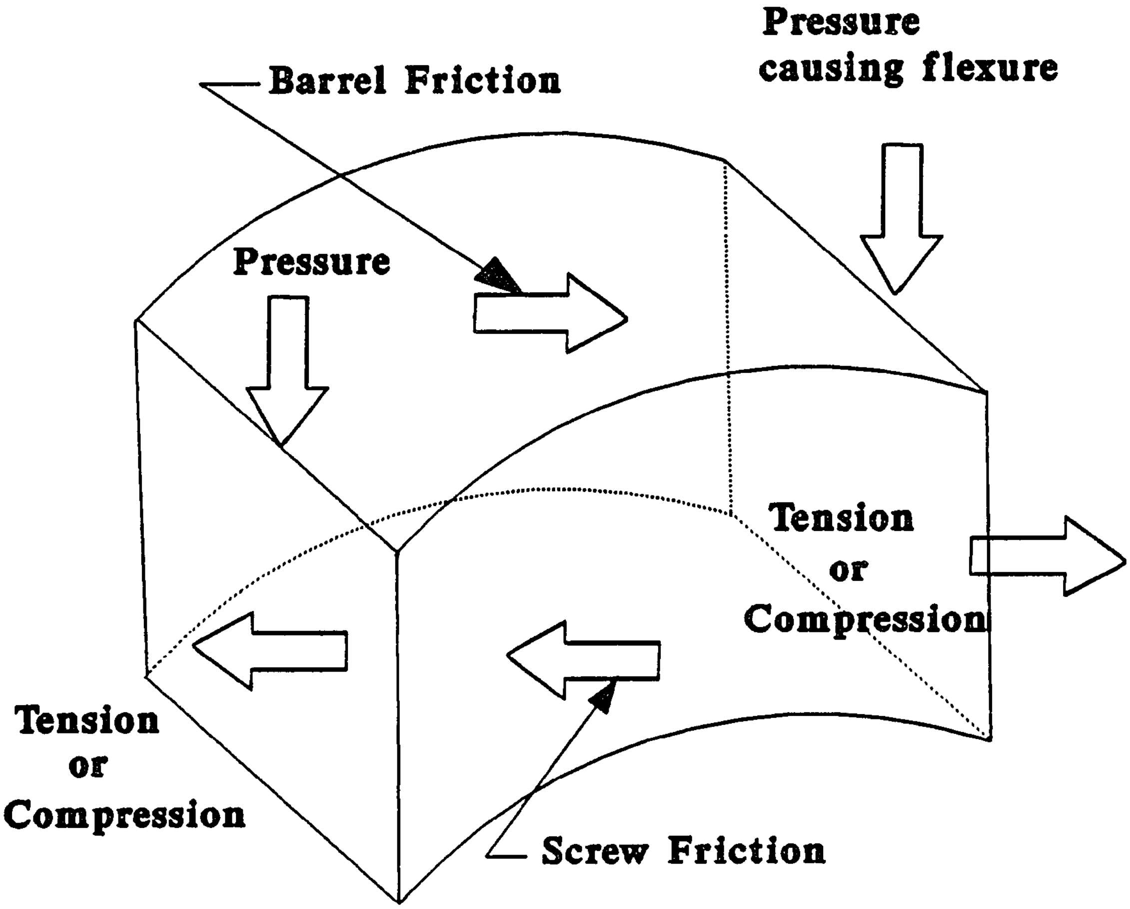


Figure 1.3 Forces Acting on a Portion of the Solids Bed.

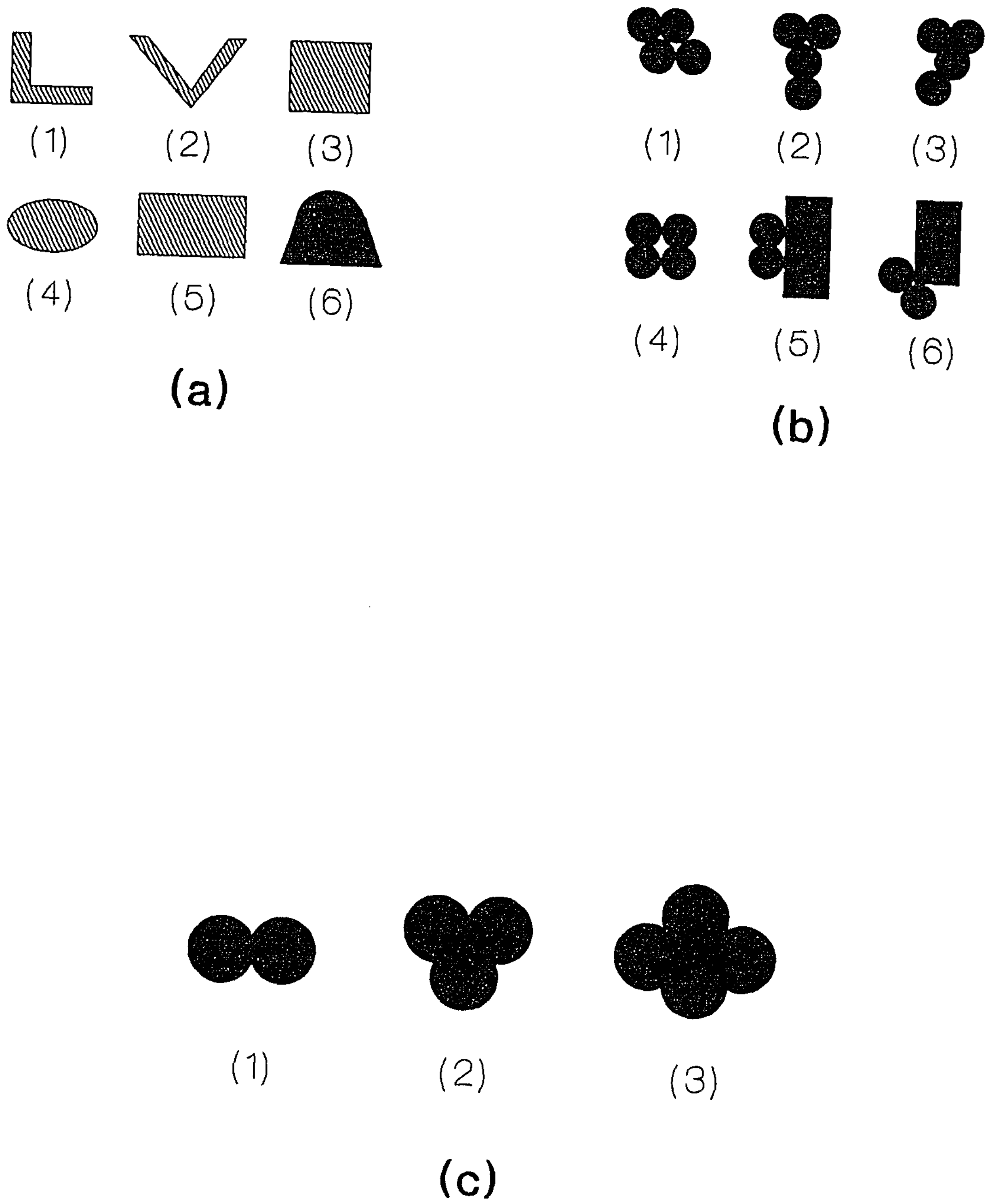


Figure 1.4 Non-Circular Pellet Cross-Sections, (a) Possible Geometries, (b) Possible Interlocking Mechanisms, (c) Multi-Lobals.

# CHAPTER 2

# THE BASIS FOR ENHANCING THE INTERPARTICULATE FRICTION COEFFICIENT IN PLASTICATING EXTRUSION

## 2.1 Fundamentals of Single Screw Extruders

The single screw extruder is the most important equipment used in the polymer processing field. All polymers pass through an extruder at least once in the production path from the polymerization reactor to the finished product. The single screw extruder is in fact the central component of a whole group of processing machines, such as the melt extruder, the injection and blow molding machines.

The single screw extruder is shown in Figure 2.1. The plasticating process is divided into three zone. These are,

a. solid conveying zone

b. melting zone

c. melt conveying zone

The solid conveying zone transfers the granules, or pellets, from the hopper at the input of the extruder, and conveys the solid to the melting zone. Its conveying capacity must be at least equal to the metering capacity on a weight basis. In the feed section the solid plastic particles, generally in the form of cylindrical pellets, are pushed along the channel by the rotating screw. The solids conveying zone is considered to end where the solids begin melting. The melting and compression zone starts at that transition point. After all the solids is totally melt, it enters the melt conveying zone.

The variables which control the solid delivery are discussed by Decker [17]. These are the shape and dimensions of the channel, surface temperature, back pressure. and the coefficient of friction between the plastic and the metal of both the screw and the barrel surface.

## 2.2 Solids Conveying Zone

The solids conveying mode was proposed by Decker [17]. Though, the conclusions given by Decker correlate qualitatively with experience, the formulas given do not relate well to actual behavior. In 1947 Weber [54] treated the plastic plug as a solid continuum but neglected the forces acting between the barrel and the material.

A much more realistic approach for the conveying of solids in the screw extruder is given by Pawlowski [35]. He proposed a balance of forces on the screw channel. The analysis of this balance is based on the estimation of the mechanical forces acting upon the solid plug of plastic from the barrel and screw. All forces result in either pressures normal to the flight surface or shearing forces due to friction parallel to the contacting surfaces.

Maillefer [28] also discussed the solids conveying section, but his analysis was not made in curved channels where torques are involved, and therefore, did not include all forces acting on the solid plug. Simonds, et al. [44] stressed the importance of friction on solids transport and introduced the balance of torques, but this treatment can predict only whether or not solids will be conveyed. Jackson, et al. [24] performed a similar analysis to that of Maillefer but included the normal force that the pushing flight exerts on the plastic plug. However, because they did not perform the essential balance of torques, the equations have little value.

The most thorough analysis for the conveying of solids in the single screw extruder was performed by Darnell and Mol [16], who also reviewed previous work in this area. The analysis presented by Darnell and Mol [16], will be followed with some modifications. Among these, the width of the flights will be incorporated into the derivation, and different friction coefficients will be assumed on the barrel and screw surfaces. Since friction forces between the solid polymer and barrel and screw surfaces play a decisive role in the solids conveying mechanism.

## 2.3 Melting Zone

The melting zone, or phase transition zone, is defined as that portion of the screw in which solid polymer and melt coexist. The melting mechanism in screw extruders was first investigated by Maddock [27] and by Street [46]. They developed the experimental techniques which led to the development of a qualitative mechanism for melting through visual observation, and then enabled the development of a theoretical model for melting through quantitative analysis by Tadmor [48], and by Tadmor, Duvdevani and Klein [47].

Furthermore, a good understanding of the melting mechanism is of paramount importance for the understanding of plasticating screw extruders. The solid pellets which are fed into the hopper start moving toward the die, at a certain point the barrel starts heating, the solid pellets which touch the hot barrel surface. They melt and form a thin film of melted polymer on the barrel surface. When the pellets reach this point, they are no longer loosely packed, since considerable pressure is developed. It tends to compact the pellets into a sturdy solid bed. The bed has the shape of the helical channel and slides in it. In spite of the compacting, the pellets retain their individuality, and the boundaries between the individual pellets are clearly visible in the solid bed way down the channel. The barrel surface is moving relative to the solid bed and the screw. Due to this relative movement, a velocity profile develops in the melt film between the solids bed and surface of the barrel. Thus, the melt in the film starts to flow toward the advancing flight, and as it meets the flight, the latter scrapes the melt off the barrel. The melt collects in the pool of melt in the rear of the channel in front of the advancing flight. As the solid bed slides down the channel, more and more melt is carried into the pool of melt, the size of which consequently increases, while that of the solid bed decreases. Thus, in spite of the fact that most of the melting occurs at the barrel surface, or rather at the interface of the melt film and the solid bed, the height of the solid bed does not decrease and the solid bed is continuously rearranged while maintaining a constant height. In effect this rearrangement causes the solid bed to continuously move into the interface where it melts. Consequently, the width of the solid bed gradually decreases as it moves down the channel. The total length from the onset of melting to the point where the solid bed width drops to zero is termed length of melting zone. It must be realized that there are two sources of heat in the melting mechanism. One is the heat which comes from the heaters on the barrel. This heat conducted from the hot barrel surface through the film into the interface. Another is the heat that originates from viscous dissipation due to the relative velocity of the barrel and screw shearing the thin film. The ratio of these two heat sources depends entirely on the operating conditions and the polymer properties. The solid bed is composed of compacted solid particles. If the solid bed can not resist the shear force, it will usually break up at some point in the channel. The gap created by the breaking up of the solid bed is quickly filled with melt. This breaking up process, if it occurs, is not accidental or random. The solid bed is dragged forward by the barrel. In addition, large pressure gradients exist in the channel, and the solid bed has a different velocity from that of the neighboring melt. Meanwhile, the rest of the solid bed will move forward until once more external forces overcome the resisting forces. This second and sequent breaking of the solid bed usually occurs at approximately the same point in the extruder as the previous one. Obviously there seems to be an inherent instability in the melting process. The solid bed break up occurs, accompanied by surging of the output. The solid bed fractures as a result of shear loading, then increases in the resistance of the solid bed to shear will clearly reduce, or eliminate, the solid bed break up. Clearly , the resistance to any applied shear force will be increased in proportion to the interparticulate friction coefficient. Therefore, the surging phenomena may be inhibited or postponed.

## 2.4 Melt Conveying Zone

The melt conveying zone is the last section of the screw preceding the die. It produces the die pressure which controls the flow rate of the extruder. It acts as a metering pump from which the molten plastics material is delivered to the die system at constant volume and pressure. There are two distinct melt conveying mechanisms. One is downstream the melting zone after the completion of melting, Another melt conveying mechanism occurs in the melt pool, which extents side by side with the solid bed profile, in the melting zone the width of the melt pool changes in the flow direction. Where the model for the melt conveying zone of a plasticating screw extruder discussed by Tadmor and Klein [49] stipulates the equations for calculating the flow rate, pressure, temperature, and velocity distributions across the channel as well as down the channel. In order to solve the basic flow equations, there are two different theoretical models proposed. One is a simplified flow theory where the nature of the polymer melt and the temperature conditions in the channel is based on isothermal Newtonian flow, which was proposed by Rowell and Finlayson [38] and later by Carley, Mallouk and McKelvey [9]. Another is non-Newtonian flow by using the "power law" fluid model, which was proposed by Ostwald [34] and Glyde and Holmes-Walker [20]. Here the melt conveying model is used to calculate local pressure gradients and temperature changes over small finite axial increments using the mean local flow rate and melt pool size. It also provides additional information relevant to extruder design and operation, specifically the power input required for this zone.

## 2.5 Extrudate Quality

The object of melt extrusion of thermoplastics is the continuous production of useful products of given, uniform cross section, and quality. The appearance of rough extrudates and those whose shapes do not conform to the cross section of the openings of the extrusion dies may result from any of the following causes, such as the presence of volatile material and gel particles in the polymer, extrudate swelling, poor die finish, and melt fracture.

It is well known that volatile constituents such as water may cause crater-like depressions from burst surface bubbles and that gel particles may cause small bumps. Elimination of such defects obviously requires elimination of the volatiles and gels.

The dimensions of the cross section of extrudates always tend to be larger than the corresponding dimensions of the extrusion dies. The extrusion swelling does not usually cause roughness. However, it may result in considerable distortion of the extrudate shape relative to that of the die. The amount of extrudate swelling may be reduced by any of the following - drawing the melt, raising the temperature, lengthening the die, and lowering the throughout.

Rough interior surfaces on extrusion dies may result in rough extrudate surfaces. Tool marks or scratches in a die land in the direction of flow tend to cause marks or streaks along the length of the product. However, a mirror finish on die lands may not be necessary. Sand blasted surfaces and those on which the tool marks are transverse to the flow direction appear to have little effect on the finish of the extrudate surface.

At low extrusion pressures or shear stresses, extrudates are smooth and regular, and the flow rates low. As the pressure is increased, the flow rate and the diameter of the extrudate increases. At and above a critical pressure the extrudates become increasingly irregular. Melt fracture initiates and propagates in die inlets at and above critical pressures described by Tordella [51]. The irregular shapes of the extrudates result from "elastic memory". After emerging from the die, the extrudates tend to regain the configuration they had before extrusion. Melt fracture, which is an irreversible process, makes the recovered shape asymmetric, Spirals and segments result.

Since melt fracture occurs at and above a critical stress, it may be avoided by suitable manipulation of the extrusion variables to keep the stress below the critical level. Any combination of the following methods may be used to reduce the shear stress to eliminate melt fracture,

1. Lower the viscosity by raising the temperature,
2. Use a streamlined ar gradually tapered inlet,
3. Lower the throughput by reducing the pressure.

Of the above expedients by which melt fracture may be avoided, use of streamlined inlets is the most effective. No other change in the operation may be required.

Melt fracture sometimes occurs when operating an extruder at a high throughput rate. The extrudate takes on a rough irregular appearance which cannot be attributed to any other cause than the physical breakdown of the melt or 'melt fracture'. This phenomenon occurs when the shear stress of the melt exceeds its shear strength such as for example in an extrusion die where, due to a substantial reduction in channel width, a sudden increase occurs in the shear rate. Original investigations by Tordella [51] showed that melt fracture occurred at a critical pressure which varied with the viscosity of the melt, the die pressure and the die geometry. As the last fracture was the only one which could be modified without causing a loss of output, the effect of the inlet geometry, and land length of the dies was considered. The theoretical aspects of melt fracture have also been studied by Schulken and Boy [42] and applied to the development of a method of calculating the die entrance geometry. What Tordella [51] called a critical pressure, Schulken and Boy [42] call a critical shear rate which is dependent principally on the die entry geometry and viscosity.

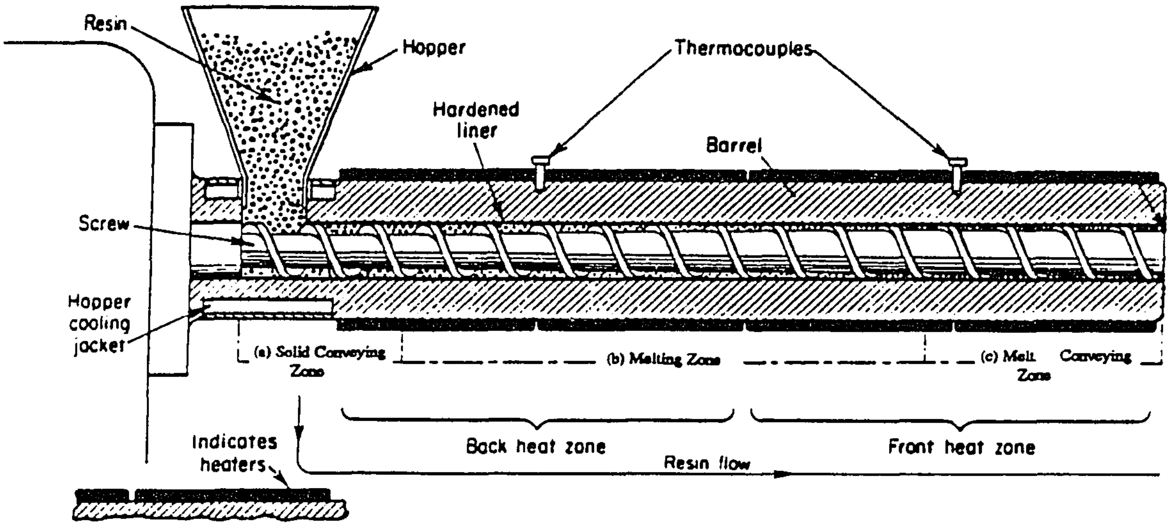


Figure 2.1 Typical Single Screw Extruder with Three Zones (a) Solid Conveying Zone, (b) Melting Zone, (c) Melt Conveying Zone.

(From "Petrothene® Polyolefins: Aprocessing Guide," 3d ed., U.S. Industrial Chemicals Co., New York, 1965)

# CHAPTER 3

# DESIGN OF EXTRUSION PROFILE DIES FOR THE MANUFACTURE OF PELLETS WITH PROFILED CROSS-SECTIONS

## 3.1 Aspects of Die Design

Extrusion dies can be designed to produce special shapes for different end products. The specific dies are classified into several kinds, such as for sheet, for film, for pipe and tube, for wire covering, and for profiles. The quality of an extruded product, however, depends not only on the extruder and the material used, but also on the efficiency of the die and other pieces of equipment which are part of the process.

The function of an extrusion die is to form the molten material delivered by a screw into a required cross-section. The die is, therefore, a channel whose profile changes from that of the extruder bore to an orifice which produces the required form. The behavior of a thermoplastics melt over the required range of shear rates and temperature and to be able to relate this viscosity with the flow of the melt under pressure through the different sections of which the channel is composed, must be predicted.

Basically, Corbett [14] and Weeks [55] described that the following must be taken into account in designing profile dies: 1. The flow channel must not have any " dead spots" (stagnation points), 2. From the time that it enters the die until it leaves, the melt must be accelerated as constantly as possible until the desired exit velocity of the melt is reached in the die land, 3. The construction of the die should be keep simple and the die should be easily dismountable for cleaning and possible corrections to the flow channel.

There are plate dies and streamline entry dies. The first is illustrated in Figure 3.1 and shows that the shaping orifice is in a flat plate attached to a die holder. It is evident that there is a great deal of stagnation in the region behind the die. For some materials, such as the polyolefins, which are thermally stable, that is not a serious problem. On the other hand, thermally sensitive materials, such as rigid PVC, cannot be run for a significant length of time in plate dies. The degraded material which forms in the stagnation regions will start to release stained and decomposed resin and the result will be an unstable product. Figure 3.2 illustrates a streamlined die which has a transition section that matches the flow from the extruder head diameter to the product shape. This type of tool construction is used to prevent stagnation of material in the die.

### 3.1.1 Die Swell

The die swell is a characteristic of the material which results as it exits from the die orifice. The visible swelling of the material at the die exit has its cause in the reversible deformations, which are stored in the material as it leaves the die and are a function of the prior deformation and relaxation history investigated by Graessley, Glasscock, and Crawley [21], as well as the rearrangement of the velocity profile at the die orifice to a block profile, which results in local extensions in the cross-section. The two phenomena cannot be separated from each other. Rothermeyer [37] reported that the effect of the prior history on the achievable cross-section was shown in Figure 3.3. It demonstrated that star-shaped and circular inlet regions were selected in the square outer die ring of length L; $R_{eff} = (2\ A_{die}/\text{perimeter of die})$, corresponding to a comparison radius in the region similar to half the "hydraulic diameter". The influence of the inlet zone decreases as the length of the outer die ring and therefore the residence time increases. Figure 3.3 also illustrated that a star-shaped die would be required in the exit region in order to produce an exactly square profile.

This strictly phenomenological finding can also be quantified by calculating the reversible elastic deformations at the outer die ring; for this purpose, experimental data for the material under consideration is required in order to establish a correlation between the calculated values and the swell. It must be noted that these analyses and calculations were carried out one dimensionally, that is, only over the height of the flow channel. The results are therefore directly applicable only to simple profiles such as round, strand, pipe, plane, and sheet. A calculation of the distribution of reversible deformations over a complicated profile of any cross-section is still pending. The already referred to rearrangement of the velocity profile for any profile has also not yet been calculated. However, it is expected that the calculations for both problems will be carried out by the "method of finite elements" in the future.

The swell potential, that is, the reversible deformation, can be decreased in a parallel die land. If the effect of the prior history, in the pre-zone and the inlet zone, on the geometry of the emerging profile cross-section is to be avoided a length, L must be chosen for the die land described by Tanner [50] shown as below,

$$L > \tau_{relax} \frac{V}{A} \qquad (3.1)$$

Here $\tau_{relax}$ is a characteristic relaxation time, which can be obtained from experimental, rheological investigations of the flow. Deformations, which are introduced in the die land, also be regarded as providing only an estimate in the case of geometrically complicated profile cross-sections.

The difficulties associated with calculating the swell and the unawareness of the order of magnitude of the velocity profile rearrangement, which also contributes macroscopically to the deformation of the profile emerging from the die orifice, have contributed to the fact that empirical values are used in practice for correcting the die exit cross-section for swell.

### 3.1.2 Die Land Length

Practical experience has to some extent determined this parameter. In the form of the rule of thumb the land length/orifice thickness ratios which are widely used an about 10 : 1 for materials of high viscosity such as unplasticised PVC and up to a ratio of 30 : 1 may be used for low density polyethylene.

Although it is instructive to calculate the approximate flow through an extrusion die using the foregoing formula, it must be pointed out that the usefulness of this exercise is confined to comparison values only. There are usually far too many imponderables to allow the accurate calculation of die dimensions from theoretical considerations alone and practical experience must, be the guide at least in the early design stages. The die land/orifice thickness ratios referred to above for example take into account the experience of the designer, for surface finish, compound lubrication, filler loading, the construction of the die upstream of the land and the system of product sizing to be used. It is obviously difficulty to describe such factors in mathematical terms so that in the final analysis the die land/orifice thickness and other ratios established over the years by trial and error usually form the basis of most practical die designs.

The calculations are, however, often of great value when changes or modifications are required. It has been inferred above that the pressure drop across the lands of a die is proportional to the cube of the thickness. Thus if the wall thickness of a tube is changed to produce a product of different dimensions, the land must be changed by the cube of this difference to maintain the same pressure gradient at the same melt temperature, or viscosity.

In applying the cubic relationship, it is also important to realize that with dies of very small wall thickness such as used for the production of polyethylene film, the shear rates encountered in the narrow annulus may be quite high. Besides causing a considerable local decrease in viscosity and thus of pressure drop these high rates of shear can also cause a considerable departure from Newtonian flow on which the cubic relationship is based. Moreover, the rigorous application of the cubic relationship to the design of dies for very heavy sections would result in very long dies which could tend to become prohibitive as the thickness increased. However, provided these two extreme conditions are dealt with in an intelligent manner, the cubic expression for land length/annulus width relationship can form a very useful guide in die design.

### 3.1.3 Die Entry Geometry

By testing each resin with a standard set of capillaries having different entrance angles and plotting the critical shear rate against the half angle of entry was presented by Levy [26], Figure 3.4, a curve for each resin is obtained, which can be used as a reference for calculating entrance geometry from,

$$\dot{\gamma} = \frac{4\,Q}{\pi\, r^3} \qquad (3.2)$$

where,

Q is the desired rate of flow,

r is the capillary radius,

$\dot{\gamma}$ is the shear rate.

If the desired output and shear rate are determined, the orifice radius can be calculated from Eq. (3.2),

$$r = \sqrt[3]{\frac{\dot{\gamma}\pi}{4Q}} \qquad (3.3)$$

The influence on extrudate quality of die entry length has also been given by White and Kondo [56]. The die entry geometry is shown in Figure 3.5. The importance of entry geometry is not confined to melt fracture problems. Melt expression caused by elastic recovery of the melt as it leaves the die is important in establishing die design.

### 3.2 Specific Die Design

The original die is schematically shown in Figure 3.6. It is composed of two parts, one part, A, is a flanged type connector, the other part, B, is a long channel profile die. This kind of die design is suitable for simple shapes of profile. If the shape of profile is complicated, due to the long channel, it is hard to fabricate all of part B. Therefore, in order to manufacture different shapes of pellet, the original die has been changed into a four parts assembly, which is schematically shown in Figure 3.7. It is composed of four parts, A, B, C , and D. The part A is the same as in Figure 3.6. It is more convenient to change the different profile dies for the manufacturing process for different shapes of pellets. Only part D is changed. This process can be performed within ten minutes, while the whole body of the profile is unaffected.

Moreover, the new die design, eliminates the disadvantage of the original one. It not only saves the cost of remaking the whole of B for the original die, but also saves the time for replacing the flanged type connector, in order to insert the different shapes of profile die. It is apparent that the channel of the profile is shorter and easier to fabricate than the original die.

### 3.3 Profile Die Inserts

In order to manufacture the different shape of pellets, seven profile die inserts were used. Each was fabricated in the work shop of the M.E. Department. The specification of the profile die inserts is categoried in Table 3.1. The first digit represent the number of orifice in the profile die insert, and the second the radius of the orifice. The last indicates the die land length of the die insert.

In Figure 3.8, it contains seven die inserts. The profile die inserts A211 (A201-01) and A212 (A201-02) have the same radius of orifice, but the die land length is different. The profile die inserts A221 (A202-01) and A231 (A203-01) have the same radius of orifice, but the distance between the orifice is different. The profile die inserts A241 (A204-01) has the largest diameter of orifice for the bilobal profile die. The profile die insert A311 (A301-01) has three orifice in profile die for manufacturing the trilobal pellet. The profile die insert A411 (A401-01) is a quadrilobal die for producing the quadrilobal pellet.

Table 3.1 Specification of the Profile Die Inserts.

| No | Profile Die | (1th digit) Orifice Number | (2nd digit) Orifice Diameter (in) | (3rd digit) Orifice Die Length (in) |
|---|---|---|---|---|
| 1. | A211 | 2 | 5/64 | 1.0 |
| 2. | A212 | 2 | 5/64 | 1.5 |
| 3. | A221 | 2 | 1/16 | 1.0 |
| 4. | A231 | 2 | 1/16 | 1.0 |
| 5. | A241 | 2 | 3/32 | 1.0 |
| 6. | A311 | 3 | 5/64 | 1.0 |
| 7. | A411 | 4 | 5/64 | 1.0 |

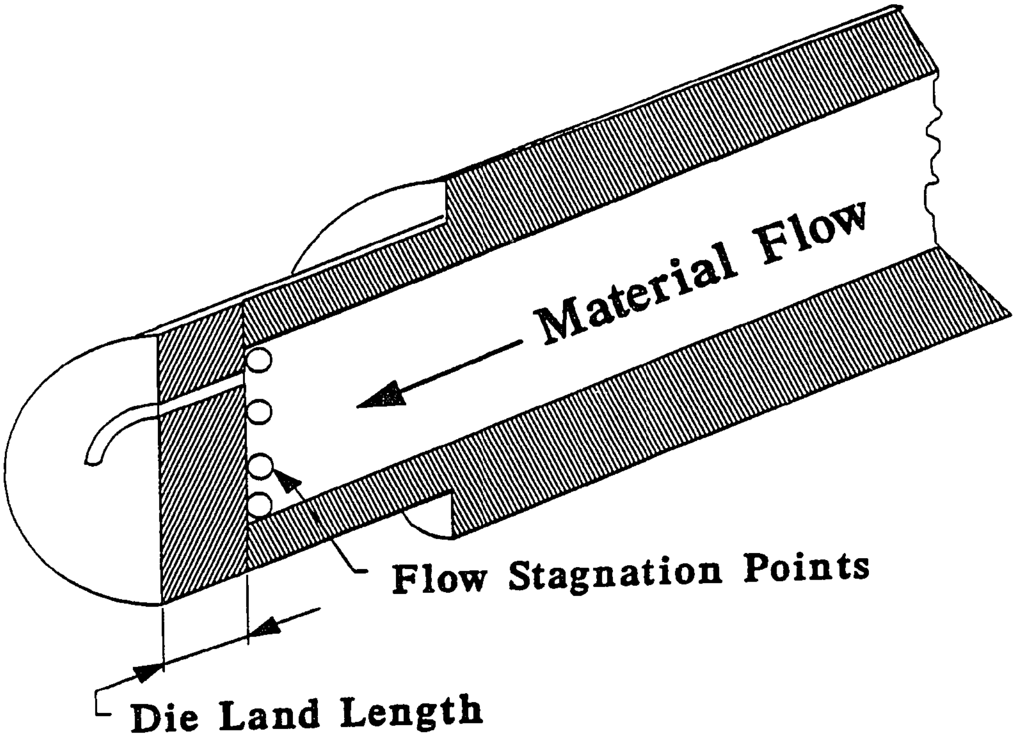


Figure 3.1 Plate Type Profile Extrusion Die.

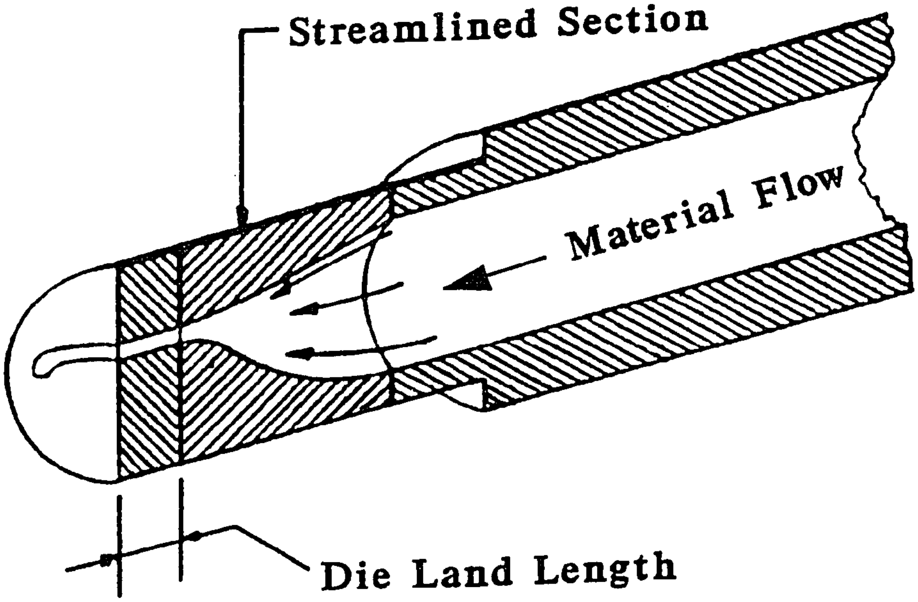


Figure 3.2 Streamlined Profile Extrusion.

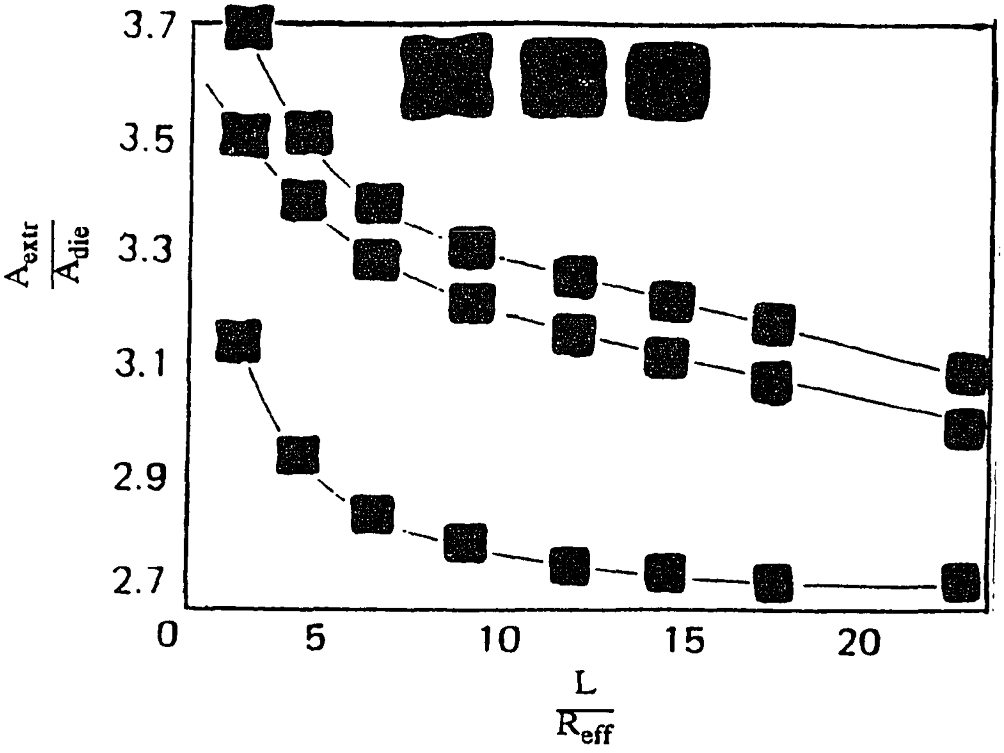


Figure 3.3 Effect of Entrance Flow Channel and Die Length on Extrudate Swelling. (From F. Rothemeyer, Kunststoffe, 59, 333 1969)

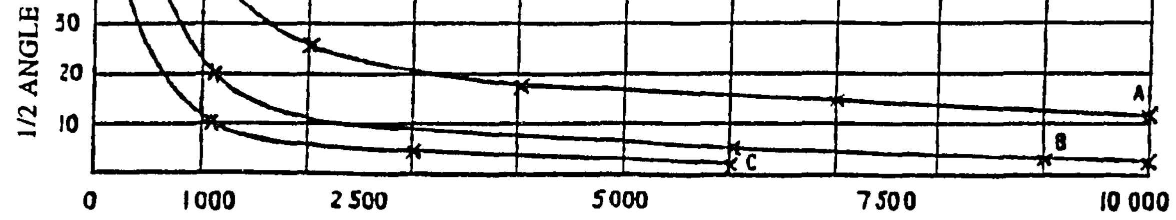


Figure 3.4 Typical Curves Showing Effect of Capacity Entry Angle on Critical Shear Rate for Three Different Resin.
(From E. G. Fisher, "Extrusion of Plastics," New York, 1976)

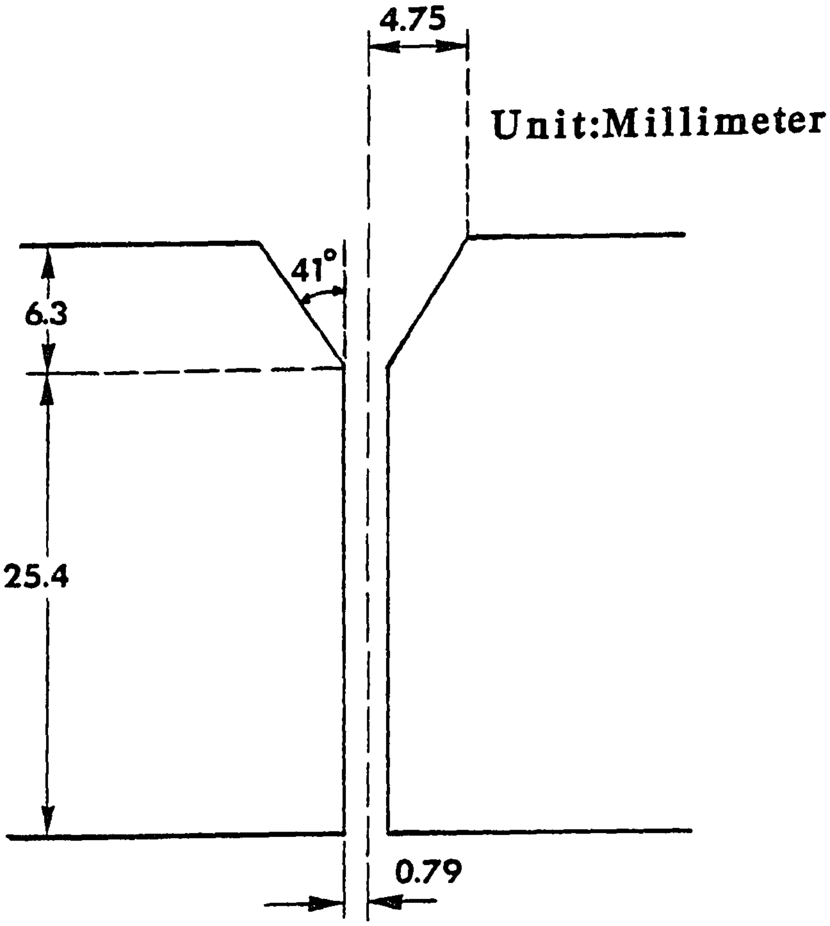


Figure 3.5 Diagram of Entry Geometry.

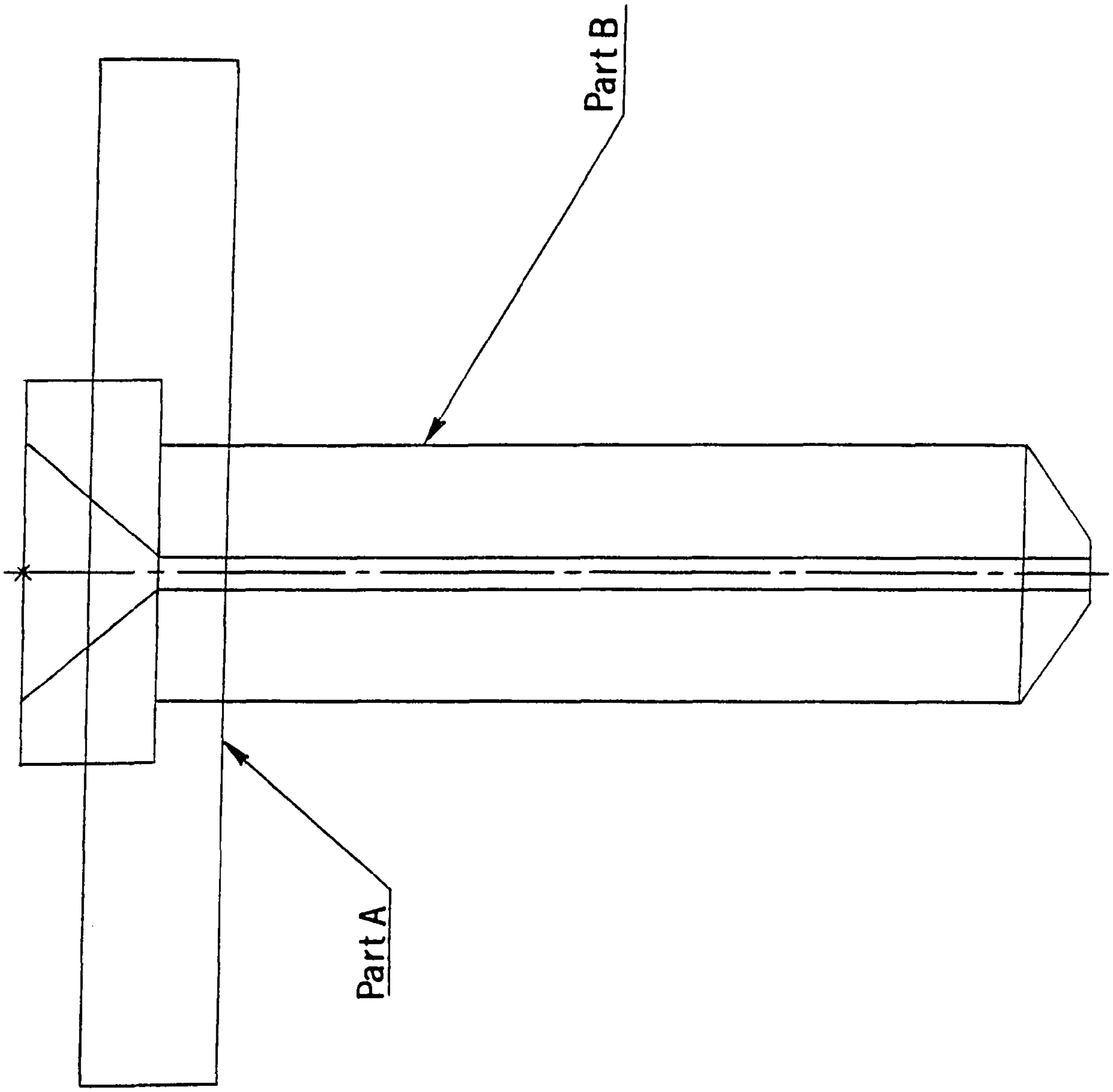


Figure 3.6 Original Die in Test Extruder.

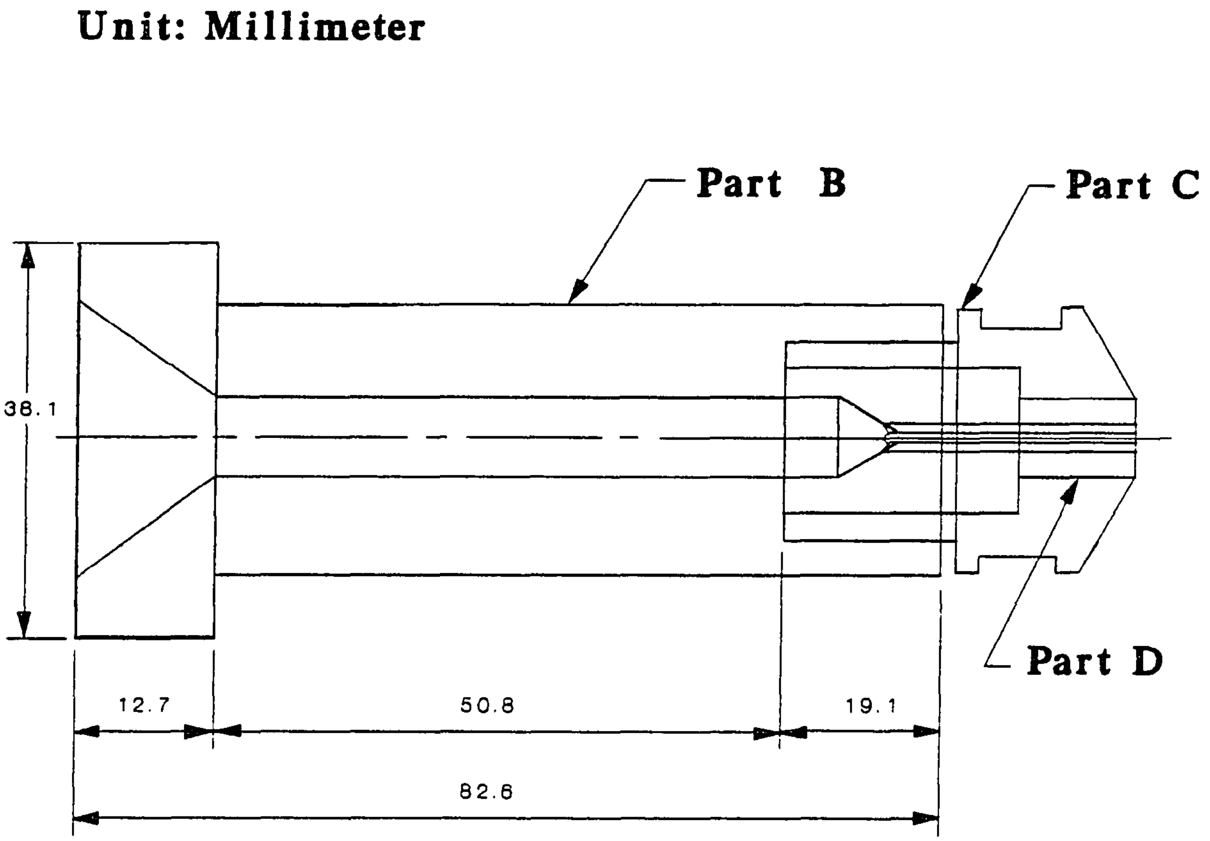


Figure 3.7 Modified Die in Test Extruder.

**Material:Stainless Steel**
**Unit:Millimeter**

|  | L1 | R1 | L2 |
|---|---|---|---|
| **A211** | 38.1 | 0.99 | 2.4 |
| **A212** | 50.8 | 0.99 | 2.4 |
| **A221** | 38.1 | 0.79 | 3.0 |
| **A231** | 38.1 | 0.79 | 2.0 |
| **A241** | 38.1 | 1.2 | 2.82 |

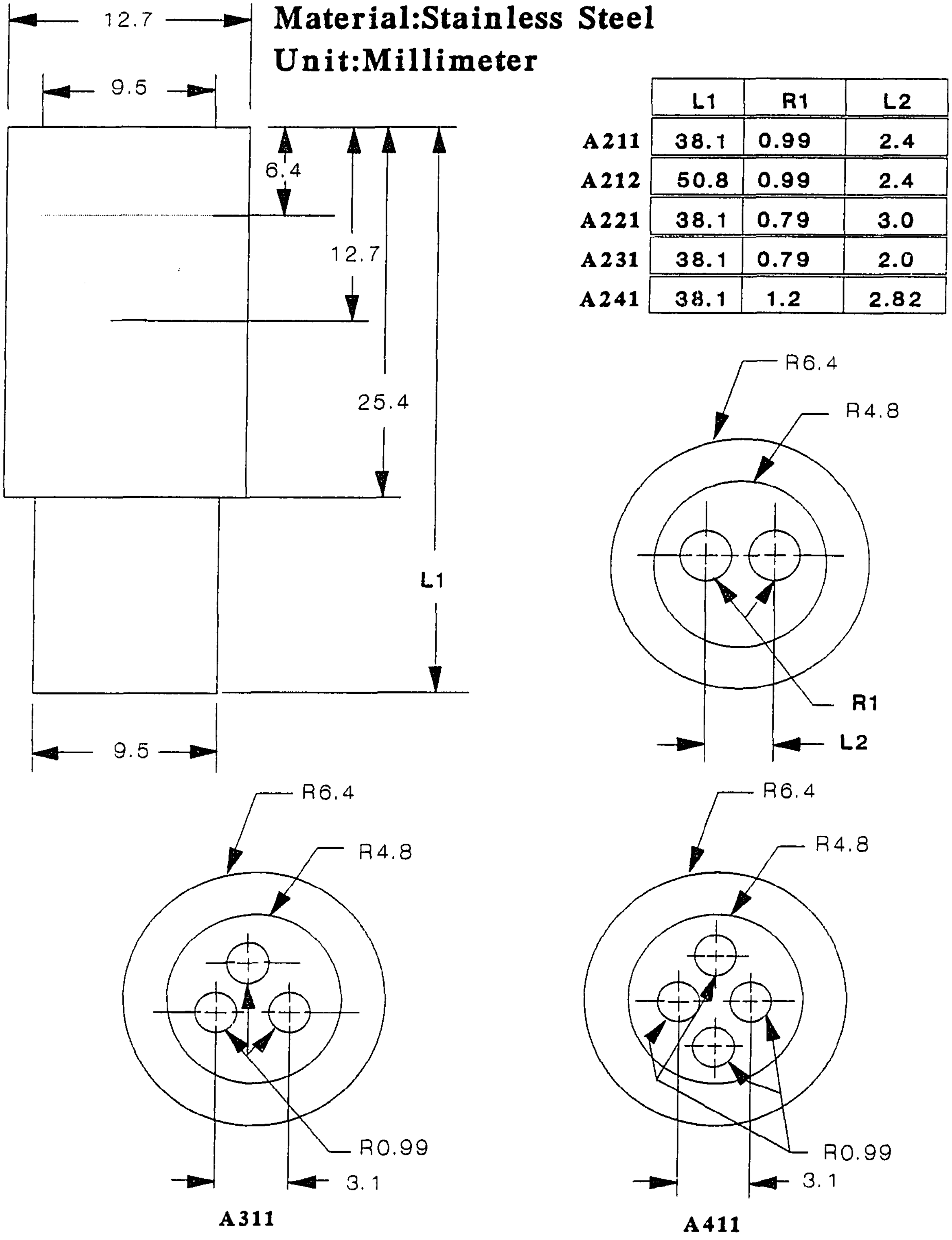


Figure 3.8 Profile Die A211, A212, A221, A231, A241, A311 and A411 - Details

# CHAPTER 4

# MANUFACTURE OF PELLETS OF NON-CIRCULAR CROSS-SECTIONS

## 4.1 Preparation of the Polymer Feedstock

Most of the materials is used in the manufacturing the multi-lobal pellets, must be put into the drying oven manufactured by Blue M. Electric, Co. A photograph is shown in Figure 4.1. The feedstocks were dried according to the recommended drying conditions of the feedstock manufacturer. These are shown in Table 4.1.

The extrusion conditions observed in actual processing vary considerably. Extruders differ, for example, in the way in which they run on different materials. Base resins differ from maker to maker. The type of granule, and the class of product will also have an effects on the conditions of extrusion. The following materials were used in this study.

### 4.1.1 Acetal Copolymer

Acetal copolymer is an engineering thermoplastic offering a unique combination of properties and predictable performance. Because of its highly crystalline structure, it offers a balance of high tensile strength, fatigue resistance, stiffness and toughness. These properties, coupled with excellent creep resistance, resilience, abrasion resistance, low moisture absorption and dimensional stability. Acetal copolymer resins are divided into a number of grades, made by varying the molecular weight [39]. Molecular weight has a direct influence on both certain mechanical properties and on melt viscosity. The various grades of Acetal copolymer resins are classified in terms of their melt viscosity (1.0-45.0). These grades are explained below noting their important characteristics and typical applications.

Polyacetal has have been successfully extruded on both conventional and metering type screws of L/D ratio 15 : 1 and above. It is important that both the extruder and the profile die used for processing these materials should be free of dead spots where the material could stagnate, leading to discoloration and depolymerization. U10-01 (POM1), with a melt index of 1.0 (mg/min), provides excellent processability in extrusion blow, injection blow molding and extrusion. The applications of U10-01 include aerosols, containers, industrial articles, rod, tube, slab, profiles and gas tank floats. M25 (POM2), with a melt index is 2.5 (mg/min), it has good processability for injection blow and injection molding. It also provides increased toughness, elongation and impact strength, and it can be extruded into tubing, profiles and sheet. M90 is a general purpose resin for injection molding, offering an excellent balance of moldability and excellent stability in processing. It also provides parts with high surface gloss and good dimensional and property stability. The melt index of M90 (POM3) is 9.0 (mg/min). The applications of M90 include gears, cams, bearings, housings, alternating drive train assemblies, pump impellers, and gasoline pump parts. M270 (POM4), with a melt index is 27.0 (mg/min), offers high flow and hence, fast molding cycles. It also has high surface gloss and good dimensional stability. The applications of M270 include thin walled parts or complex multi-cavity parts, such as pens, pencils, and cassette components. The melt index of M450 (POM5) is 45.0 (mg/min), It offers the highest flow and fastest molding cycles. The applications of M450 include injection molding with complex geometries.

### 4.1.2 Nylon 6

Nylon 6 (PA 6), or polyamide, is melt processable material available to the extruder, characterized by its processing temperature. it has rapid transition from solid to fluid within a narrow temperature range, and also has a tendency to absorb moisture. The extrusion equipment and its operation must, therefore, be arranged to cope with these characteristics. A minimum screw length of 20D is recommended with short transition and shallow channel depth. Heater capacity must be sufficient to cope with the high melting point and low shear rate. The applications of nylon 6 include gears, bearings, paint oven, engine fans and wheels.

### 4.1.3 Polyethylene

Generally speaking the polyethylene (PE) is the easiest material to extrude and the good results which can be obtained on any reasonable machine are reflected in the vast quantity of extruded polyethylene products currently available. In order to obtain optimum output and quality with the higher density materials, however, a long metering type screw with an L/D ratio not less than 20 : 1 is recommended, with a compression ratio between 2.5 and 3.5 : 1 depending upon the final extrudate form. The applications of polyethylene in extrusion include cable, fuel tank, water pipe and profiles.

### 4.1.4 Polypropylene

Polypropylene (PP), like polyethylene, is also a member of the polyolefin family of thermoplastic materials. The processing of polypropylene is very similar to that of the polyethylene and the same recommendations are applicable. Polypropylene however, develops less frictional heat in the extruder screw and consequently more external heat must generally be supplied by the barrel heaters. The applications of polypropylene in extrusion include textile fibers and filaments.

### 4.1.5 Polystyrene

Polystyrene (PS) is greatly used at the present time for packaging products (containers, lids, bottles), disposable medical ware, tape reels, and storm windows because of its clarity and fabrication ease. This material gives few problems in extrusion on modern equipment with long screws, but generally the long metering type of screw is preferred. There are many foam applications for polystyrene include egg cartons, meat packaging trays and cushioning material.

### 4.1.6 Acrylonitrile-Butadiene-Styrene

Acrylonitrile-butadiene-styrene (ABS), terpolymer, is with a uniform molecular structure and therefore differs from other modified polystyrenes which may be blends of polymers. For best results drying of the material is recommended, or the use of a vented extruder. Extrusion temperature has been found somewhat critical within the range 347 $^{o}$F - 446 $^{o}$F. Variations in processing temperatures outside this band have a noticeable effect on surface finish. Metering type screws give a satisfactory extrudate. A point to be noted with the extrusion of these materials is that they are subject to rapid freeze. The applications of Acrylonitrile-butadiene-styrene include radiator grilles, computer housing and consoles.

The material listed in Table 4.2. were those used in this study. Some, such as polystyrene (PS) and acetal copolymers have high modulus and others, such as polyethylene (PE), polypropylene (PP), and nylon 6 (PA 6) have low modulus. Acrylonitrile-butadiene-styrene (ABS) is normal. According to the Modern Plastics Encyclopedia [40], the modulus is taken to mean the tensile modulus as defined by the slope of the initial linear portion of the load extension response (stress-strain curve) of a specimen deform temperature. The mechanical properties of those materials is listed in Table 4.3.

## 4.2 Procedure for Operating the Extruder

The extruder used to manufacture the multi-lobal pellets was a 1 inch diameter unit manufactured by Wayne Tool and Die, Co. A photograph is shown in Figure 4.2. The unit conveys the feedstock, melts it and pumps it to the die where it is shaped into a multi-lobal strand, which is cooled in a water bath and then pelletized by a Wayne pelletizer. The speed of the plasticating screw, and the pelletizer speed can be adjusted to control the size, and shape of the pellets from the die, to some extent. Thus, for each die, a range of pellet geometries for friction testing can be produced, by varying the extruder screw speed.

The material is divided into two categories for manufacturing the pellet. Acetal copolymer is chosen as one group, since the melting points of POM1, POM2, POM3, POM4 and POM5 is roughly at the same temperature. The other group includes polyethylene (PE), polypropylene (PP), polystyrene (PS), nylon 6 (PA 6) and acrylonitrile-butadiene-styrene (ABS). The operating conditions is dramatically change depending on the melting points of the materials.

In the development stage of the manufacturing system, several die orifice geometries were constructed and tested. To minimize cost, the die was designed such that only a small die insert had to be changed, and the same die body was used throughout. The design of the die body and inserts is illustrated in chapter three. The dies are readily interchangeable and changeover including temperature stabilization took only ten minutes. However, profile dies are not easy to design and in industry are made by trial and error. Rothemeyer [37] has explained some of the difficulties, the most significant being the difference in shape of the die and the extrudate cross-section due to die swelling. The die swelling is different at different points in the face of the die orifice due to the different local shear rates. The result is that the pellet has not only a different size than the die orifice, as is the case with pellets of circular cross-section, but also a different shape. This was extensively reported by Rothemeyer [37]. After many hours of trial and error, trying to make pellets with a multi-lobal cross-sections from die orifices with multi-lobal cross-sections, it was discovered that the easiest die orifice geometry with which to make multi-lobal pellets was multiple orifices. The pellets were then formed outside of the die, as in tube-on cable coating.

The pellets were manufactured on the Wayne extrusion compounding line, dried according to the manufacturer's recommended drying conditions, and stored in moisture-proof bags ready for testing in the shear cell. Each sample was clearly labelled with the pertinent information relevant to manufacture, the die used, the output rate and the extruder speed.

## 4.3 The Operating Conditions for Profile Extrusion

The operating conditions for the acetal copolymer are shown in Tables 4.4 - 10. According to the different profile die inserts, operating temperature varied for the acetal copolymer. The operating conditions for polyethylene (PE), polystyrene (PS) polypropylene (PP), nylon 6 (PA 6), and acrylonitrile-butadiene-styrene (ABS) are shown in Tables 4.11 - 17, respectively.

Table 4.1 Drying Conditions of the Polymer Feedstocks for Acetal Copolymer, Polyethylene, Polypropylene, Polystyrene, Nylon 6 and ABS.

| No | Polymer Material | Temperature ($^{o}$F) |
|---|---|---|
| 1. | Acetal Copolymer | |
| | U10-01 (POM1) | 220 |
| | M25 (POM2) | 220 |
| | M90 (POM3) | 220 |
| | M270 (POM4) | 220 |
| | M450 (POM5) | 220 |
| 2. | Polyethylene (PE) | 180 |
| 3. | Polypropylene (PP) | N/A |
| 4. | Polystyrene (PS) | 180 |
| 5. | Nylon 6 (PA 6) | 180 |
| 6. | Acrylonitrile-butadiene-styrene (ABS) | N/A |

Table 4.2 Material Resin & Codes.

| No | Material | Abbreviation | Material Supplier | Trade name | Code |
|---|---|---|---|---|---|
| 1. | Polyethylene | PE | Soltex | Portiflex | PE |
| 2. | Polypropylene | PP | Soltex | P4D 0326-61 | PP |
| 3. | Polystyrene | PS | Dow | 484-27W | PS |
| 4. | Nylon 6 | PA | Allied Chemical | (XPN,917, CLEAR) | PA 6 |
| 5. | Acrylonitrile-butadiene-styrene | ABS | Monsanto | 248 | ABS |
| 6. | Acetal Copolymer | Celcon | Hoechst Celanese | U10-01<br>M25<br>M90<br>M270<br>M450 | POM1<br>POM2<br>POM3<br>POM4<br>POM5 |

Table 4.3 Material Mechanical Properties.

| No | Material | Density (Kg/m$^3$) | Tensile Modulus (GN/m$^2$) |
|---|---|---|---|
| 1. | Polyethylene(PE) | 950 | 0.8 |
| 2. | Polypropylene(PP) | 905 | 1.3 |
| 3. | Polystyrene(PS) | 1050 | 2.9 |
| 4. | Nylon 6(PA 6) | 1140 | 0.7 |
| 5. | Acrylonitrile-butadiene-styrene (ABS) | 1040 | 2.4 |
| 6. | Acetal Copolymer (Celcon) | | |
| | U10-01 | 1190 | 3.6 |
| | M25 | 1087 | 3.6 |
| | M90 | 1042 | 3.6 |
| | M270 | 1239 | 3.6 |
| | M450 | 1265 | 3.6 |

Table 4.4 Operating Conditions of Profile Die A211 for Acetal Copolymer.

| | Profile Die A211 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 440 | 450 | 280 | 11.7 | 105.3 | 3 | 6.0 |
| | 10rpm | 440 | 450 | 280 | 30.0 | 269.9 | 6 | 8.0 |
| | 15rpm | 435 | 450 | 280 | 44.8 | 403.1 | 8 | 10.0 |
| | 20rpm | 430 | 450 | 280 | 60.9 | 548.0 | 11 | 11.0 |
| Material M25 | 5rpm | 440 | 450 | 290 | 9.4 | 93.4 | 7 | 1.0 |
| | 10rpm | 440 | 450 | 285 | 18.8 | 162.7 | 11 | 2.0 |
| | 15rpm | 440 | 450 | 280 | 28.6 | 265.1 | 14 | 2.5 |
| | 20rpm | 440 | 450 | 280 | 40.6 | 353.5 | 16 | 3.0 |
| Material M90 | 5rpm | 440 | 450 | 280 | 16.1 | 112.1 | 13 | 2.0 |
| | 10rpm | 440 | 455 | 280 | 32.1 | 301.7 | 17 | 3.5 |
| | 15rpm | 440 | 455 | 280 | 43.0 | 414.8 | 20 | 4.5 |
| | 20rpm | 440 | 455 | 280 | 61.1 | 564.6 | 24 | 6.0 |
| Material M270 | 5rpm | 440 | 460 | 260 | 9.9 | 135.7 | 13 | 0.2 |
| | 10rpm | 440 | 460 | 260 | 27.0 | 215.0 | 18 | 1.0 |
| | 15rpm | 440 | 460 | 270 | 38.5 | 298.6 | 23 | 1.5 |
| | 20rpm | 435 | 460 | 270 | 47.5 | 392.9 | 26 | 2.0 |
| Material M450 | 5rpm | 440 | 460 | 260 | 15.5 | 81.1 | 26 | 0.2 |
| | 10rpm | 440 | 460 | 255 | 26.5 | 226.1 | 31 | 0.5 |
| | 15rpm | 435 | 460 | 250 | 34.8 | 289.9 | 38 | 1.2 |

Table 4.5 Operating Conditions of Profile Die A212 for Acetal Copolymer.

| | Profile Die A212 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 430 | 455 | 285 | 15.6 | 142.4 | 3 | 4.0 |
| | 10rpm | 430 | 450 | 285 | 31.7 | 289.4 | 6 | 8.0 |
| | 15rpm | 440 | 450 | 290 | 45.3 | 413.5 | 8 | 10.5 |
| | 20rpm | 440 | 450 | 290 | 55.4 | 505.7 | 10 | 12.0 |
| Material M25 | 5rpm | 440 | 450 | 285 | 9.3 | 92.9 | 6 | 0.5 |
| | 10rpm | 440 | 450 | 290 | 16.2 | 161.9 | 10 | 1.0 |
| | 15rpm | 440 | 450 | 290 | 26.4 | 263.8 | 13 | 2.0 |
| | 20rpm | 440 | 450 | 290 | 35.2 | 351.8 | 15 | 2.5 |
| Material M90 | 5rpm | 445 | 450 | 290 | 10.7 | 111.5 | 12 | 2.0 |
| | 10rpm | 440 | 450 | 290 | 28.8 | 300.2 | 16 | 3.0 |
| | 15rpm | 440 | 450 | 290 | 39.6 | 412.8 | 19 | 4.0 |
| | 20rpm | 440 | 460 | 290 | 53.9 | 561.9 | 22 | 5.0 |
| Material M270 | 5rpm | 450 | 445 | 295 | 15.4 | 135.0 | 14 | 0.2 |
| | 10rpm | 445 | 450 | 290 | 24.4 | 213.9 | 18 | 0.5 |
| | 15rpm | 440 | 450 | 285 | 33.9 | 297.2 | 22 | 1.0 |
| | 20rpm | 440 | 460 | 285 | 44.6 | 391.0 | 25 | 2.0 |
| Material M450 | 5rpm | 440 | 450 | 290 | 9.4 | 80.7 | 26 | 0.1 |
| | 10rpm | 440 | 455 | 295 | 26.2 | 225.0 | 31 | 0.3 |
| | 15rpm | 440 | 455 | 290 | 33.6 | 288.5 | 35 | 1.0 |
| | 20rpm | 440 | 460 | 290 | 44.2 | 379.6 | 38 | 1.5 |

Table 4.6 Operating Conditions of Profile Die A221 for Acetal Copolymer.

| | Profile Die A221 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 440 | 460 | 290 | 12.7 | 226.4 | 3 | 4.0 |
| | 10rpm | 445 | 460 | 295 | 31.6 | 563.4 | 5 | 6.0 |
| | 15rpm | 450 | 460 | 300 | 42.3 | 754.2 | 7 | 8.0 |
| | 20rpm | 450 | 460 | 300 | 51.5 | 918.2 | 9 | 10.0 |
| Material M25 | 5rpm | 425 | 450 | 280 | 7.8 | 152.2 | 4 | 1.0 |
| | 10rpm | 430 | 450 | 285 | 15.9 | 310.3 | 6 | 2.0 |
| | 15rpm | 435 | 455 | 290 | 23.1 | 450.9 | 7 | 2.5 |
| | 20rpm | 440 | 460 | 295 | 34.1 | 665.6 | 9 | 3.5 |
| Material M90 | 5rpm | 440 | 450 | 280 | 15.9 | 323.7 | 7 | 1.0 |
| | 10rpm | 440 | 460 | 290 | 30.3 | 617.0 | 13 | 3.0 |
| | 15rpm | 450 | 460 | 290 | 40.1 | 816.5 | 18 | 4.0 |
| | 20rpm | 450 | 460 | 300 | 60.3 | 1127.8 | 24 | 6.0 |
| Material M270 | 5rpm | 440 | 450 | 285 | 10.3 | 176.4 | 12 | 0.2 |
| | 10rpm | 445 | 450 | 290 | 25.9 | 443.5 | 18 | 0.5 |
| | 15rpm | 450 | 460 | 295 | 36.4 | 623.3 | 24 | 0.8 |
| | 20rpm | 450 | 460 | 295 | 47.6 | 815.1 | 27 | 1.0 |
| Material M450 | 5rpm | 440 | 460 | 290 | 14.1 | 236.5 | 18 | 0.1 |
| | 10rpm | 440 | 460 | 290 | 24.8 | 416.0 | 23 | 0.4 |
| | 15rpm | 440 | 460 | 290 | 33.9 | 568.6 | 27 | 0.6 |
| | 20rpm | 450 | 460 | 295 | 46.4 | 778.2 | 32 | 0.8 |

Table 4.7 Operating Conditions of Profile Die A231 for Acetal Copolymer.

| | Profile Die A231 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 440 | 450 | 290 | 13.7 | 244.3 | 5 | 2.5 |
| | 10rpm | 440 | 450 | 290 | 29.3 | 522.4 | 7 | 5.0 |
| | 15rpm | 440 | 455 | 300 | 38.9 | 693.6 | 12 | 7.0 |
| | 20rpm | 440 | 460 | 300 | 54.0 | 962.8 | 15 | 9.0 |
| Material M25 | 5rpm | 435 | 440 | 285 | 6.0 | 117.1 | 8 | 1.0 |
| | 10rpm | 440 | 445 | 285 | 15.1 | 294.7 | 13 | 2.0 |
| | 15rpm | 440 | 445 | 290 | 24.0 | 468.4 | 17 | 2.5 |
| | 20rpm | 440 | 450 | 290 | 32.1 | 626.5 | 20 | 3.0 |
| Material M90 | 5rpm | 430 | 440 | 285 | 14.7 | 299.3 | 12 | 2.0 |
| | 10rpm | 435 | 450 | 285 | 27.1 | 551.8 | 15 | 3.0 |
| | 15rpm | 440 | 450 | 285 | 40.3 | 820.6 | 20 | 4.0 |
| | 20rpm | 440 | 450 | 290 | 53.7 | 1093.4 | 25 | 5.0 |
| Material M270 | 5rpm | 440 | 450 | 290 | 10.3 | 176.4 | 14 | 0.2 |
| | 10rpm | 440 | 450 | 290 | 23.4 | 400.7 | 20 | 1.2 |
| | 15rpm | 440 | 450 | 300 | 33.5 | 573.7 | 26 | 1.5 |
| | 20rpm | 440 | 450 | 300 | 44.3 | 758.6 | 36 | 2.0 |
| Material M450 | 5rpm | 440 | 450 | 300 | 8.3 | 139.2 | 17 | 0.1 |
| | 10rpm | 440 | 450 | 300 | 19.9 | 333.8 | 25 | 0.3 |
| | 15rpm | 440 | 450 | 300 | 28.9 | 484.7 | 32 | 1.0 |
| | 20rpm | 440 | 460 | 300 | 37.4 | 627.3 | 38 | 1.5 |

Table 4.8 Operating Conditions of Profile Die A241 for Acetal Copolymer.

| | Profile Die A241 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 440 | 450 | 290 | 14.8 | 78.2 | 4 | 4.0 |
| | 10rpm | 440 | 450 | 290 | 33.6 | 177.5 | 6 | 6.0 |
| | 15rpm | 450 | 460 | 295 | 45.8 | 241.9 | 8 | 8.0 |
| | 20rpm | 450 | 460 | 300 | 63.3 | 334.4 | 10 | 10.0 |
| Material M25 | 5rpm | 430 | 440 | 290 | 8.1 | 46.8 | 4 | 1.0 |
| | 10rpm | 430 | 450 | 295 | 22.5 | 130.1 | 6 | 2.5 |
| | 15rpm | 430 | 450 | 300 | 32.2 | 186.2 | 10 | 3.0 |
| | 20rpm | 440 | 460 | 300 | 43.2 | 249.8 | 13 | 4.0 |
| Material M90 | 5rpm | 435 | 450 | 290 | 16.5 | 99.5 | 5 | 1.0 |
| | 10rpm | 440 | 455 | 290 | 31.9 | 192.5 | 10 | 2.0 |
| | 15rpm | 440 | 455 | 295 | 46.3 | 279.3 | 14 | 3.5 |
| | 20rpm | 440 | 460 | 300 | 60.9 | 367.4 | 16 | 4.5 |
| Material M270 | 5rpm | 435 | 450 | 300 | 16.8 | 85.2 | 6 | 0.5 |
| | 10rpm | 440 | 450 | 300 | 38.3 | 194.3 | 10 | 2.0 |
| | 15rpm | 440 | 450 | 300 | 46.4 | 235.4 | 14 | 3.0 |
| | 20rpm | 440 | 460 | 300 | 63.6 | 322.7 | 20 | 3.5 |
| Material M450 | 5rpm | 440 | 460 | 300 | 12.8 | 63.6 | 10 | 0.2 |
| | 10rpm | 440 | 460 | 300 | 25.5 | 126.7 | 18 | 0.4 |
| | 15rpm | 440 | 460 | 300 | 43.4 | 215.7 | 22 | 0.6 |
| | 20rpm | 440 | 460 | 305 | 50.1 | 249.0 | 26 | 0.8 |

Table 4.9 Operating Conditions of Profile Die A311 for Acetal Copolymer.

| | Profile Die<br>A311 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 430 | 450 | 285 | 11.4 | 135.5 | 3 | 2.5 |
| | 10rpm | 440 | 450 | 285 | 25.8 | 306.7 | 5 | 4.5 |
| | 15rpm | 440 | 450 | 285 | 37.9 | 450.5 | 7 | 6.0 |
| | 20rpm | 440 | 455 | 285 | 54.8 | 651.4 | 9 | 8.0 |
| Material M25 | 5rpm | 440 | 450 | 290 | 7.8 | 101.5 | 7 | 1.0 |
| | 10rpm | 440 | 455 | 290 | 15.1 | 1996.5 | 9 | 1.5 |
| | 15rpm | 440 | 460 | 290 | 23.2 | 301.9 | 11 | 2.5 |
| | 20rpm | 440 | 460 | 290 | 33.3 | 433.3 | 13 | 3.5 |
| Material M90 | 5rpm | 440 | 460 | 290 | 16.8 | 228.0 | 12 | 1.5 |
| | 10rpm | 440 | 460 | 290 | 26.8 | 363.8 | 15 | 3.0 |
| | 15rpm | 440 | 460 | 290 | 40.3 | 547.0 | 18 | 4.0 |
| | 20rpm | 440 | 460 | 290 | 55.0 | 746.6 | 21 | 5.0 |
| Material M270 | 5rpm | 440 | 460 | 290 | 13.2 | 150.7 | 15 | 0.5 |
| | 10rpm | 440 | 460 | 290 | 24.1 | 275.1 | 20 | 1.5 |
| | 15rpm | 440 | 460 | 290 | 35.4 | 404.1 | 25 | 2.0 |
| | 20rpm | 440 | 460 | 290 | 47.2 | 538.8 | 28 | 2.5 |
| Material M450 | 5rpm | 440 | 460 | 290 | 10.1 | 112.9 | 20 | 0.2 |
| | 10rpm | 440 | 460 | 290 | 22.6 | 252.7 | 26 | 0.5 |
| | 15rpm | 445 | 460 | 295 | 32.9 | 367.9 | 32 | 1.5 |
| | 20rpm | 445 | 460 | 295 | 41.5 | 464.0 | 36 | 2.0 |

Table 4.10 Operating Conditions of Profile Die A411 for Acetal Copolymer.

| | Profile Die A411 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material U10-01 | 5rpm | 430 | 460 | 280 | 14.3 | 127.5 | 3 | 6.0 |
| | 10rpm | 440 | 460 | 285 | 25.9 | 230.9 | 5 | 9.5 |
| | 15rpm | 440 | 460 | 285 | 38.3 | 341.4 | 7 | 10.5 |
| | 20rpm | 440 | 460 | 285 | 55.8 | 494.4 | 9 | 12.0 |
| Material M25 | 5rpm | 440 | 460 | 290 | 10.6 | 103.4 | 4 | 0.5 |
| | 10rpm | 440 | 460 | 290 | 15.7 | 153.2 | 6 | 1.5 |
| | 15rpm | 440 | 460 | 290 | 24.3 | 237.2 | 8 | 2.0 |
| | 20rpm | 440 | 460 | 290 | 34.0 | 331.8 | 10 | 2.5 |
| Material M90 | 5rpm | 430 | 450 | 295 | 17.0 | 173.1 | 16 | 2.0 |
| | 10rpm | 435 | 450 | 295 | 30.2 | 307.5 | 20 | 3.0 |
| | 15rpm | 440 | 455 | 295 | 40.6 | 433.7 | 25 | 4.0 |
| | 20rpm | 445 | 460 | 295 | 55.6 | 566.0 | 28 | 6.0 |
| Material M270 | 5rpm | 435 | 450 | 300 | 13.4 | 114.7 | 20 | 0.4 |
| | 10rpm | 435 | 455 | 300 | 24.3 | 208.1 | 24 | 1.0 |
| | 15rpm | 440 | 455 | 300 | 35.8 | 306.5 | 28 | 2.0 |
| | 20rpm | 440 | 460 | 300 | 47.4 | 405.8 | 34 | 2.5 |
| Material M450 | 5rpm | 440 | 460 | 295 | 10.5 | 88.1 | 28 | 0.2 |
| | 10rpm | 440 | 460 | 295 | 23.0 | 192.9 | 32 | 0.5 |
| | 15rpm | 440 | 460 | 295 | 33.5 | 280.9 | 36 | 0.8 |
| | 20rpm | 440 | 460 | 300 | 41.8 | 350.5 | 40 | 1.5 |

Table 4.11 Operating Conditions of Profile Die A211 for PE, PP, PA 6, ABS and PS.

| | Profile Die A211 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 490 | 500 | 300 | 10.2 | 115.0 | 12 | 3.0 |
| | 10rpm | 490 | 510 | 300 | 24.5 | 276.2 | 15 | 4.5 |
| | 15rpm | 490 | 510 | 300 | 38.5 | 434.0 | 18 | 6.0 |
| | 20rpm | 490 | 510 | 300 | 53.0 | 597.4 | 21 | 6.5 |
| Material PP | 5rpm | 480 | 500 | 280 | 12.2 | 144.4 | 17 | 0.5 |
| | 10rpm | 480 | 500 | 280 | 21.8 | 257.9 | 20 | 1.5 |
| | 15rpm | 480 | 500 | 280 | 31.6 | 373.9 | 23 | 2.0 |
| | 20rpm | 480 | 500 | 280 | 40.9 | 483.9 | 26 | 3.0 |
| Material Nylon 6 | 5rpm | 520 | 535 | 320 | 14.3 | 134.3 | 16 | 3.0 |
| | 10rpm | 520 | 535 | 320 | 23.5 | 220.7 | 20 | 6.0 |
| | 15rpm | 520 | 540 | 320 | 35.2 | 330.6 | 23 | 8.0 |
| | 20rpm | 525 | 540 | 320 | 47.2 | 443.3 | 25 | 10.0 |
| Material ABS | 5rpm | 485 | 495 | 365 | 13.1 | 134.9 | 15 | 1.0 |
| | 10rpm | 485 | 495 | 365 | 30.7 | 316.1 | 20 | 2.0 |
| | 15rpm | 485 | 495 | 365 | 40.6 | 418.0 | 28 | 3.0 |
| | 20rpm | 485 | 495 | 365 | 55.8 | 574.5 | 32 | 4.0 |
| Material PS | 5rpm | 530 | 540 | 375 | 13.0 | 132.6 | 22 | 1.0 |
| | 10rpm | 530 | 540 | 375 | 24.8 | 252.9 | 25 | 3.0 |
| | 15rpm | 530 | 540 | 375 | 36.0 | 367.1 | 28 | 3.5 |
| | 20rpm | 535 | 540 | 375 | 49.8 | 507.9 | 31 | 4.0 |

Table 4.12 Operating Conditions of Profile Die A212 for PE, PP, PA 6, ABS and PS.

| | Profile Die A212 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 490 | 500 | 300 | 10.4 | 117.2 | 10 | 4.0 |
| | 10rpm | 500 | 500 | 300 | 23.5 | 264.9 | 14 | 6.0 |
| | 15rpm | 500 | 500 | 300 | 34.3 | 386.6 | 19 | 7.0 |
| | 20rpm | 500 | 510 | 300 | 50.7 | 571.5 | 23 | 7.5 |
| Material PP | 5rpm | 480 | 500 | 280 | 10.8 | 127.8 | 13 | 0.5 |
| | 10rpm | 480 | 500 | 280 | 20.2 | 236.6 | 19 | 2.0 |
| | 15rpm | 480 | 500 | 280 | 29.2 | 345.5 | 24 | 2.5 |
| | 20rpm | 480 | 500 | 280 | 39.8 | 470.9 | 29 | 3.5 |
| Material PS | 5rpm | 510 | 540 | 320 | 14.4 | 135.3 | 15 | 3.0 |
| | 10rpm | 520 | 540 | 320 | 23.0 | 216.0 | 21 | 6.0 |
| | 15rpm | 520 | 540 | 320 | 35.5 | 333.5 | 23 | 10.0 |
| | 20rpm | 520 | 540 | 320 | 42.5 | 399.2 | 25 | 11.0 |
| Material Nylon 6 | 5rpm | 530 | 540 | 340 | 13.0 | 109.1 | 16 | 2.0 |
| | 10rpm | 530 | 540 | 345 | 24.8 | 214.2 | 20 | 3.5 |
| | 15rpm | 530 | 540 | 345 | 36.0 | 326.3 | 24 | 4.0 |
| | 20rpm | 535 | 540 | 345 | 49.8 | 453.8 | 28 | 5.5 |

Table 4.13 Operating Conditions of Profile Die A221 for PE, PP, PA 6, ABS and PS.

| | Profile Die A221 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 490 | 500 | 295 | 12.5 | 279.2 | 14 | 4.0 |
| | 10rpm | 490 | 500 | 295 | 23.9 | 533.8 | 17 | 5.5 |
| | 15rpm | 490 | 500 | 295 | 32.7 | 730.3 | 21 | 6.5 |
| | 20rpm | 490 | 500 | 295 | 44.9 | 1022.8 | 24 | 7.5 |
| Material PP | 5rpm | 480 | 490 | 280 | 9.8 | 229.7 | 14 | 1.0 |
| | 10rpm | 480 | 490 | 280 | 17.4 | 407.9 | 22 | 1.5 |
| | 15rpm | 480 | 490 | 280 | 26.3 | 616.6 | 27 | 2.0 |
| | 20rpm | 480 | 490 | 280 | 36.6 | 858.0 | 32 | 3.0 |
| Material Nylon 6 | 5rpm | 525 | 540 | 350 | 9.8 | 182.4 | 11 | 4.0 |
| | 10rpm | 530 | 540 | 350 | 20.0 | 372.2 | 13 | 7.0 |
| | 15rpm | 530 | 540 | 350 | 29.6 | 550.9 | 15 | 9.0 |
| | 20rpm | 530 | 540 | 350 | 38.0 | 707.2 | 17 | 11.0 |
| Material ABS | 5rpm | 480 | 490 | 360 | 11.0 | 242.8 | 21 | 2.0 |
| | 10rpm | 480 | 490 | 360 | 27.8 | 567.1 | 25 | 3.0 |
| | 15rpm | 480 | 490 | 360 | 40.4 | 824.2 | 27 | 4.0 |
| | 20rpm | 480 | 490 | 360 | 53.7 | 1095.5 | 32 | 5.0 |
| Material PS | 5rpm | 540 | 550 | 370 | 12.9 | 242.5 | 14 | 2.0 |
| | 10rpm | 540 | 550 | 370 | 24.8 | 493.0 | 26 | 3.0 |
| | 15rpm | 540 | 550 | 370 | 34.5 | 697.1 | 32 | 4.0 |
| | 20rpm | 540 | 550 | 370 | 46.4 | 937.6 | 41 | 5.0 |

Table 4.14 Operating Conditions of Profile Die A231 for PE, PP, PA 6, ABS and PS.

| | Pofile Die A231 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 490 | 500 | 300 | 14.2 | 317.1 | 15 | 4.0 |
| | 10rpm | 490 | 500 | 300 | 26.1 | 582.9 | 18 | 6.0 |
| | 15rpm | 490 | 500 | 300 | 38.1 | 850.9 | 21 | 7.0 |
| | 20rpm | 490 | 500 | 300 | 51.2 | 1143.5 | 24 | 8.0 |
| Material PP | 5rpm | 480 | 490 | 280 | 9.2 | 215.7 | 19 | 0.5 |
| | 10rpm | 480 | 490 | 280 | 20.7 | 485.3 | 24 | 2.0 |
| | 15rpm | 480 | 490 | 280 | 29.1 | 682.2 | 28 | 2.5 |
| | 20rpm | 480 | 490 | 280 | 38.9 | 912.0 | 34 | 3.5 |
| Material Nylon 6 | 5rpm | 520 | 530 | 320 | 11.4 | 212.2 | 12 | 5.0 |
| | 10rpm | 520 | 530 | 320 | 24.6 | 457.8 | 14 | 7.0 |
| | 15rpm | 520 | 530 | 320 | 35.3 | 657.0 | 16 | 8.0 |
| | 20rpm | 520 | 530 | 320 | 47.4 | 882.2 | 20 | 9.0 |
| Material ABS | 5rpm | 480 | 490 | 355 | 12.2 | 248.9 | 17 | 1.5 |
| | 10rpm | 480 | 490 | 355 | 26.6 | 542.7 | 25 | 2.5 |
| | 15rpm | 480 | 490 | 355 | 38.7 | 789.5 | 32 | 3.5 |
| | 20rpm | 480 | 490 | 355 | 53.2 | 1085.3 | 40 | 4.5 |
| Material PS | 5rpm | 535 | 545 | 360 | 9.0 | 181.9 | 21 | 2.0 |
| | 10rpm | 535 | 545 | 360 | 22.8 | 460.7 | 24 | 3.5 |
| | 15rpm | 535 | 550 | 360 | 33.1 | 668.8 | 29 | 4.5 |
| | 20rpm | 535 | 550 | 360 | 46.8 | 945.7 | 37 | 6.0 |

Table 4.15 Operating Conditions of Profile Die A241 for PE, PP, PS, PA 6 and ABS.

| | Pofile Die A241 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 500 | 510 | 310 | 11.1 | 73.5 | 11 | 2.0 |
| | 10rpm | 500 | 510 | 310 | 26.3 | 174.0 | 14 | 3.0 |
| | 15rpm | 500 | 510 | 300 | 40.5 | 268.0 | 17 | 3.5 |
| | 20rpm | 500 | 510 | 300 | 52.9 | 350.1 | 20 | 4.0 |
| Material PP | 5rpm | 485 | 495 | 280 | 10.1 | 70.2 | 20 | 0.5 |
| | 10rpm | 480 | 495 | 280 | 20.5 | 140.4 | 23 | 2.0 |
| | 15rpm | 480 | 495 | 280 | 30.6 | 212.6 | 25 | 2.5 |
| | 20rpm | 480 | 495 | 280 | 41.1 | 285.5 | 27 | 3.5 |
| Material PS | 5rpm | 520 | 540 | 320 | 12.6 | 69.5 | 8 | 4.0 |
| | 10rpm | 520 | 540 | 320 | 29.7 | 163.8 | 11 | 6.0 |
| | 15rpm | 520 | 540 | 330 | 41.6 | 229.4 | 14 | 9.0 |
| | 20rpm | 520 | 540 | 330 | 50.3 | 277.4 | 18 | 10.0 |
| Material Nylon 6 | 5rpm | 485 | 495 | 370 | 9.8 | 59.2 | 12 | 1.0 |
| | 10rpm | 485 | 495 | 370 | 27.5 | 166.2 | 15 | 2.0 |
| | 15rpm | 485 | 495 | 370 | 40.1 | 242.4 | 18 | 3.0 |
| | 20rpm | 485 | 495 | 370 | 56.6 | 342.1 | 21 | 3.5 |
| Material ABS | 5rpm | 535 | 545 | 365 | 14.7 | 88.0 | 12 | 2.0 |
| | 10rpm | 535 | 545 | 365 | 23.3 | 139.5 | 15 | 3.0 |
| | 15rpm | 535 | 545 | 370 | 33.9 | 203.0 | 20 | 4.0 |
| | 20rpm | 535 | 545 | 370 | 46.5 | 278.4 | 24 | 5.0 |

Table 4.16 Operating Conditions of Profile Die A311 for PE, PP, PA 6 and PS.

| | Pofile Die A311 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 500 | 510 | 300 | 12.6 | 187.6 | 14 | 3.0 |
| | 10rpm | 500 | 510 | 300 | 23.9 | 355.8 | 17 | 4.0 |
| | 15rpm | 500 | 510 | 300 | 34.8 | 518.1 | 20 | 5.5 |
| | 20rpm | 500 | 510 | 300 | 47.4 | 705.7 | 23 | 6.5 |
| Material PP | 5rpm | 485 | 490 | 270 | 10.8 | 168.8 | 21 | 1.0 |
| | 10rpm | 485 | 490 | 270 | 18.5 | 289.1 | 25 | 2.0 |
| | 15rpm | 480 | 490 | 270 | 29.3 | 457.9 | 29 | 3.0 |
| | 20rpm | 480 | 490 | 270 | 39.0 | 609.5 | 33 | 4.0 |
| Material Nylon 6 | 5rpm | 535 | 550 | 330 | 13.2 | 163.8 | 18 | 4.0 |
| | 10rpm | 535 | 550 | 330 | 23.7 | 294.1 | 21 | 7.0 |
| | 15rpm | 535 | 550 | 330 | 32.0 | 397.0 | 23 | 9.0 |
| | 20rpm | 530 | 550 | 330 | 43.3 | 537.2 | 25 | 11.5 |
| Material PS | 5rpm | 535 | 545 | 365 | 11.5 | 154.9 | 16 | 2.0 |
| | 10rpm | 535 | 545 | 365 | 19.4 | 261.3 | 20 | 3.5 |
| | 15rpm | 535 | 545 | 365 | 33.5 | 451.3 | 24 | 4.5 |
| | 20rpm | 535 | 545 | 365 | 44.4 | 598.1 | 28 | 5.5 |

Table 4.17 Operating Conditions of Profile Die A411 for PE and PP.

| | Pofile Die<br>A411 | Temperature | | | Mass flow rate (g/min) | Shear rate (1/s) | Pelletizer speed (rpm) | DC Motor Current (amperes) |
|---|---|---|---|---|---|---|---|---|
| | | Front (°F) | Middle (°F) | Die (°F) | | | | |
| Material PE | 5rpm | 490 | 500 | 310 | 12.4 | 138.5 | 8 | 3.0 |
| | 10rpm | 490 | 500 | 310 | 26.8 | 299.3 | 11 | 4.0 |
| | 15rpm | 490 | 500 | 310 | 36.9 | 412.0 | 13 | 5.0 |
| | 20rpm | 490 | 500 | 310 | 49.1 | 548.3 | 16 | 6.0 |
| Material PP | 5rpm | 485 | 495 | 280 | 91 | 106.7 | 16 | 1.0 |
| | 10rpm | 485 | 495 | 280 | 21.0 | 246.2 | 18 | 2.0 |
| | 15rpm | 485 | 495 | 280 | 30.1 | 352.8 | 21 | 2.5 |
| | 20rpm | 485 | 495 | 280 | 38.9 | 456.0 | 24 | 3.5 |

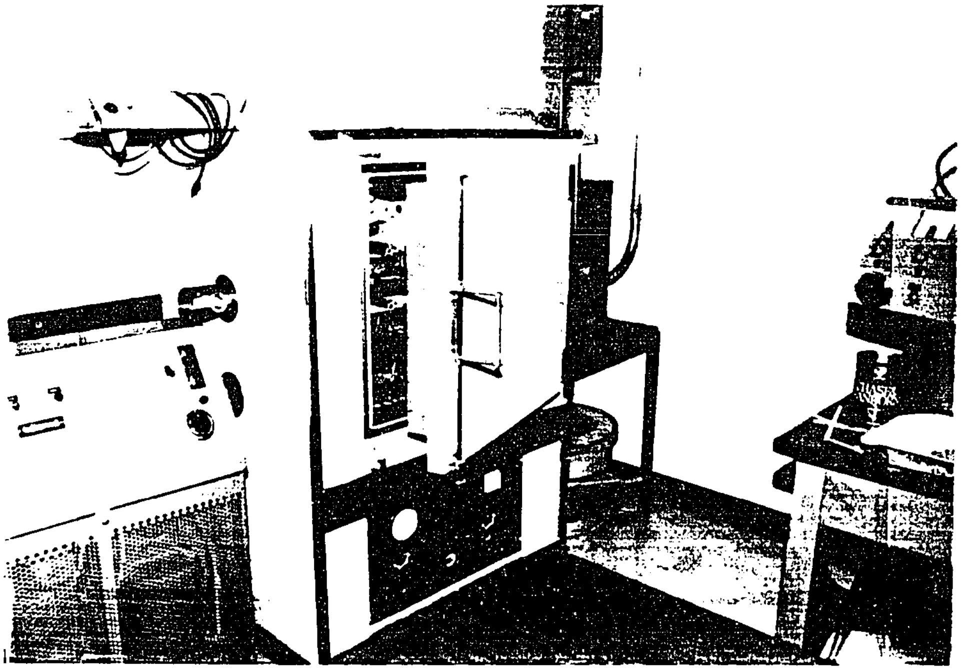


Figure 4.1 Drying Oven Manufactured by Blue M. Electric, Co.

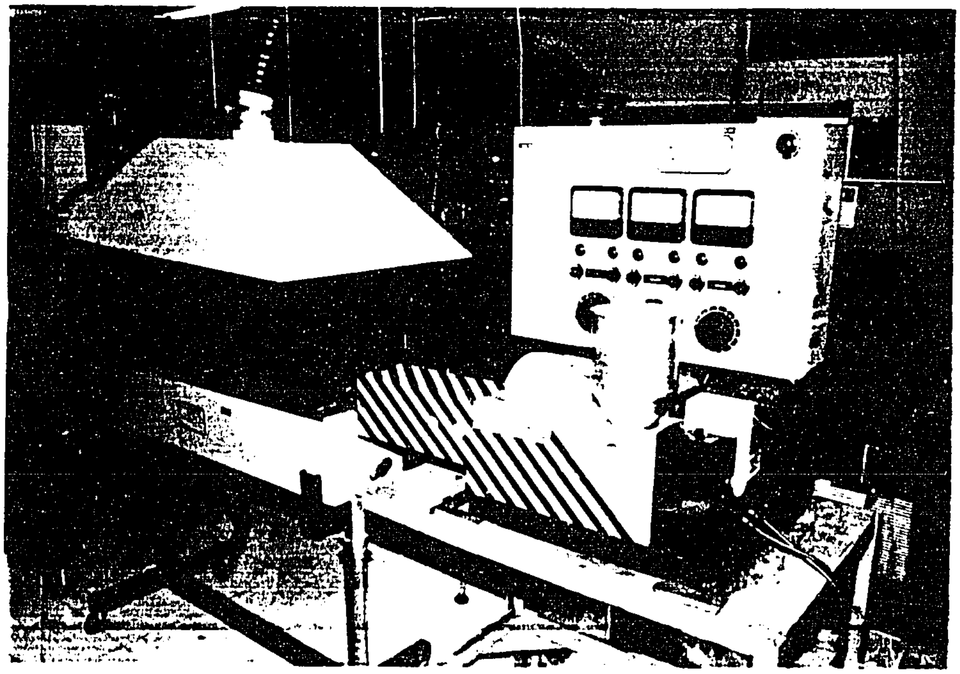


Figure 4.2 Extruder Manufactured by Wayne Tool and Die, Co.

# CHAPTER 5

## MECHANISM OF INTERPARTICULATE FRICTION IN POLYMERIC PARTICULATE CONTINUA

### 5.1 Mechanics of Friction

The interparticular friction between solid and solid is of great importance in polymer processing. Friction is the tangential resistance offered to the sliding of one solid over another. The values of the friction coefficients are in general determined empirically. The interparticulate friction coefficients of particulate materials may be measured in a number of ways. The most common method is the use of a "shear cell", or "shear tester". The principles of operation of these devices are described in great detail by Jenike [25], Carr and Walker [10], Schwedes [43], Roberts [36]. Jenike [25] developed an experimental apparatus, known as a shear cell for measuring the shear properties of particulate solids. It consists of a stationary base and a moving ring. Loads are applied to the ring causing shear in the particulate continuum. The limiting friction coefficient is the interparticulate friction coefficient. The theoretical development of statics of particulate solids commences with the work of Coulomb [15]. There are some concepts in elementary statics that are essential for the understanding of the behavior of particulate solid. It shall be dealing with a condition of static equilibrium that also holds at the limiting condition of incipient flow, that is, The interparticulate friction coefficient $\mu$ is defined as:

$$\mu = \frac{S}{N} \tag{5.1}$$

where,

S = the mean tangential frictional force

and N = the normal force applied perpendicular to the plane of shear

The Eq. (5.1) is known as Amonton's law [1]. It indicates that frictional resistance is proportional to the normal force.

### 5.2 Agglomeration

The term agglomeration may vary in meaning between different industries and different fields of research. In this work, it describes the forming of an aggregate from the individual particles, such as, the building up clusters from polymeric pellets during conveying. Agglomeration is undesirable when it happens in a free flowing system , but it is desirable for pelleting, and similar processes. In either case, it is important to understand the physical mechanisms involved [33]. Agglomeration occurs because of the binding forces exceed the disruptive or break-up forces between the particles [52]. Bowden and Tabor [6] proposed that solid-solid forces are significantly amplified by increases in pressure and temperature, which induce simultaneously an increase in contact area. Agglomeration greatly depends on the particulate material. There are two different kinds of material, which display different relationship among the processes.

The first kind of material is referred to as cohesive. If the intrinsic shear strength under zero consolidation load is large. Using Amonton's friction law given by Eq. (5.1), the yield locus at incipient failure can be written as,

$$\tau=(\tan\phi)\sigma + c \qquad (5.2)$$

where c is the coefficient of cohesion. It is simply the intercept of the internal yield locus on the shear axis as shown on Figure 5.1. A cohesive particulate system gains strength when pressure is applied. Consequently, the relation between the normal stress and the shear stress is a function of the consolidation pressure and consolidation time.

Another kind of material, termed cohesionless is used to described those granular materials whose intrinsic shear strength under zero consolidation load ($\sigma=0$) is negligible. In this case the yield locus shown in Figure 5.2 for plastic failure given by,

$$\tau=(\tan\phi)\sigma \qquad (5.3)$$

where,

$\tau$ =shear stress

$\phi$ =the angle of internal friction

and $\sigma$ =normal stress

In plasticating processes, including extrusion, particulate pellets are agglomerated and compacted prior to melting. The mechanical properties of agglomerates control the deformation and rupture of the particulate system. The interparticulate friction coefficient plays an important role in the behavior of the particulate system.

### 5.3 Interparticulate Strength

The strength of the packed particles is dominated by the fractional density. The variation in tensile strength with fractional density and particle size can be approximated from [2,3,8,11,19]. It is formulated as below:

$$\sigma_t=\frac{Cf^nP_cF_c}{D^2} \qquad (5.4)$$

where,

$\sigma_t$ =tensile strength

C =factor dependent on the particle shape

$f$ =the fractional density

$P_c$ =the packing coordination

$n$ =an exponent typically near unity

$F_c$ =the cohesive bond strength between particle

and $D$ =the particle diameter

The packing density is important because it controls the number of contacts per unit volume. Beyond these factors, the strength is also sensitive to the particle shape and size distribution. The more irregular the particle shape, the higher the strength at a given fractional density. Various relations have been proposed between the shear strength $\tau$ and the normal stress $\sigma$, such as, derived from [13,31,32,45].
that is,

$$\tau^n = F_c\left(1 + \frac{\sigma}{\sigma_t}\right) \qquad (5.5)$$

where,

$n$ =the shear index

and $F_c$ =the cohesive strength of the pellets

The cohesive strength is approximately twice the interparticle tensile strength. The shear index, n, ranges between one and two. For large spherical particles it approaches two. It can be approximated as follows,

$$n = 1 + \frac{0.5}{D^{2/3}} \qquad (5.6)$$

where,

$D$ =the particle diameter in millimeters

Particle compaction creates bonding planes and increases the interlocking at the interfaces, greatly increasing the interparticulate strength. The process of compaction initially causes local deformation by flattening surface. With continued pressurization, there occurs a transition from a loose particle mass to a higher packing density, with a high volumetric population of interparticulate contacts, resulting in greater strength. The effect of the particle shape is mixed in the degree of mechanical interlocking. Mechanical interlocking of the particles increases for the non-circular, irregular particle shapes. Therefore, the pellets with multi-lobal cross-sections had a tendency to lock each other more tightly than the pellets with circular cross-sections under the same pressure conditions.

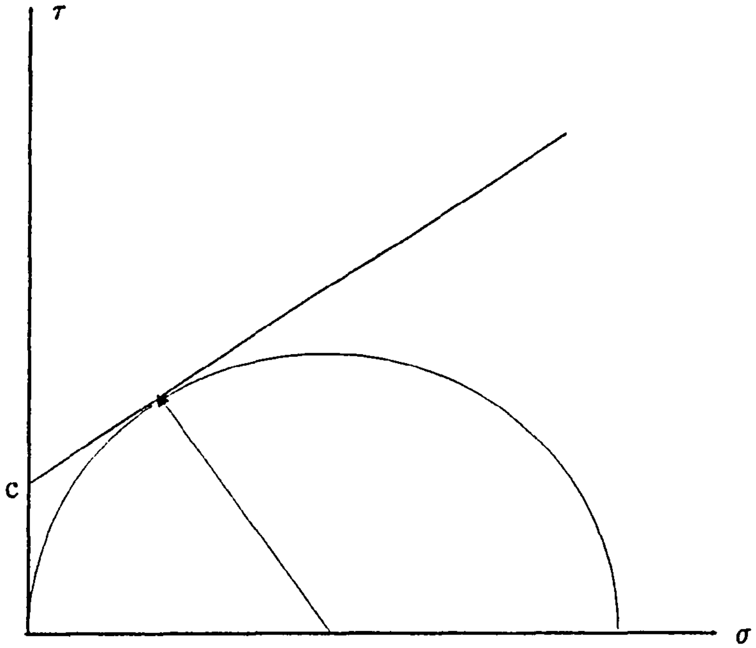


Figure 5.1 The Yield Locus of Cohesive System.

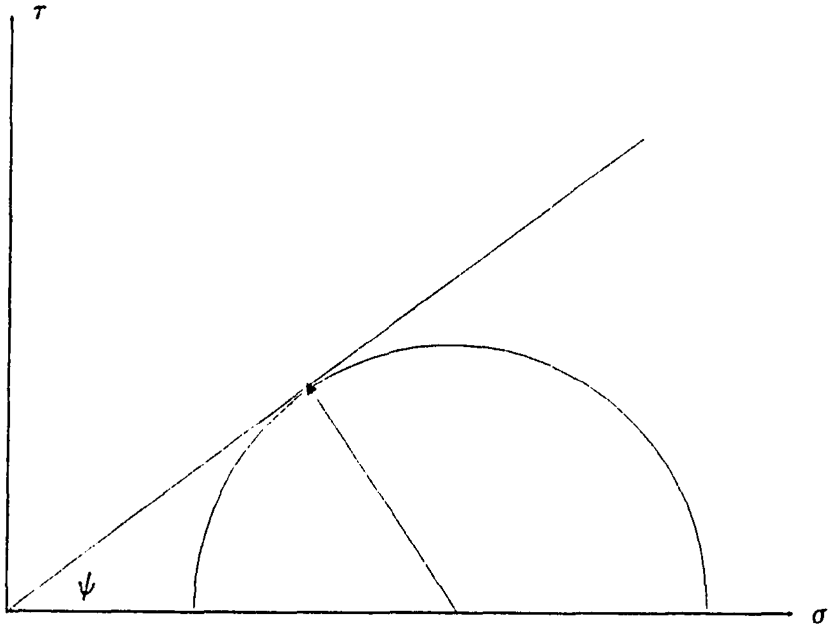


Figure 5.2 The Yield Locus of Noncohesive System.

# CHAPTER 6

# TEST APPARATUS AND TEST PROCEDURE FOR THE MEASUREMENT OF THE INTERPARTICULATE FRICTION COEFFICIENT

## 6.1 Test Apparatus

The original experimental test apparatus used for the measurement of the IPFC was developed by Chen [12]. The system is similar to the Jenike shear cell [25]. It is composed of five pieces with an upper ring, a low ring, a cover, a pulley, and a connecting cable. Due to the limitations of the design, it was not possible to measure the exact value of the IPFC. This can be remedied by using a direct shear cell apparatus. A photograph is shown in Figure 6.1. The test shear cell is mounted on a table, it contains the shear box housing, the upper moving ring, the cover and the load cell on one side. On the other side, it contains the gear box with a hand wheel for controlling the pushing rod, which connects to the strain gages for detection of the horizontal force at the shear plane. The direct shear cell arrangement is schematically shown in Figure 6.2. The shear box housing is fixed on the base of shear cell frame. The moving ring is placed on the top of the ring in the shear box housing. The cover holds the sample in the shear box during shear testing. The applied shear force is derived from the pushing stud by rotating the hand wheel. A strain gage is placed on the compressive ring to detect the applied shear force. In performing the test, the sample is loaded in the shear cell, and then the normal force is applied on the cover. The pushing stud applies the shear force to the moving ring, and when motion begins the induced strain is measured using a strain gage, recorded, and converted to a shear force.

## 6.2 Test Procedure

The direct shear cell arrangement is described as above. It is a static test, but is valid in its application to plasticating extrusion since the break-up of the solid bed is with respect to a static co-ordinate reference frame convected in the solid bed.

The polymeric pellets are packed into the shear cell and then sheared under the chosen normal force, which is applied to the top of the shear cell. The shear force is then applied to the moving ring, and when motion begins the induced strain is measured by using a strain gage. It records the scale indicator shown on the strain gage, which is then converted to a shear force. The interparticulate friction coefficient, $\mu$, is defined as the ratio of the shear force to the normal force, as motion commences, that is,

$$\mu = \frac{S}{N} \qquad (6.1)$$

where,

S is the shear force which causes motion,

and N is the normal force applied.

The behavior of the polymeric pellets can be investigated at other chosen stress conditions, by increasing the normal stress to the desired value and then reshearing. Each test was repeated five times to ensure accuracy. The material can readily be returned to the original prepared state by increasing the normal load from 20.5kPa to 45.2kPa.

## 6.3 V-Blender

A tumbler mixer is used to mix the pellets of non-circular cross-sections with surfactants in weight percentage from 0.25% to 2%. The mixer, a totally enclosed vessel rotating about an axis, causes the particles within the mixer to tumble over each other on the mixer surface. Rotation can be effected by placing the cylinder on driving rollers. In most other cases, the vessel is attached to a drive shaft and supported on one or two bearings. The vessel is shaped like the V as shown in Figure 6.3.

## 6.4 Method of Calculation for IPFC

The acting force on the shear force is shown in Figure 6.4, where a contact is assumed between the ring and the base. Some of the forces work around the whole circumference of the ring. The horizontal friction force $F_h$ in this situation originates from two sources,

1. The weight of the ring $W_r$
2. The silo effect in the upper ring, which causes a part of the vertical force N on the cover to be transmitted by friction to the wall $W_f$.

The force balance of the system is,

$$T - F_h = S \tag{6.2}$$

$$F_h = \mu_2 F_v \tag{6.3}$$

$$F_v = W_r + W_f \tag{6.4}$$

$$W_f = \mu_1 N \tag{6.5}$$

$$F_h = \mu_2(W_r + N\,\mu_1) \tag{6.6}$$

$$T - \mu_2(W_r + N\,\mu_1) = S \tag{6.7}$$

where,

$\mu_1$ = friction coefficient between polymer and steel,

$\mu_2$ = friction coefficient between ring and base,

$F_h$ = horizontal friction force between ring and base, N,

$F_v$ = vertical contact force between ring and base, N,

N = total vertical force on the cover, N,

S = real shearing force at shearing plane, N,

T = total externally applied horizontal force, N,

$W_r$ = vertical force due to weight of ring, N,

$W_f$ = vertical friction force between ring and material inside, due to silo effect, N.

The friction coefficient, $\mu_1$, between the polymer and steel is dependent on the material. The friction coefficient, $\mu_1$, data of acetal copolymer is found from the typical properties of acetal copolymer [53]. The friction coefficient, $\mu_1$, data of polyethylene, polypropylene, polystyrene, nylon 6 and ABS are found from Egan Machinery Co. [22]. The values, $\mu_1$, are listed in Table 6.1.

The friction coefficient, $\mu_2$, between the ring and base is dependent on the material of shear cell. It can be calibrated by pushing the upper shear cell by measuring the scale indicated on the strain gage, and then converting to the value $\mu_2$

### 6.5 Validation of the Test Results

In order to confirm the satisfactory operation of the shear cell some statistical tests were conducted. The cell was set up forty times for the same feedstock, and the friction force was measured. The mean and standard deviation for the forty data points were calculated, and based on these values the minimum number of sample tests required to determine a true average was determined from Blank [5]. The procedure is as follow.

Consider the (1-$\alpha$) 100 percent confidence interval for a population mean m, as given,

$$m = X + Z\alpha/2\frac{\sigma}{\sqrt{n}} \qquad (6.8)$$

The term $Z\alpha/2\frac{\sigma}{\sqrt{n}}$ is bound on the estimation error that is achieved with probability (1-$\alpha$) , planning the sample size to estimate m, There are a number of reasons for trying to keep the sample size small. The reasons for sampling in the first place, the cost of data collection and processing, and the time needed to acquire data. On the other hand, the sample must be large enough to achieve the goals, the desire for reliable and accurate estimation, the need to meet contractual obligations, and to satisfy industry and government test standards.

Consider the problem of choosing the sample size for estimating a population mean m, using the mean X of a random sample, the probability is (1-$\alpha$) that the estimation error will not exceed $Z\alpha/2\frac{\sigma}{\sqrt{n}}$. Suppose the decision maker determines that this bound should not exceed a value B. Then it is easy to determine the minimum sample size needed to achieve this accuracy. The $Z\alpha/2=Z_{0.025}=1.96$, $B=0.05$, $\sigma=0.053$.

$$Z\alpha/2\frac{\sigma}{\sqrt{n}} \leq B \tag{6.9}$$

$$n \geq (Z\alpha/2\frac{\sigma}{B})^2 \tag{6.10}$$

$$n \geq (1.96\frac{0.053}{0.05})^2 \tag{6.11}$$

$$n \geq 4.32 \tag{6.12}$$

It was determined that five tests were required to make an accurate estimation of the interparticulate friction coefficient in the direct shear cell. This procedure was therefore carried out in all of the test results taken. Namely, the values of the interparticulate friction coefficients were averaged from the five results.

Table 6.1 The Friction Coefficients of the Polymer for Acetal Copolymer, Polyethylene, Polypropylene, Polystyrene, Nylon 6, and ABS on Steel Surface.

| No | Polymer Material | Friction Coefficient $\mu_2$ |
|---|---|---|
| 1. | Acetal Copolymer | |
| | U10-01(POM1) | 0.15 |
| | M25(POM2) | 0.15 |
| | M90((POM3) | 0.15 |
| | M270(POM4) | 0.15 |
| | M450(POM5) | 0.15 |
| 2. | Polyethylene(PE) | 0.24 |
| 3. | Polypropylene(PP) | 0.32 |
| 4. | Polystyrene(PS) | 0.25 |
| 5. | Nylon 6(PA 6) | 0.28 |
| 6. | Acrylonitrile-butadiene-styrene(ABS) | 0.36 |

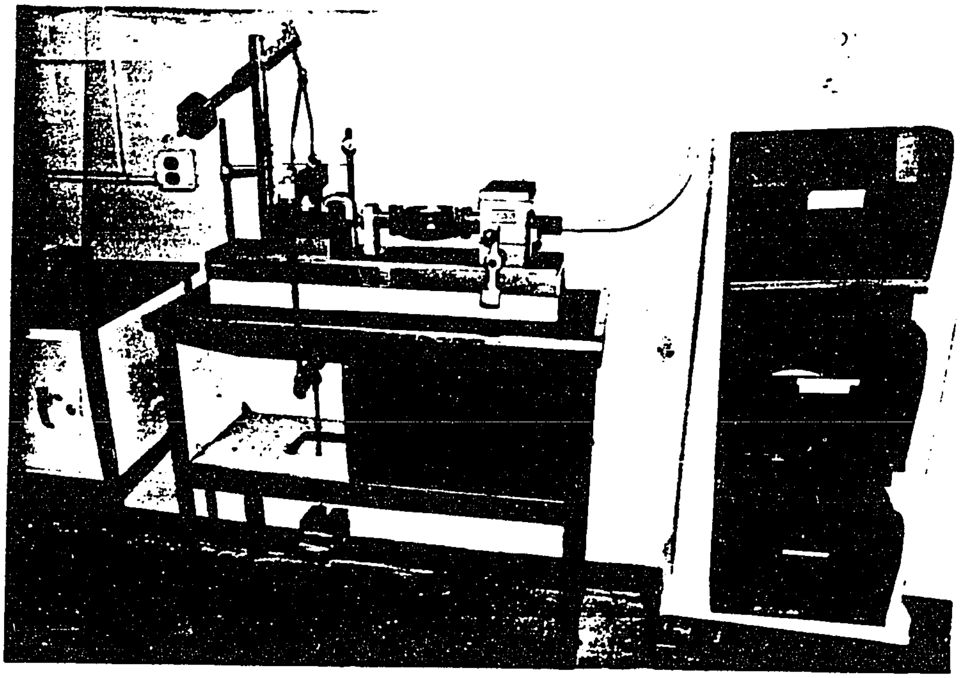


Figure 6.1 Direct Shear Cell Apparatus.

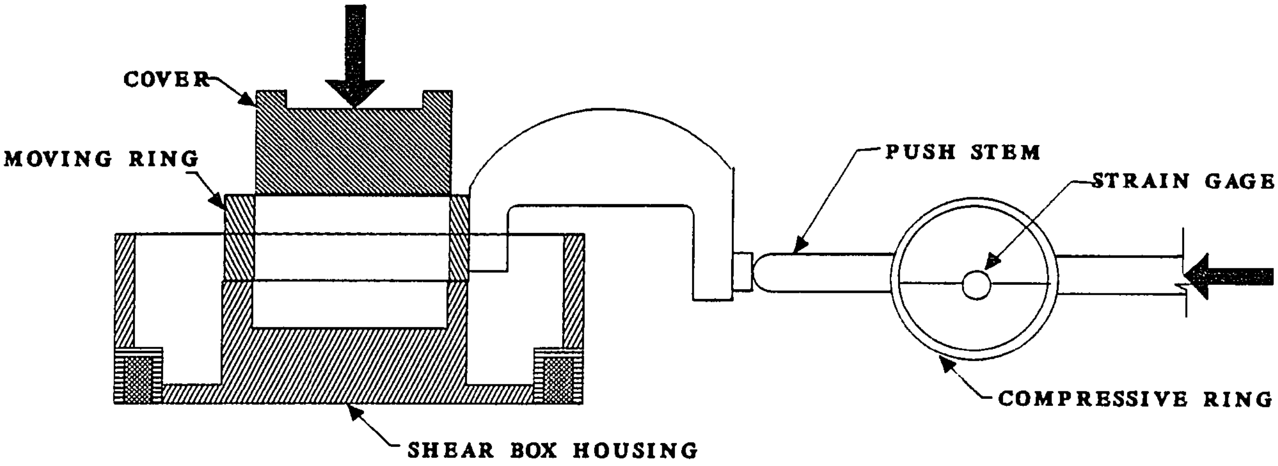


Figure 6.2 Schematic Diagram of the Shear Cell for the Measurement of the Interparticulate Friction Coefficient.

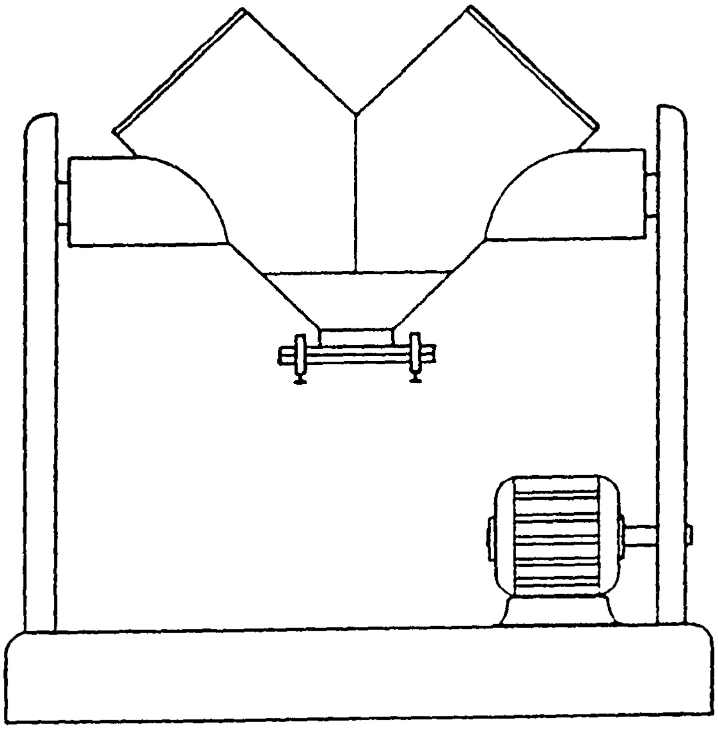


Figure 6.3 V-Blender.

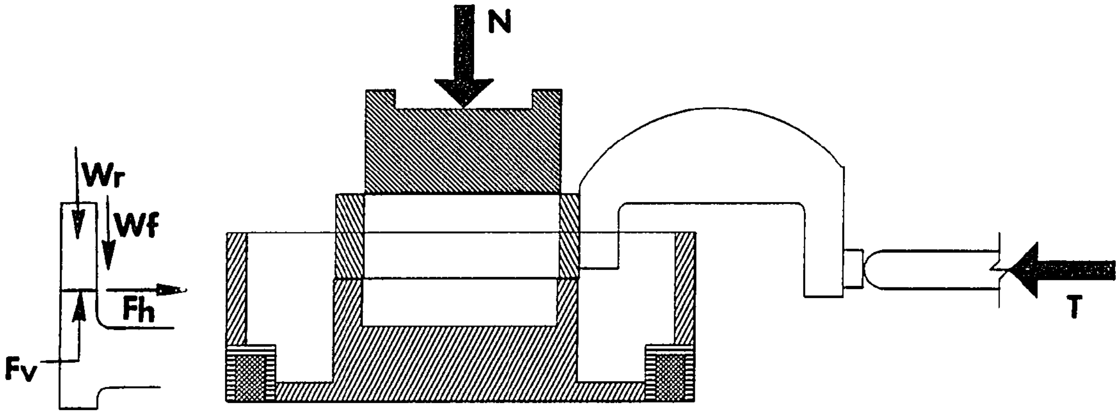


Figure 6.4 Acting Force on Shear Cell.

# CHAPTER 7

## EXPERIMENTAL RESULTS FOR THE INTERPARTICULATE FRICTION COEFFICIENT

In order to obtain a control datum, pellets with a circular cross-section. manufactured from the materials listed in Table 4.3 were first tested. The results for the measurement of the interparticulate friction coefficients, using the procedure described in chapter six are presented here. The pellets used in the tests with different profiled cross-sections were all manufactured using the specific die inserts, and designate by the code for the die inserts. For example, the bilobal pellets of polyethylene was manufactured by using the die insert A211 (A201-01). The pellet is classified as A211 of PE bilobal pellets.

The of X-axis is the normal pressure (Pascal) obtained by dividing the normal load (N) by the cross-sectional area of the shear cell ($m^2$), and the Y-axis is the IPFC obtained as in chapter six. Therefore, IPFC as a function of pressure for circular, bilobal, trilobal and quadrilobal cross-sections was plotted for each test. The results are described in the following sections.

### 7.1 Pellets with Circular Cross-Sections

The pellets with a circular cross-section for all five acetal copolymer samples were first tested. The results are presented in Figure 7.1. The only variables introduced were the pressure, the extruder screw speed, and the melt indices of the polymers from which the pellets were manufactured. Interparticulate friction coefficients for U10-01 (POM1) from 0.25 to 0.31 were recorded. Interparticulate friction coefficients for M25 (POM2) from 0.15 to 0.19 were recorded.

Interparticulate friction coefficients for M90 (POM3) from 0.17 to 0.24 were recorded. Interparticulate friction coefficients for M270 (POM4) from 0.16 to 0.185 were recorded. Interparticulate friction coefficients for M450 (POM5) from 0.15 to 0.17 were recorded. These values are very similar to the published data by [53]. Each result is based on an average of five measurements in accordance with the statistical determinations made in the chapter six.

The pellets with a circular cross-section of materials for polyethylene (PE), polypropylene (PP), polystyrene (PS), nylon 6 (PA 6), and acrylonitrile-butadiene-styrene (ABS) were also tested. The results are presented in Figure 7.2. Interparticulate friction coefficients for polyethylene from 0.25 to 0.275 were recorded. Interparticulate friction coefficients for polypropylene from 0.22 to 0.24 were recorded. Interparticulate friction coefficients for polystyrene from 0.23 to 0.29 were recorded. Interparticulate friction coefficients for nylon 6 from 0.265 to 0.29 were recorded. Interparticulate friction coefficients for acrylonitrile-butadiene-styrene from 0.16 to 0.19 were recorded. Each result is based on an average of five measurements in accordance with the statistical determinations made in the chapter six.

### 7.2 Pellets with Bilobal Cross-Sections

First, the die, A211 (A201-01), was installed on the extruder and pellets were manufactured at different extruder screw speeds ranging from 5 rpm to 20 rpm for each of the five samples of acetal copolymer. Samples of the pellets were collected for later testing, in accordance with the procedure described in chapter four. Then, this procedure was repeated for dies A212 (A201-02), A221 (A202-01), A231 (A203-01), A241 (A204-01), A311 (A301-01) and A411 (A401-01). Each of the samples was then placed in the shear cell and the interparticulate friction coefficient was measured as a function of normal pressure.

Figures 7.3 - 7.7 show the IPFC as a function of pressure of all bilobal dies for acetal copolymer grade U10-01 (POM1). The value of the IPFC is presented as described here. Figure 7.3 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.382 to 0.459. Figure 7.4 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.355 to 0.448. Figure 7.5 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221 for. The value of the IPFC is approximate 0.398 to 0.0.480. Figure 7.6 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231 for. The value of the IPFC is approximate 0.32 to 0.45. Figure 7.7 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.33 to 0.485.

Figures 7.8 - 7.12 show the IPFC as a function of pressure of all bilobal die for acetal copolymer grade M25 (POM2). The value of the IPFC is presented as described here. Figure 7.8 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.35 to 0.42. Figure 7.9 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.31 to 0.43. Figure 7.10 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.32 to 0.395. Figure 7.11 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.22 to 0.34. Figure 7.12 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.34 to 0.52.

Figures 7.13 - 7.17 show the IPFC as a function of pressure of all bilobal die for acetal copolymer grade M90 (POM3). The value of the IPFC is presented as described here. Figure 7.13 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.34 to 0.42. Figure 7.14 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.33 to 0.43. Figure 7.15 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.375 to 0.445. Figure 7.16 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.245 to 0.32. Figure 7.17 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.34 to 0.42.

Figures 7.18 - 7.22 show the IPFC as a function of pressure of all bilobal die for acetal copolymer grade M270 (POM4). The value of the IPFC is presented as described here. Figure 7.18 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.31 to 0.40. Figure 7.19 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.30 to 0.45. Figure 7.20 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.36 to 0.46. Figure 7.21 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.17 to 0.25. Figure 7.22 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.23 to 0.42.

Figures 7.23 - 7.27 show the IPFC as a function of pressure of all bilobal die for acetal copolymer grade M450 (POM5). The value of the IPFC is presented as described here. Figure 7.23 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.33 to 0.43. Figure 7.24 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.33 to 0.43. Figure 7.25

shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.385 to 0.455. Figure 7.26 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.17 to 0.235. Figure 7.27 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.35 to 0.44.

Second, with the same procedure described as above, the die, A201-01, was installed on the extruder and pellets were manufactured at different extruder screw speeds ranging from 5 rpm to 20 rpm for polyethylene (PE), polypropylene (PP), polystyrene (PS), nylon 6 (PA 6), and acrylonitrile-butadiene-styrene (ABS). Samples of the pellets were collected for later testing, in accordance with the procedure described in chapter four. Then, this procedure was repeated for dies A201-02, A202-01, A203-01, A204-01, A301-01, and A401-01. Each of the samples was then placed in the shear cell and the interparticulate friction coefficient was measured as a function of normal pressure.

Figures 7.28 - 7.32 show the IPFC as a function of pressure of all bilobal die for polyethylene (PE). The value of the IPFC is presented as described here. Figure 7.28 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.26 to 0.345. Figure 7.29 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.29 to 0.35. Figure 7.30 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.31 to 0.37. Figure 7.31 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.295 to 0.36. Figure 7.32 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.32 to 0.395.

Figures 7.33 - 7.37 show the IPFC as a function of pressure of all bilobal die for polypropylene (PP). The value of the IPFC is presented as described here. Figure 7.33 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.275 to 0.32. Figure 7.34 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.24 to 0.285. Figure 7.35 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.28 to 0.33. Figure 7.36 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.26 to 0.315. Figure 7.37 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.325 to 0.395.

Figures 7.38 - 7.42 show the IPFC as a function of pressure of all bilobal die for polystyrene (PS). The value of the IPFC is presented as described here. Figure 7.38 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.278 to 0.37. Figure 7.39 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.27 to 0.35. Figure 7.40 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.39 to 0.475. Figure 7.41 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.28 to 0.36. Figure 7.42 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.32 to 0.395.

Figures 7.43 - 7.47 show the IPFC as a function of pressure of all bilobal die for nylon 6 (PA 6). The value of the IPFC is presented as described here. Figure 7.43 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die

A211. The value of the IPFC is approximate 0.29 to 0.37. Figure 7.44 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A212. The value of the IPFC is approximate 0.29 to 0.335. Figure 7.45 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.295 to 0.375. Figure 7.46 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.28 to 0.355. Figure 7.47 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.325 to 0.390.

Figures 7.48 - 7.51 show the IPFC as a function of pressure of all bilobal die except A212 for acrylonitrile-butadiene-styrene (ABS). The value of the IPFC is presented as described here. Figure 7.48 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A211. The value of the IPFC is approximate 0.25 to 0.31. Figure 7.49 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A221. The value of the IPFC is approximate 0.21 to 0.28. Figure 7.50 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A231. The value of the IPFC is approximate 0.18 to 0.245. Figure 7.51 shows the IPFC as a function of pressure for pellets with bilobal cross-sections of die A241. The value of the IPFC is approximate 0.205 to 0.31.

### 7.3 Pellets with Trilobal Cross-Sections

Next, pellets with trilobal cross-sections were manufactured using the profile die A301-01 as described in Table 3.1 and tested in the direct shear cell.

Figures 7.52 - 7.56 show the IPFC as a function of pressure of trilobal die at four different extruder screw speeds ranging from 5 rpm to 20 rpm for each of the five samples of acetal copolymer. The value of the IPFC is presented as described here. Figure 7.52 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for acetal copolymer grade U10-01 (POM1). The value of the IPFC is approximate 0.33 to 0.45. Figure 7.53 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for acetal copolymer grade M25 (POM2). The value of the IPFC is approximate 0.205 to 0.28. Figure 7.54 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for acetal copolymer grade M90 (POM3). The value of the IPFC is approximate 0.22 to 0.29. Figure 7.55 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for acetal copolymer grade M270 (POM4). The value of the IPFC is approximate 0.205 to 0.255. Figure 7.56 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for acetal copolymer grade M450 (POM5). The value of the IPFC is approximate 0.18 to 0.275.

Figures 7.57 - 7.60 show the IPFC as a function of pressure of trilobal die at four different extruder screw speeds ranging from 5 rpm to 20 rpm for polyethylene, polypropylene, polystyrene and nylon 6.. The value of the IPFC is presented as described here. Figure 7.57 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for polyethylene. The value of the IPFC is approximate 0.30 to 0.345. Figure 7.58 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for polypropylene. The value of the IPFC is approximate 0.25 to 0.295. Figure 7.59 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for polystyrene. The value of the IPFC is approximate 0.25 to 0.295. Figure 7.60 shows the IPFC as a function of pressure for pellets with trilobal cross-sections of die A311 for nylon 6. The value of the IPFC is approximate 0.315 to 0.38.

## 7.4 Pellets with Quadrilobal Cross-Sections

Next, pellets with quadrilobal cross-sections were manufactured using the profile die A401-01 as described in Table 3.1 and tested in the direct shear cell.

Figures 7.61 - 7.65 show the IPFC as a function of pressure of quadrilobal die at four different extruder screw speeds ranging from 5 rpm to 20 rpm for each of the five samples of acetal copolymer. The value of the IPFC is presented as described here. Figure 7.61 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for acetal copolymer grade U10-01 (POM1). The value of the IPFC is approximate 0.334 to 363. Figure 7.62 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for acetal copolymer grade M25 (POM2). The value of the IPFC is approximate 0.195 to 0.235. Figure 7.63 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for acetal copolymer grade M90 (POM3). The value of the IPFC is approximate 0.255 to 0.29. Figure 7.64 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for acetal copolymer grade M270 (POM4). The value of the IPFC is approximate 0.20 to 0.275. Figure 7.65 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for acetal copolymer grade M450 (POM5). The value of the IPFC is approximate 0.20 to 0.225.

Figures 7.66 - 7.67 show the IPFC as a function of pressure of quadrilobal die at four different extruder screw speeds ranging from 5 rpm to 20 rpm for polyethylene (PE), polypropylene (PP). The value of the IPFC is presented as described here. Figure 7.66 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for polyethylene. The value of the IPFC is approximate 0.335 to 0.365. Figure 7.67 shows the IPFC as a function of pressure for pellets with quadrilobal cross-sections of die A411 for polypropylene. The value of the IPFC is approximate 0.305 to 0.345.

### 7.5 Pellets with Consolidation Pressure and Consolidation Time

Using the apparatus and procedure described in chapter six, results for the IPFC were measured over extensive pressure ranges. The pellets consolidated at 126.3 kPa prior to testing. Figure 7.68 shows the IPFC as a function of pressure for pellets were manufactured from polyethylene using die A211. The value of the IPFC is 0.238 to 0.323.

The pellets also consolidated at 126.3 kPa for several different time periods. Figure 7.69 shows the IPFC as a function of consolidation time for pellets manufactured using die A211. The value of the IPFC is 0.32 to 0.36.

### 7.6 Pellets with Surface Lubricant and Additive

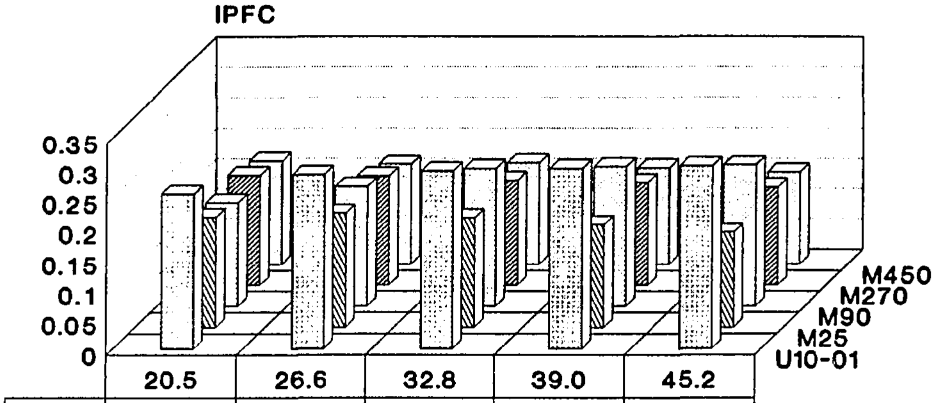
The zinc stearate, mica clay, and polyester powder (PBT) were added into the pellets with circular cross-sections and bilobal cross-sections.

Figure 7.70 shows the IPFC as a function of pressure for pellets with circular cross-sections of acetal copolymer grade M90 (POM3) by adding zinc stearate in weight percentage from 0.25% to 1.0%. The value of the IPFC is 0.119 to 0.233. Figure 7.71 shows the IPFC as a function of pressure for pellets with bilobal cross-sections manufactured using die A211 from acetal copolymer grade M90 (POM3) by adding zinc stearate in weight percentage from 0.25% to 1.0%. The value of the IPFC is 0.128 to 0.218. Figure 7.72 shows the IPFC as a function of pressure for the pellets manufactured using die A212 from acetal copolymer grade M90 (POM3) by adding zinc stearate in weight percentage from 0.25% to 1.0%. The value of the IPFC is 0.18 to 0.236.

Figure 7.73 shows the IPFC as a function of pressure for pellets with circular cross-sections of nylon 6 (PA 6) by adding mica clay in weight percentage from 0.5% to 2.0%. The value of the IPFC is 0.304 to 0.368. Figure 7.74 shows the IPFC as a function of pressure for pellets with bilobal cross-sections manufactured using die

A241 from nylon 6 (PA 6) by adding mica clay in weight percentage from 0.25% to 1.0%. The value of the IPFC is 0.35 to 0.43.

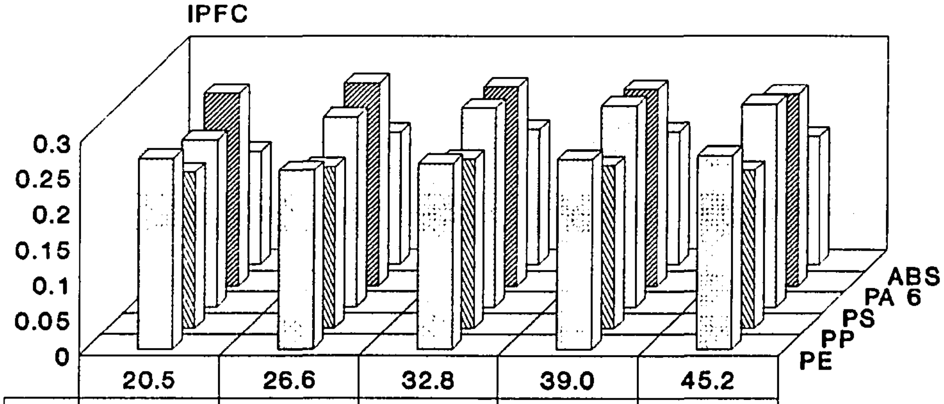
Figure 7.75 shows the IPFC as a function of pressure for pellets with circular cross-sections of acetal copolymer grade M90 (POM3) by adding polyester (PBT) powder in weight percentage from 0.5% to 2.0%. The value of the IPFC is 0.257 to 0.313. Figure 7.76 shows the IPFC as a function of pressure for pellets with bilobal cross-sections manufactured using die A212 from acetal copolymer grade M90 (POM3) by adding polyester (PBT) powder in weight percentage from 0.5% to 2.0%. The value of the IPFC is 0.248 to 0.383.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| M450 | 0.171 | 0.165 | 0.168 | 0.159 | 0.152 |
| M270 | 0.182 | 0.181 | 0.174 | 0.17 | 0.162 |
| M90 | 0.171 | 0.198 | 0.228 | 0.231 | 0.234 |
| M25 | 0.182 | 0.189 | 0.181 | 0.17 | 0.157 |
| U10-01 | 0.256 | 0.288 | 0.294 | 0.298 | 0.302 |

Normal Pressure (kPa)

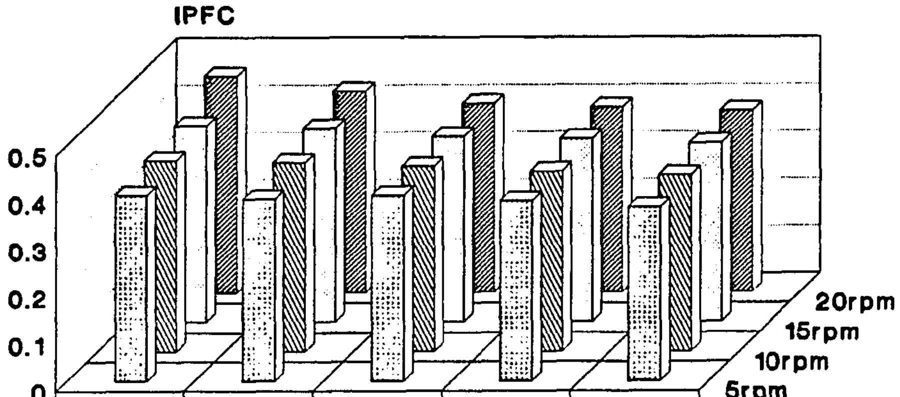
Figure 7.1 IPFC of Cylindrical for Pellets With Circular Cross-Sections (a) U-10, (b) M-25, (c) M-90, (d) M-270, (e) M-450.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| ABS | 0.159 | 0.186 | 0.19 | 0.187 | 0.18 |
| PA 6 | 0.271 | 0.285 | 0.28 | 0.276 | 0.269 |
| PS | 0.235 | 0.267 | 0.28 | 0.283 | 0.285 |
| PP | 0.22 | 0.227 | 0.238 | 0.229 | 0.222 |
| PE | 0.269 | 0.252 | 0.262 | 0.268 | 0.273 |

Normal Pressure (kPa)

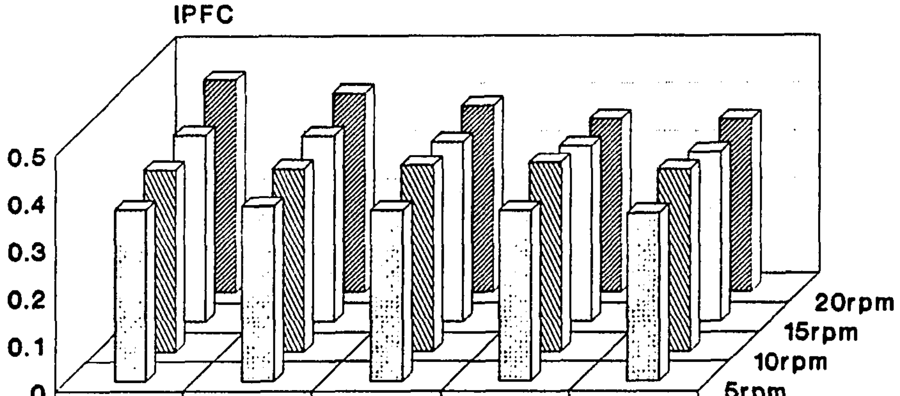
Figure 7.2 IPFC of Cylindrical for Pellets With Circular Cross-Sections (a) PE, (b) PP, (c) PS, (d) PA 6, (e) ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.459 | 0.427 | 0.4 | 0.393 | 0.384 |
| 15rpm | 0.416 | 0.411 | 0.394 | 0.388 | 0.379 |
| 10rpm | 0.405 | 0.402 | 0.394 | 0.382 | 0.374 |
| 5rpm | 0.395 | 0.386 | 0.394 | 0.382 | 0.369 |

Normal Pressure (kPa)

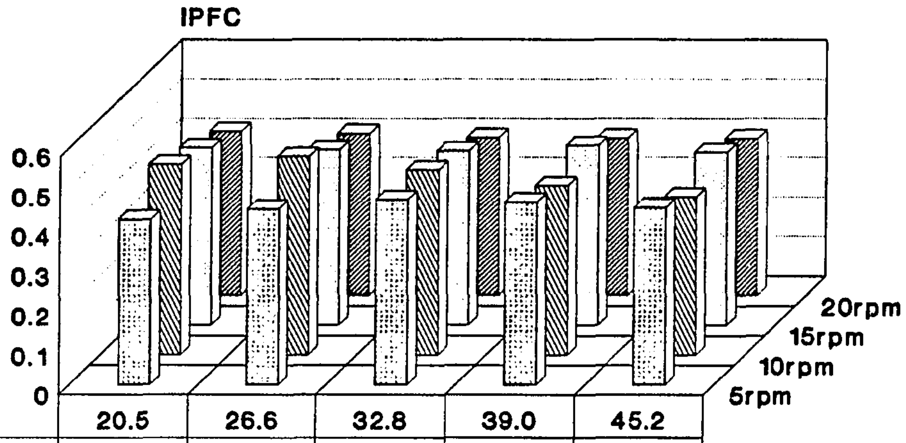
Figure 7.3 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.448 | 0.419 | 0.394 | 0.366 | 0.364 |
| 15rpm | 0.395 | 0.394 | 0.38 | 0.371 | 0.359 |
| 10rpm | 0.384 | 0.386 | 0.394 | 0.399 | 0.384 |
| 5rpm | 0.363 | 0.37 | 0.361 | 0.36 | 0.355 |

Normal Pressure (kPa)

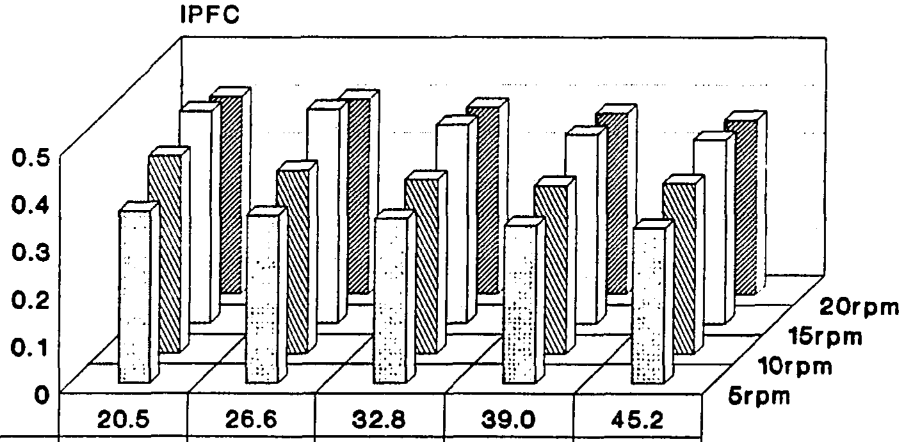
Figure 7.4 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM1



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.411 | 0.4 | 0.399 | 0.398 |
| 15rpm | 0.448 | 0.443 | 0.44 | 0.455 | 0.437 |
| 10rpm | 0.48 | 0.501 | 0.467 | 0.427 | 0.398 |
| 5rpm | 0.416 | 0.443 | 0.467 | 0.461 | 0.446 |

Normal Pressure (kPa)

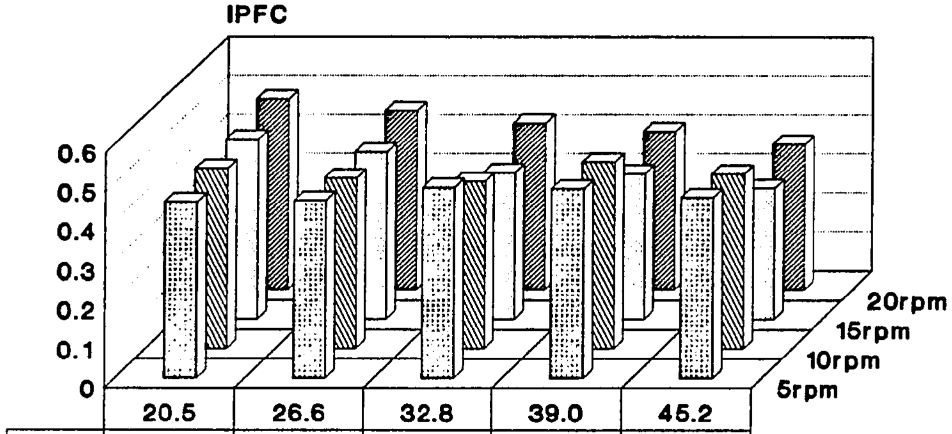
Figure 7.5 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM1.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.411 | 0.394 | 0.382 | 0.369 |
| 15rpm | 0.448 | 0.452 | 0.42 | 0.399 | 0.388 |
| 10rpm | 0.416 | 0.386 | 0.367 | 0.354 | 0.359 |
| 5rpm | 0.363 | 0.353 | 0.347 | 0.332 | 0.326 |

Normal Pressure (kPa)

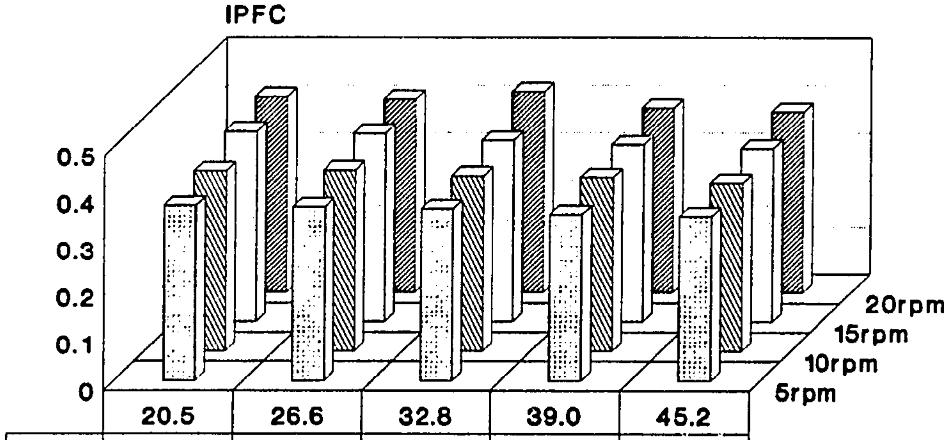
Figure 7.6 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.489 | 0.46 | 0.427 | 0.405 | 0.374 |
| 15rpm | 0.459 | 0.427 | 0.374 | 0.371 | 0.335 |
| 10rpm | 0.459 | 0.435 | 0.427 | 0.477 | 0.446 |
| 5rpm | 0.448 | 0.452 | 0.487 | 0.483 | 0.461 |

Normal Pressure (kPa)

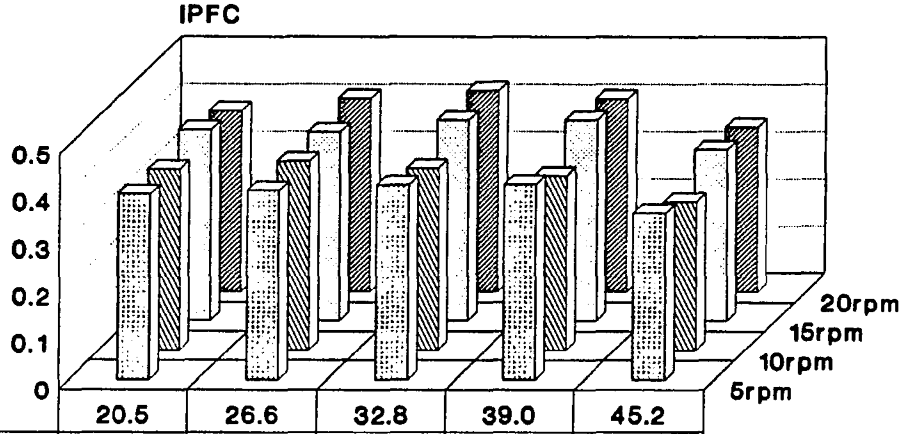
Figure 7.7 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.411 | 0.427 | 0.393 | 0.384 |
| 15rpm | 0.405 | 0.402 | 0.387 | 0.377 | 0.369 |
| 10rpm | 0.384 | 0.386 | 0.374 | 0.371 | 0.359 |
| 5rpm | 0.373 | 0.37 | 0.367 | 0.354 | 0.35 |

Normal Pressure (kPa)

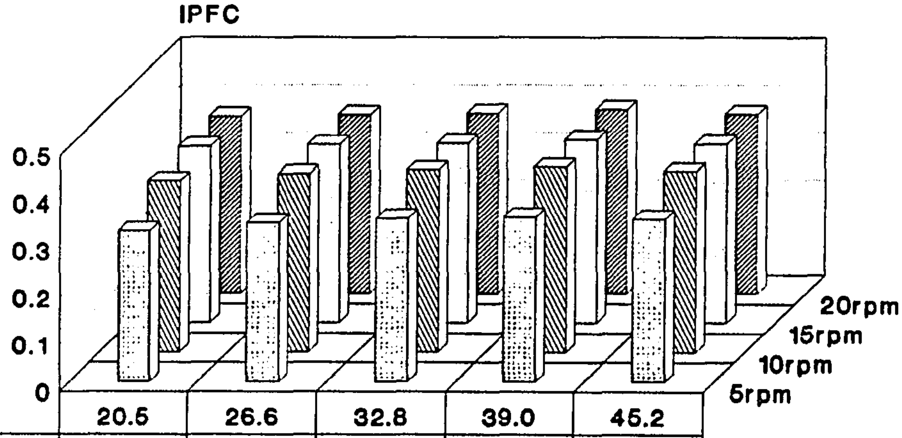
Figure 7.8 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM2



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.411 | 0.427 | 0.41 | 0.35 |
| 15rpm | 0.406 | 0.402 | 0.427 | 0.427 | 0.364 |
| 10rpm | 0.384 | 0.402 | 0.387 | 0.371 | 0.316 |
| 5rpm | 0.395 | 0.402 | 0.414 | 0.416 | 0.355 |

Normal Pressure (kPa)

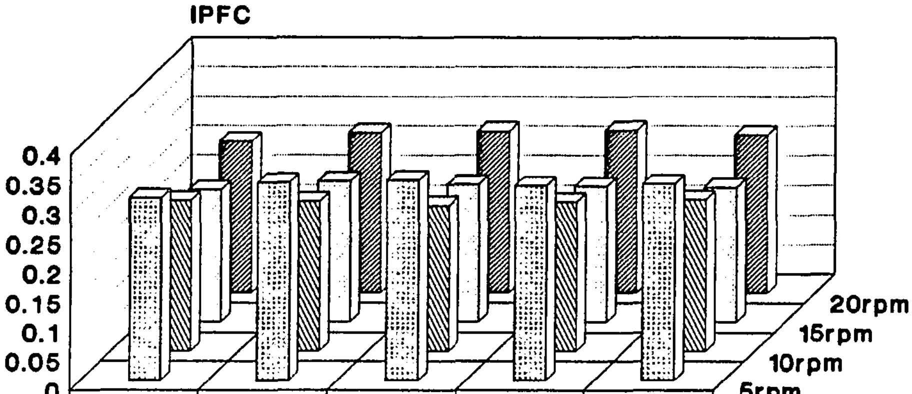
Figure 7.9 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM2 .



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.374 | 0.378 | 0.38 | 0.388 | 0.379 |
| 15rpm | 0.374 | 0.378 | 0.38 | 0.388 | 0.379 |
| 10rpm | 0.363 | 0.378 | 0.387 | 0.393 | 0.384 |
| 5rpm | 0.32 | 0.337 | 0.347 | 0.349 | 0.345 |

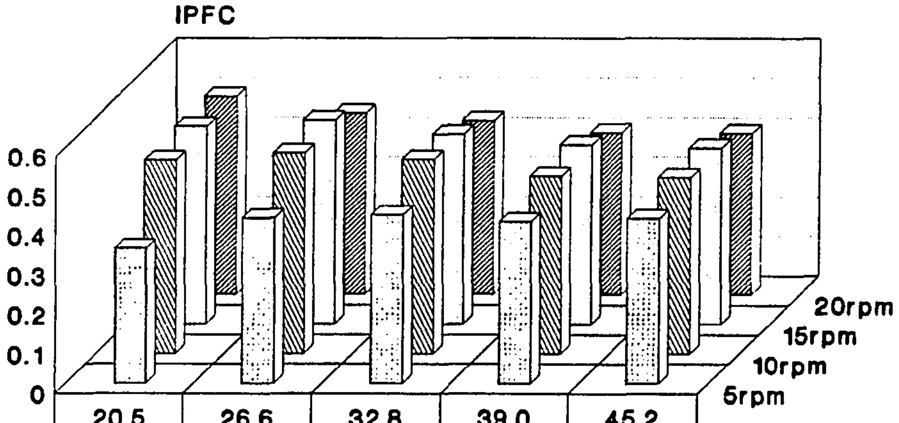
Normal Pressure (kPa)

Figure 7.10 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM2.



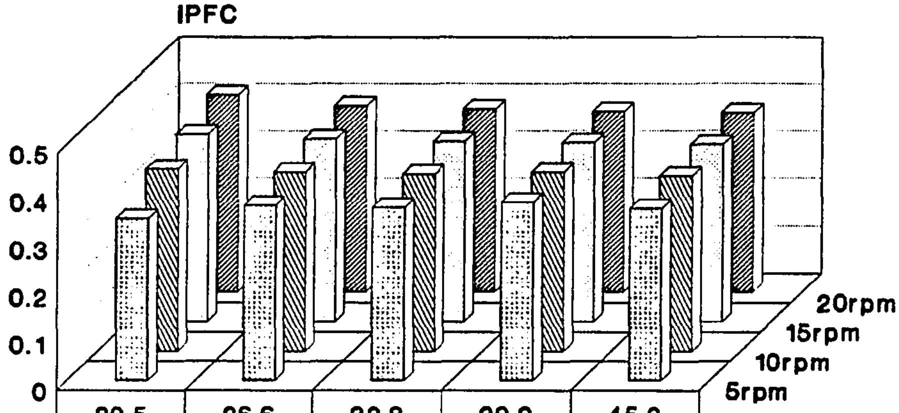
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.256 | 0.271 | 0.274 | 0.276 | 0.268 |
| 15rpm | 0.224 | 0.239 | 0.234 | 0.231 | 0.229 |
| 10rpm | 0.256 | 0.255 | 0.248 | 0.254 | 0.258 |
| 5rpm | 0.31 | 0.337 | 0.341 | 0.332 | 0.335 |

Figure 7.11 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.501 | 0.46 | 0.44 | 0.41 | 0.408 |
| 15rpm | 0.501 | 0.517 | 0.48 | 0.455 | 0.446 |
| 10rpm | 0.491 | 0.509 | 0.493 | 0.449 | 0.446 |
| 5rpm | 0.342 | 0.419 | 0.427 | 0.41 | 0.417 |

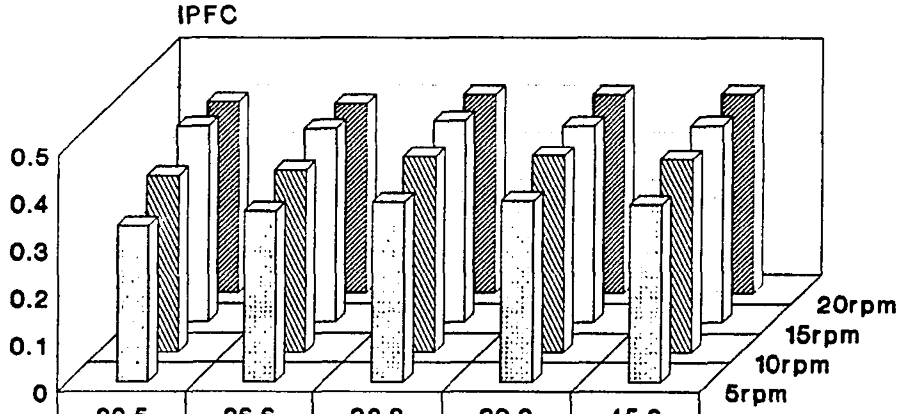
Figure 7.12 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.394 | 0.387 | 0.382 | 0.379 |
| 15rpm | 0.395 | 0.386 | 0.38 | 0.377 | 0.374 |
| 10rpm | 0.384 | 0.378 | 0.374 | 0.377 | 0.369 |
| 5rpm | 0.342 | 0.37 | 0.367 | 0.377 | 0.364 |

Normal Pressure (kPa)

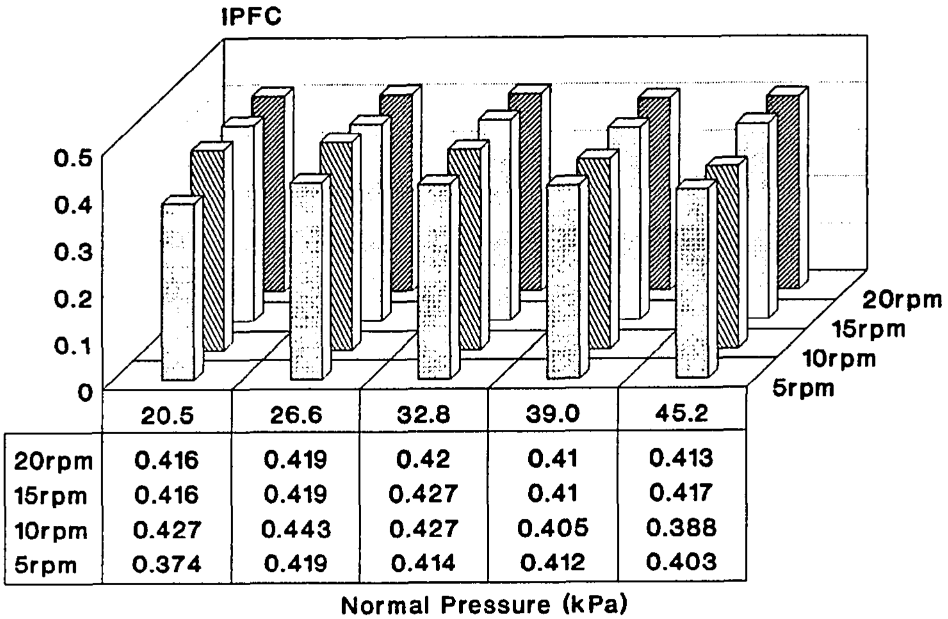
Figure 7.13 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.406 | 0.402 | 0.42 | 0.421 | 0.422 |
| 15rpm | 0.416 | 0.411 | 0.427 | 0.416 | 0.417 |
| 10rpm | 0.374 | 0.386 | 0.414 | 0.416 | 0.408 |
| 5rpm | 0.331 | 0.361 | 0.38 | 0.382 | 0.374 |

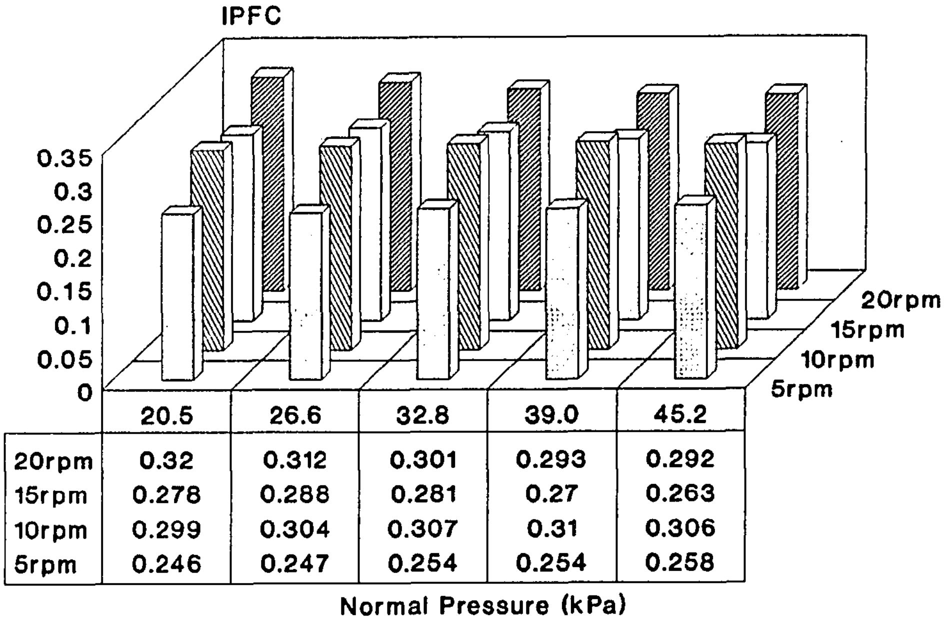
Normal Pressure (kPa)

Figure 7.14 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM3.



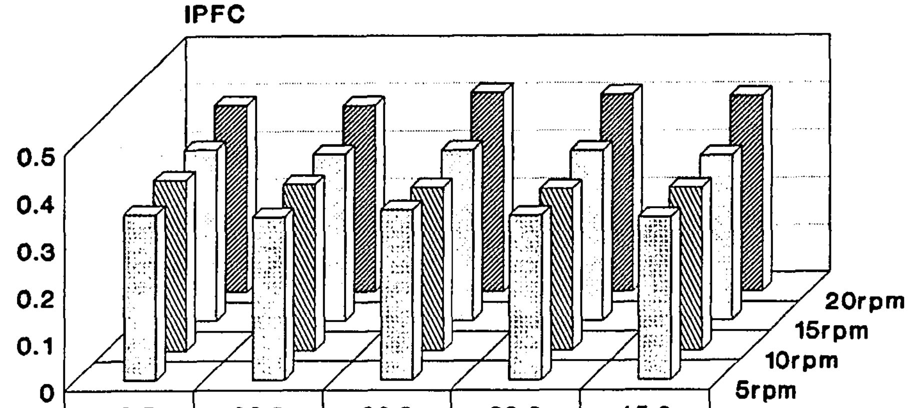
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.419 | 0.42 | 0.41 | 0.413 |
| 15rpm | 0.416 | 0.419 | 0.427 | 0.41 | 0.417 |
| 10rpm | 0.427 | 0.443 | 0.427 | 0.405 | 0.388 |
| 5rpm | 0.374 | 0.419 | 0.414 | 0.412 | 0.403 |

Figure 7.15 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.32 | 0.312 | 0.301 | 0.293 | 0.292 |
| 15rpm | 0.278 | 0.288 | 0.281 | 0.27 | 0.263 |
| 10rpm | 0.299 | 0.304 | 0.307 | 0.31 | 0.306 |
| 5rpm | 0.246 | 0.247 | 0.254 | 0.254 | 0.258 |

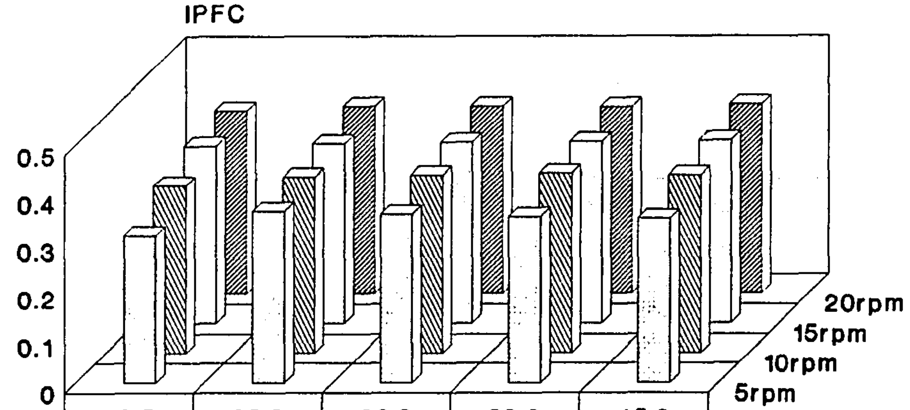
Figure 7.16 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.395 | 0.394 | 0.42 | 0.416 | 0.413 |
| 15rpm | 0.363 | 0.353 | 0.361 | 0.36 | 0.35 |
| 10rpm | 0.363 | 0.353 | 0.347 | 0.343 | 0.345 |
| 5rpm | 0.352 | 0.347 | 0.361 | 0.349 | 0.345 |

Normal Pressure (kPa)

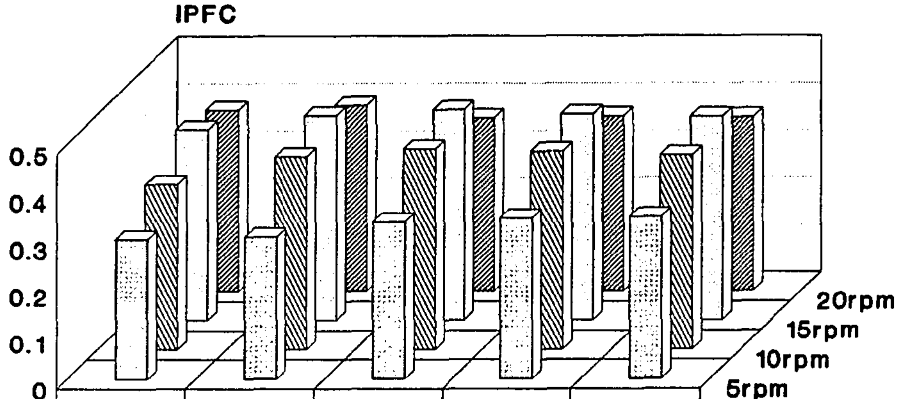
Figure 7.17 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.394 | 0.394 | 0.393 | 0.398 |
| 15rpm | 0.373 | 0.378 | 0.38 | 0.382 | 0.384 |
| 10rpm | 0.352 | 0.37 | 0.374 | 0.377 | 0.374 |
| 5rpm | 0.31 | 0.361 | 0.354 | 0.349 | 0.345 |

Normal Pressure (kPa)

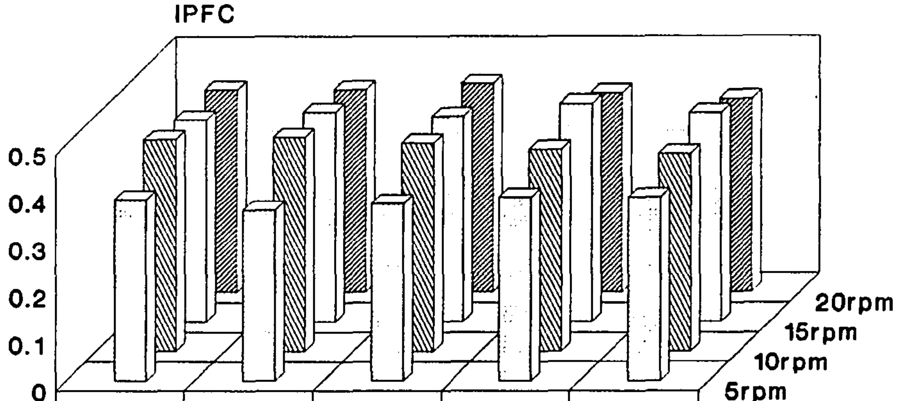
Figure 7.18 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.394 | 0.367 | 0.371 | 0.369 |
| 15rpm | 0.406 | 0.435 | 0.447 | 0.438 | 0.432 |
| 10rpm | 0.352 | 0.411 | 0.427 | 0.421 | 0.413 |
| 5rpm | 0.299 | 0.304 | 0.334 | 0.343 | 0.345 |

Normal Pressure (kPa)

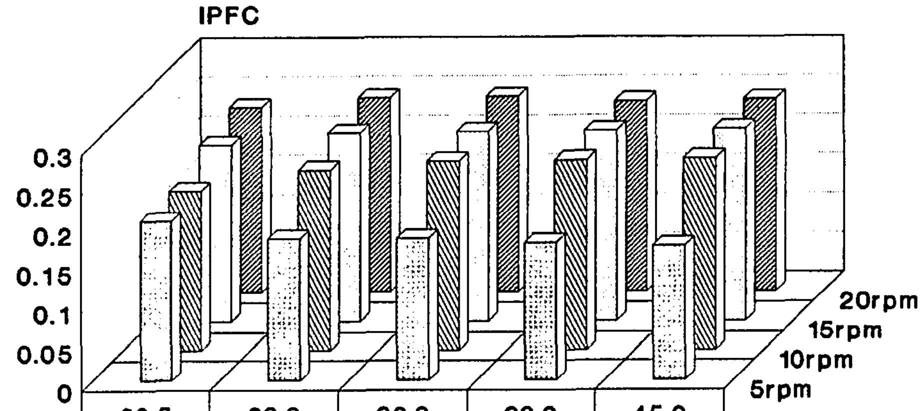
Figure 7.19 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.427 | 0.427 | 0.44 | 0.421 | 0.408 |
| 15rpm | 0.427 | 0.443 | 0.434 | 0.461 | 0.442 |
| 10rpm | 0.448 | 0.452 | 0.44 | 0.427 | 0.417 |
| 5rpm | 0.384 | 0.361 | 0.374 | 0.388 | 0.388 |

Normal Pressure (kPa)

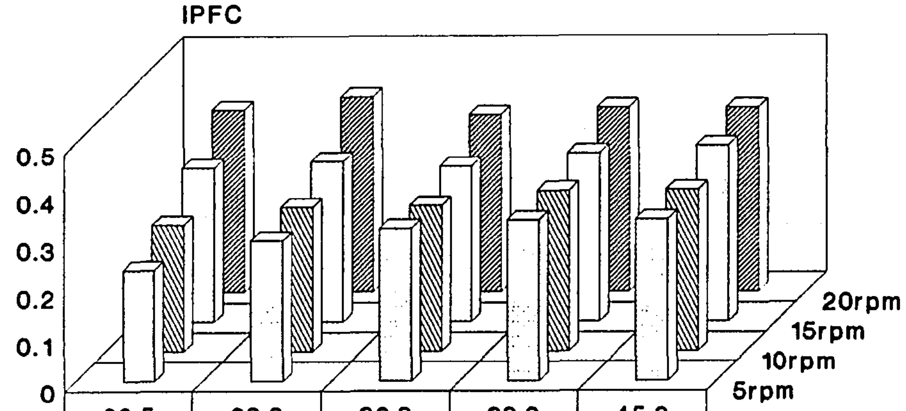
Figure 7.20 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.235 | 0.247 | 0.248 | 0.242 | 0.244 |
| 15rpm | 0.224 | 0.239 | 0.241 | 0.242 | 0.244 |
| 10rpm | 0.203 | 0.23 | 0.241 | 0.242 | 0.244 |
| 5rpm | 0.203 | 0.181 | 0.181 | 0.175 | 0.171 |

Normal Pressure (kPa)

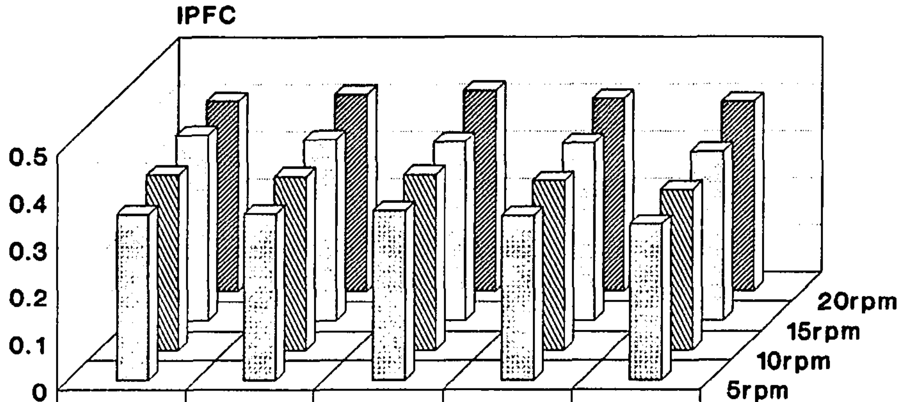
Figure 7.21 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.411 | 0.374 | 0.388 | 0.388 |
| 15rpm | 0.324 | 0.337 | 0.327 | 0.354 | 0.369 |
| 10rpm | 0.267 | 0.304 | 0.307 | 0.338 | 0.34 |
| 5rpm | 0.235 | 0.296 | 0.321 | 0.338 | 0.34 |

Normal Pressure (kPa)

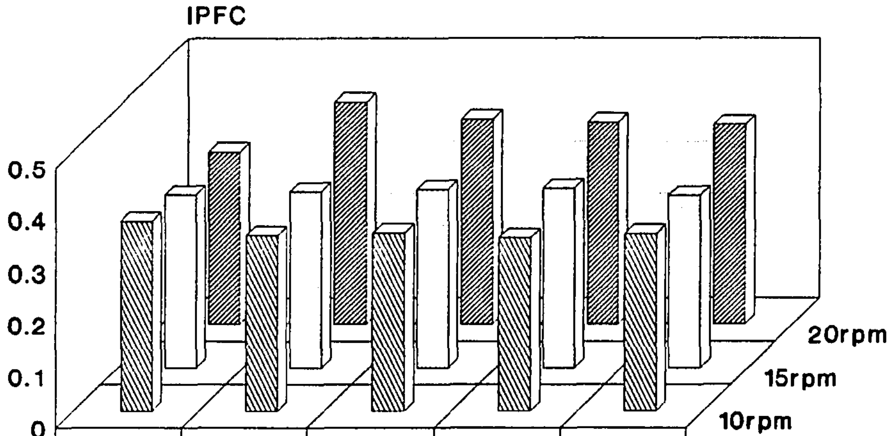
Figure 7.22 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM4.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.405 | 0.419 | 0.427 | 0.41 | 0.403 |
| 15rpm | 0.395 | 0.386 | 0.38 | 0.377 | 0.359 |
| 10rpm | 0.373 | 0.37 | 0.374 | 0.36 | 0.34 |
| 5rpm | 0.352 | 0.353 | 0.36 | 0.349 | 0.33 |

Normal Pressure (kPa)

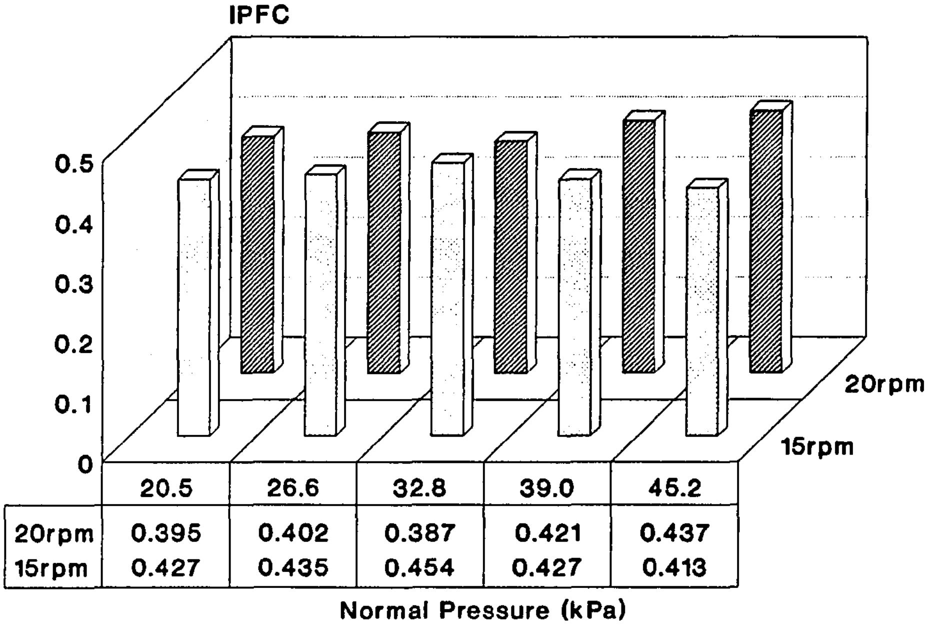
Figure 7.23 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM5.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.331 | 0.427 | 0.394 | 0.388 | 0.384 |
| 15rpm | 0.331 | 0.337 | 0.341 | 0.343 | 0.33 |
| 10rpm | 0.363 | 0.337 | 0.341 | 0.332 | 0.34 |

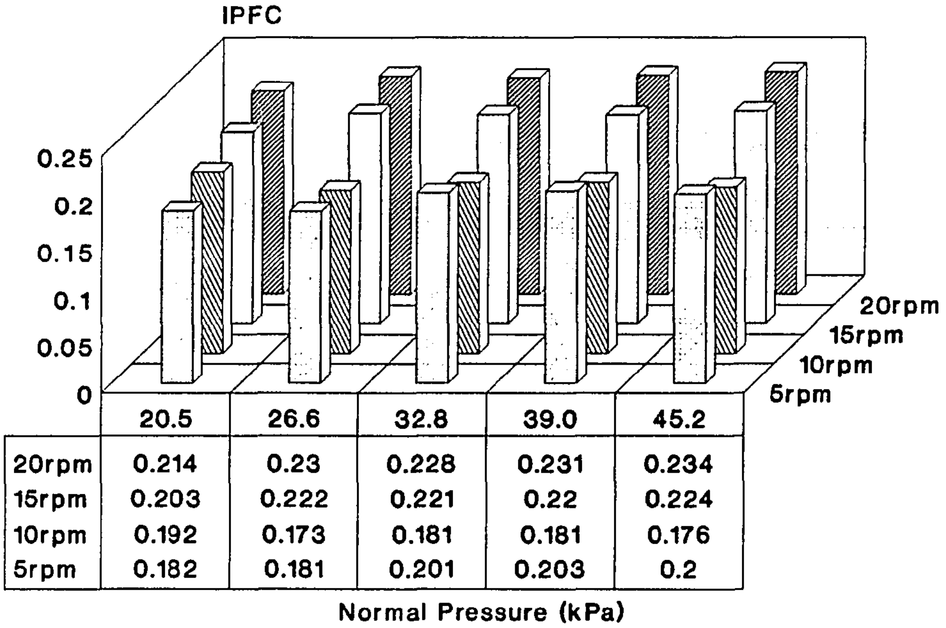
Normal Pressure (kPa)

Figure 7.24 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM5.



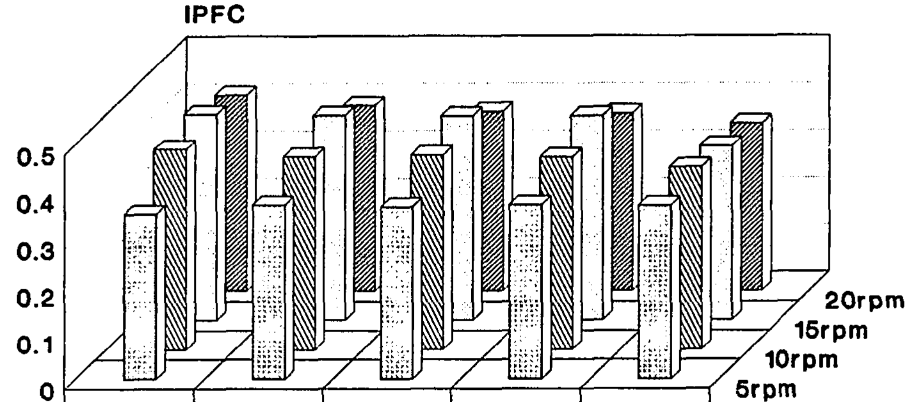
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.395 | 0.402 | 0.387 | 0.421 | 0.437 |
| 15rpm | 0.427 | 0.435 | 0.454 | 0.427 | 0.413 |

Figure 7.25 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.214 | 0.23 | 0.228 | 0.231 | 0.234 |
| 15rpm | 0.203 | 0.222 | 0.221 | 0.22 | 0.224 |
| 10rpm | 0.192 | 0.173 | 0.181 | 0.181 | 0.176 |
| 5rpm | 0.182 | 0.181 | 0.201 | 0.203 | 0.2 |

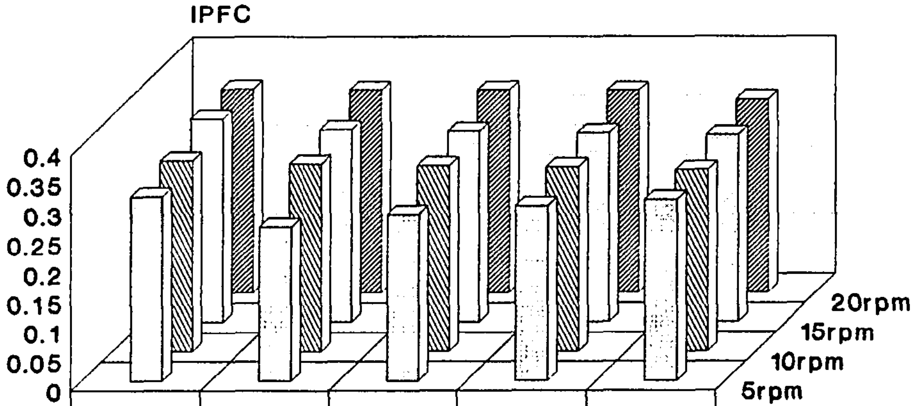
Figure 7.26 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM5.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.394 | 0.38 | 0.377 | 0.355 |
| 15rpm | 0.438 | 0.435 | 0.434 | 0.433 | 0.369 |
| 10rpm | 0.427 | 0.411 | 0.414 | 0.41 | 0.388 |
| 5rpm | 0.352 | 0.37 | 0.367 | 0.371 | 0.369 |

Normal Pressure (kPa)

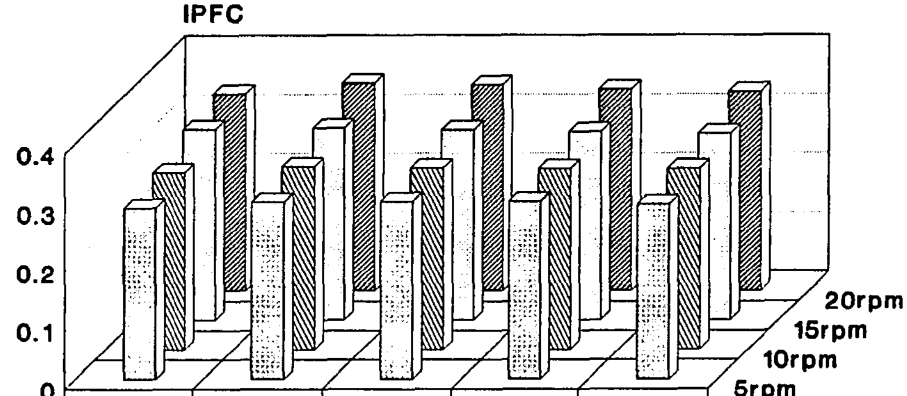
Figure 7.27 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM5.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.344 | 0.342 | 0.342 | 0.341 | 0.326 |
| 15rpm | 0.344 | 0.326 | 0.322 | 0.319 | 0.316 |
| 10rpm | 0.323 | 0.318 | 0.315 | 0.313 | 0.307 |
| 5rpm | 0.312 | 0.261 | 0.282 | 0.296 | 0.307 |

Normal Pressure (kPa)

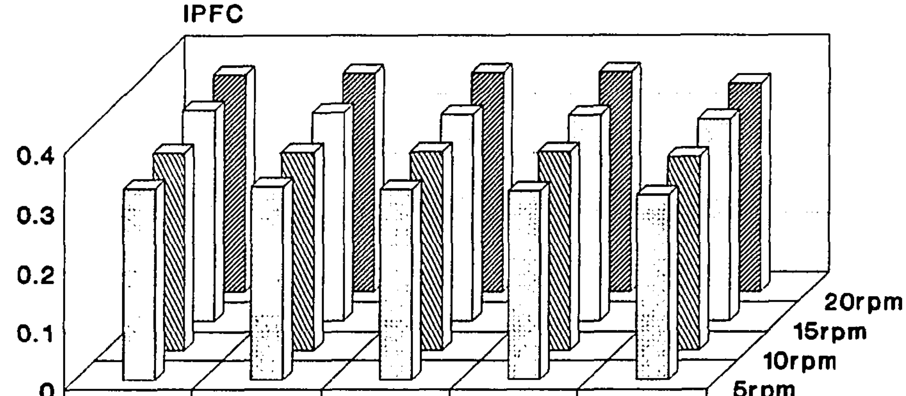
Figure 7.28 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.333 | 0.351 | 0.348 | 0.341 | 0.336 |
| 15rpm | 0.323 | 0.326 | 0.322 | 0.319 | 0.316 |
| 10rpm | 0.301 | 0.31 | 0.308 | 0.307 | 0.307 |
| 5rpm | 0.291 | 0.301 | 0.302 | 0.302 | 0.297 |

Normal Pressure (kPa)

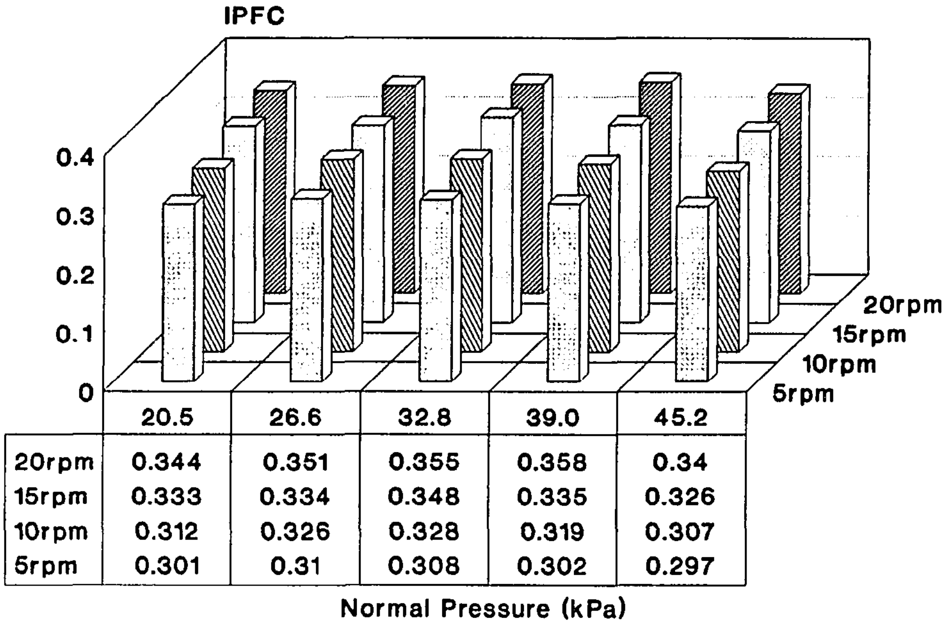
Figure 7.29 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.365 | 0.367 | 0.368 | 0.369 | 0.35 |
| 15rpm | 0.355 | 0.351 | 0.348 | 0.347 | 0.34 |
| 10rpm | 0.333 | 0.334 | 0.335 | 0.335 | 0.326 |
| 5rpm | 0.323 | 0.326 | 0.322 | 0.319 | 0.312 |

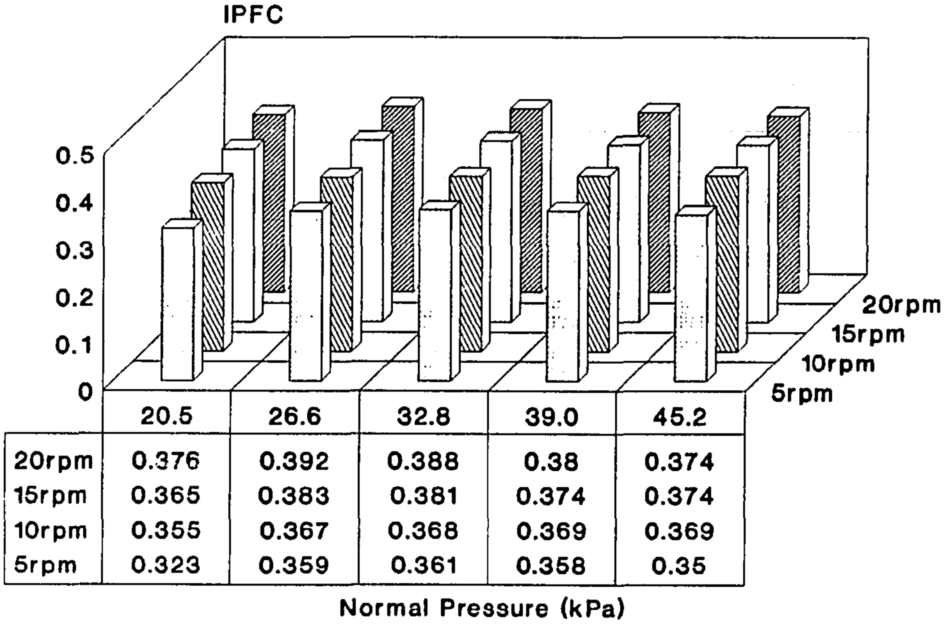
Normal Pressure (kPa)

Figure 7.30 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PE.



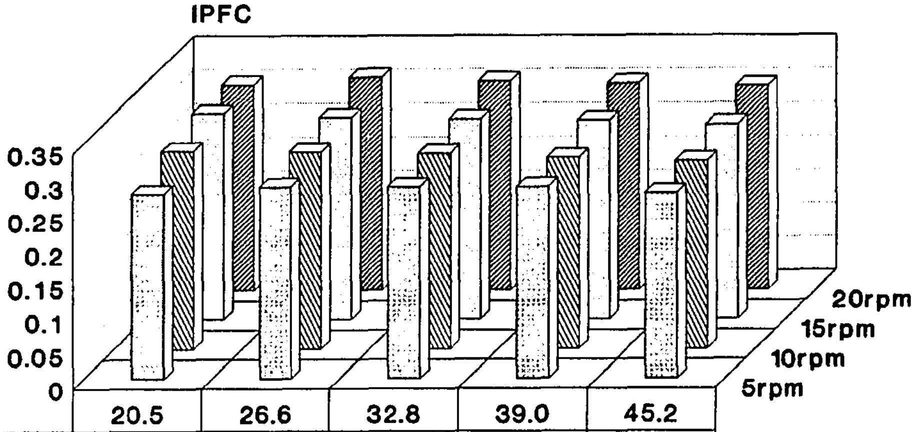
|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.344 | 0.351 | 0.355 | 0.358 | 0.34 |
| 15rpm | 0.333 | 0.334 | 0.348 | 0.335 | 0.326 |
| 10rpm | 0.312 | 0.326 | 0.328 | 0.319 | 0.307 |
| 5rpm | 0.301 | 0.31 | 0.308 | 0.302 | 0.297 |

Figure 7.31 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PE.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.376 | 0.392 | 0.388 | 0.38 | 0.374 |
| 15rpm | 0.365 | 0.383 | 0.381 | 0.374 | 0.374 |
| 10rpm | 0.355 | 0.367 | 0.368 | 0.369 | 0.369 |
| 5rpm | 0.323 | 0.359 | 0.361 | 0.358 | 0.35 |

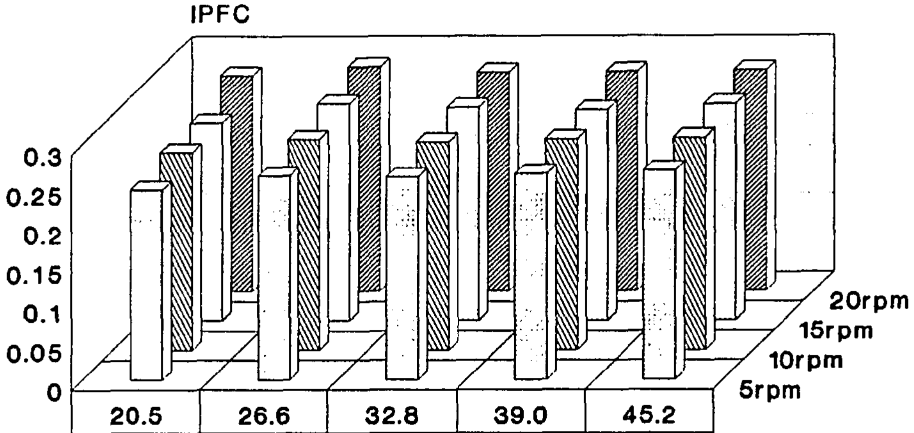
Figure 7.32 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.306 | 0.317 | 0.311 | 0.307 | 0.304 |
| 15rpm | 0.306 | 0.301 | 0.298 | 0.296 | 0.29 |
| 10rpm | 0.295 | 0.293 | 0.291 | 0.285 | 0.28 |
| 5rpm | 0.274 | 0.285 | 0.285 | 0.285 | 0.275 |

Normal Pressure (kPa)

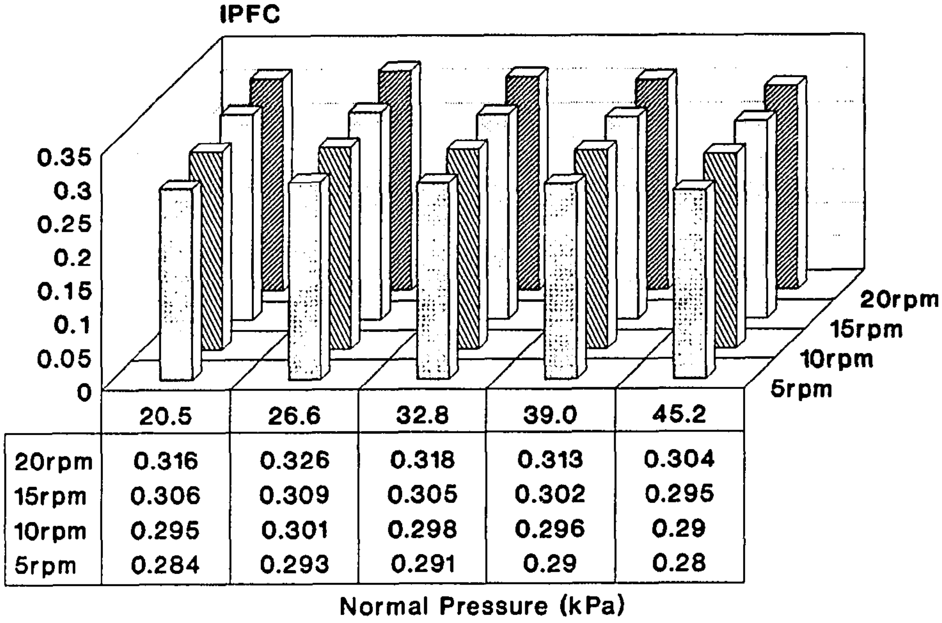
Figure 7.33 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.274 | 0.285 | 0.278 | 0.279 | 0.28 |
| 15rpm | 0.252 | 0.276 | 0.271 | 0.268 | 0.275 |
| 10rpm | 0.252 | 0.268 | 0.265 | 0.268 | 0.27 |
| 5rpm | 0.242 | 0.26 | 0.258 | 0.262 | 0.266 |

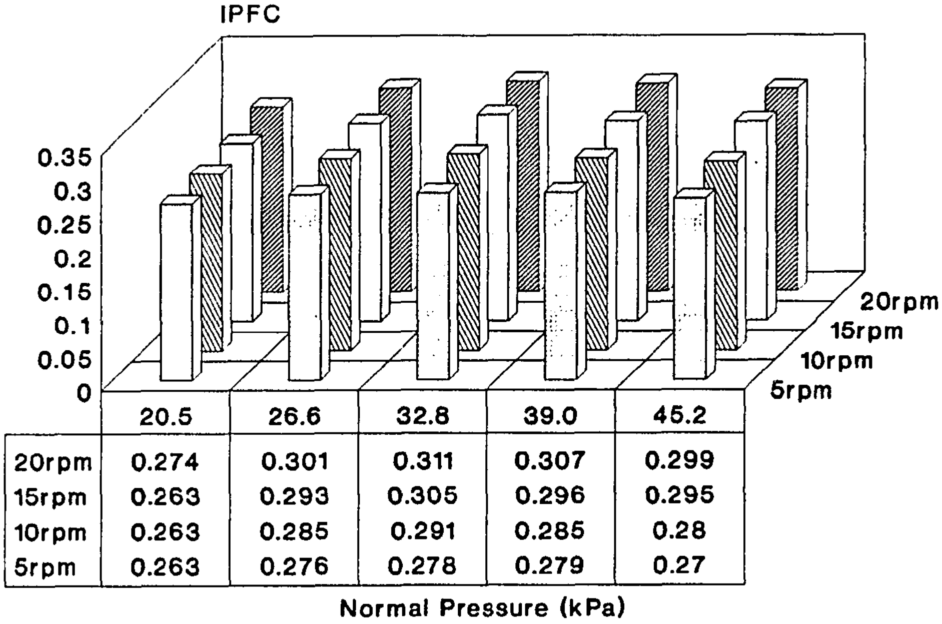
Normal Pressure (kPa)

Figure 7.34 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PP.



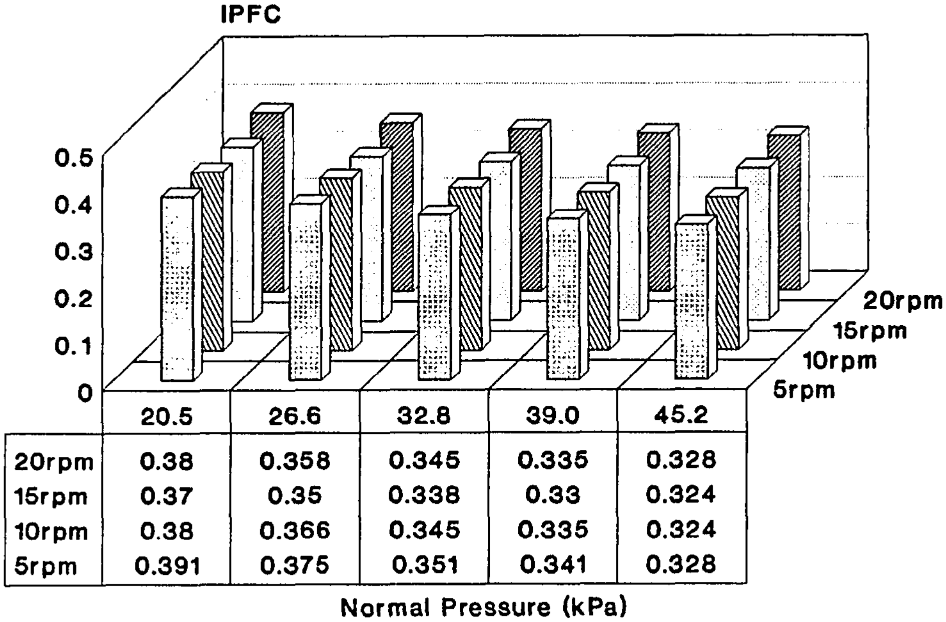
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.316 | 0.326 | 0.318 | 0.313 | 0.304 |
| 15rpm | 0.306 | 0.309 | 0.305 | 0.302 | 0.295 |
| 10rpm | 0.295 | 0.301 | 0.298 | 0.296 | 0.29 |
| 5rpm | 0.284 | 0.293 | 0.291 | 0.29 | 0.28 |

Figure 7.35 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PP.



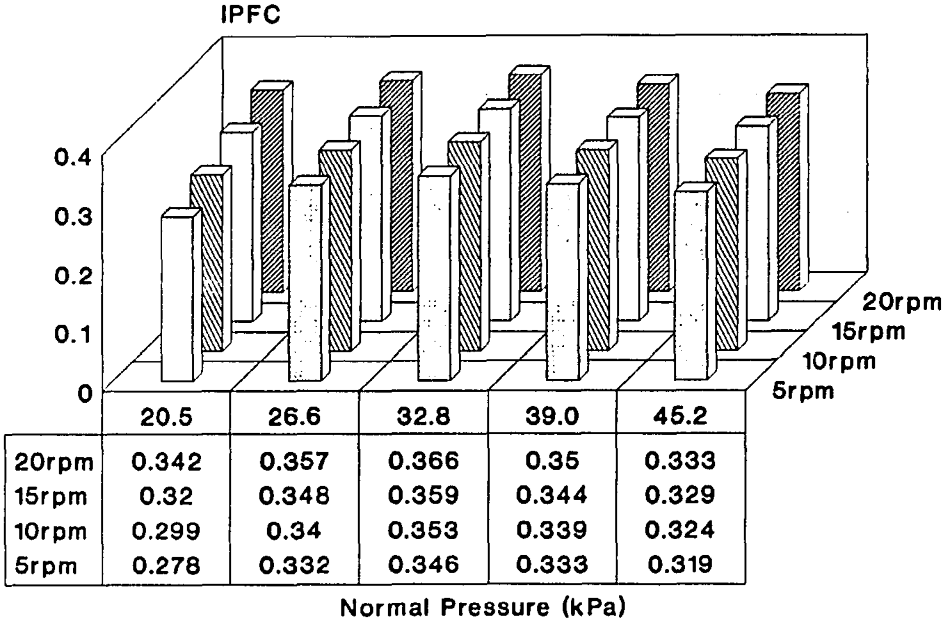
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.274 | 0.301 | 0.311 | 0.307 | 0.299 |
| 15rpm | 0.263 | 0.293 | 0.305 | 0.296 | 0.295 |
| 10rpm | 0.263 | 0.285 | 0.291 | 0.285 | 0.28 |
| 5rpm | 0.263 | 0.276 | 0.278 | 0.279 | 0.27 |

Figure 7.36 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PP.



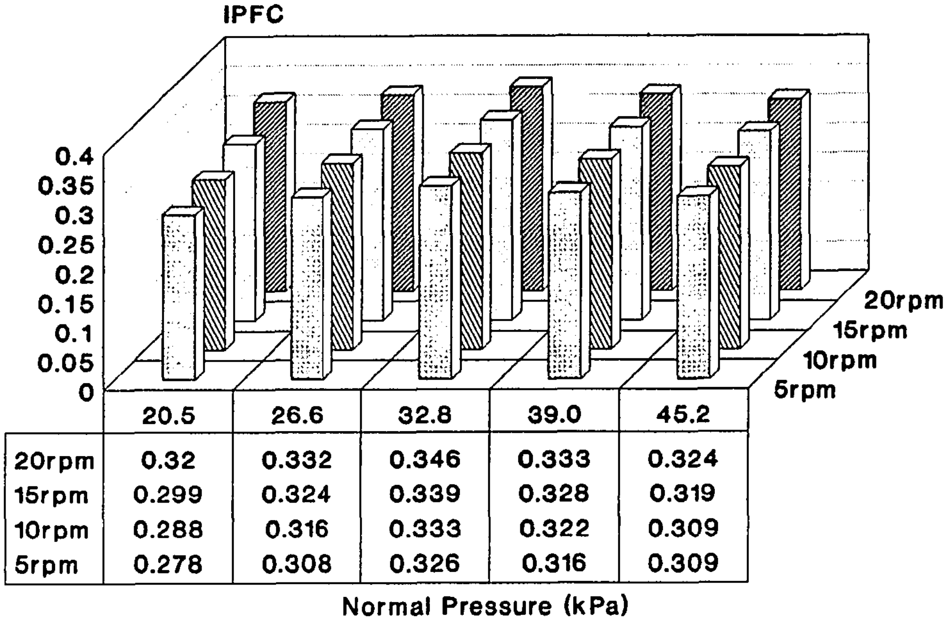
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.38 | 0.358 | 0.345 | 0.335 | 0.328 |
| 15rpm | 0.37 | 0.35 | 0.338 | 0.33 | 0.324 |
| 10rpm | 0.38 | 0.366 | 0.345 | 0.335 | 0.324 |
| 5rpm | 0.391 | 0.375 | 0.351 | 0.341 | 0.328 |

Figure 7.37 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PP.



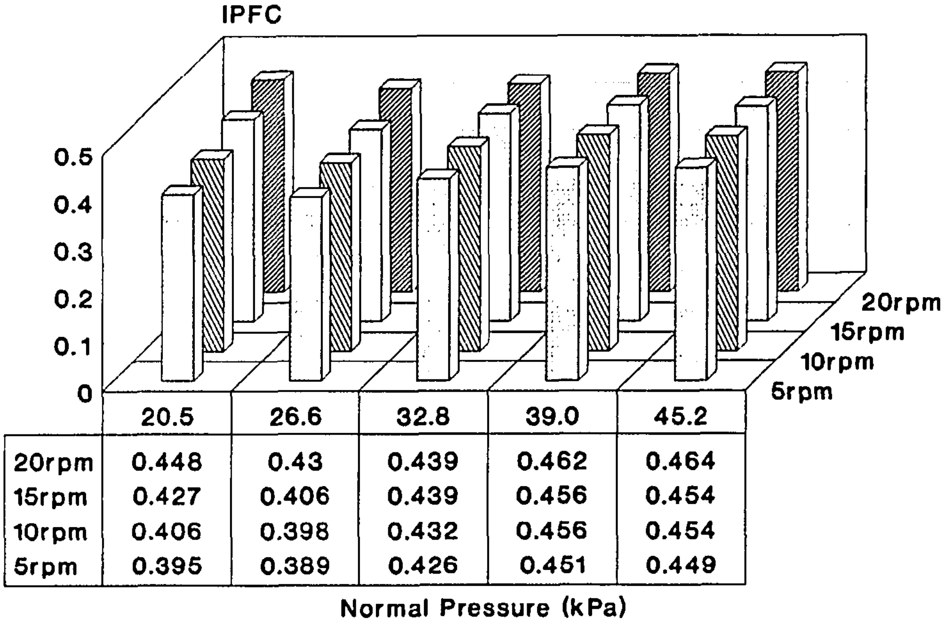
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.342 | 0.357 | 0.366 | 0.35 | 0.333 |
| 15rpm | 0.32 | 0.348 | 0.359 | 0.344 | 0.329 |
| 10rpm | 0.299 | 0.34 | 0.353 | 0.339 | 0.324 |
| 5rpm | 0.278 | 0.332 | 0.346 | 0.333 | 0.319 |

Figure 7.38 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PS.



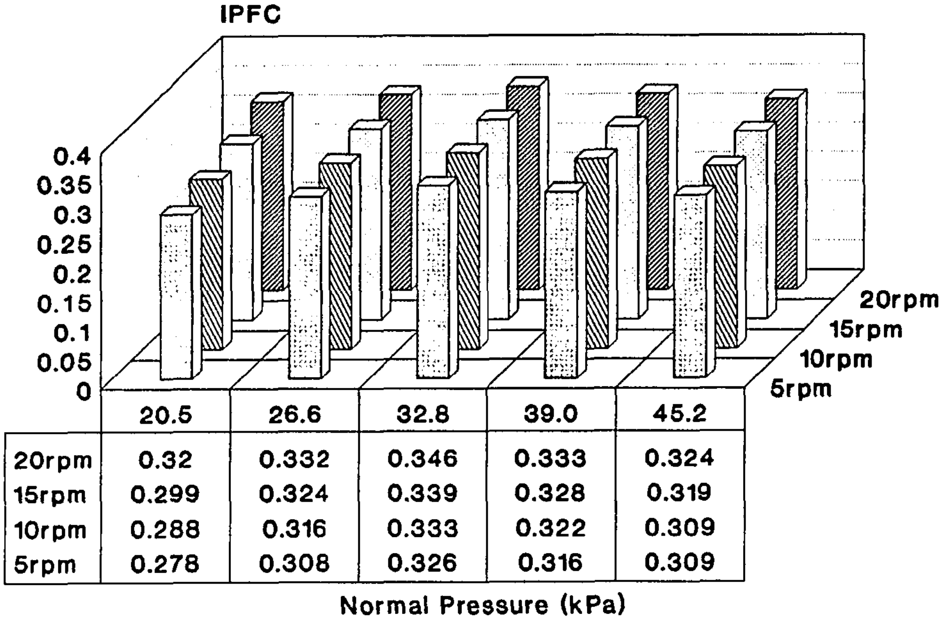
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.32 | 0.332 | 0.346 | 0.333 | 0.324 |
| 15rpm | 0.299 | 0.324 | 0.339 | 0.328 | 0.319 |
| 10rpm | 0.288 | 0.316 | 0.333 | 0.322 | 0.309 |
| 5rpm | 0.278 | 0.308 | 0.326 | 0.316 | 0.309 |

Figure 7.39 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PS.



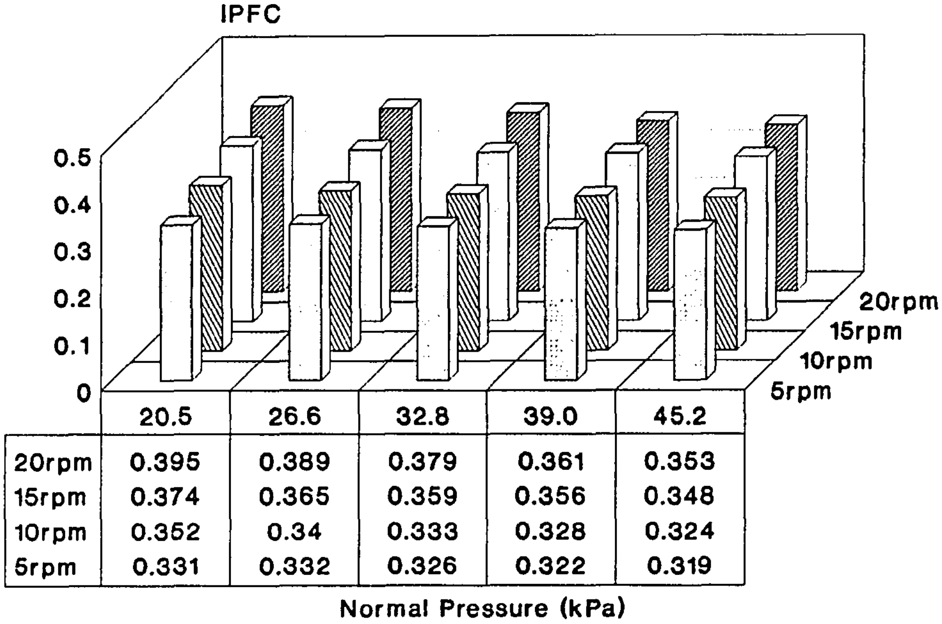
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.448 | 0.43 | 0.439 | 0.462 | 0.464 |
| 15rpm | 0.427 | 0.406 | 0.439 | 0.456 | 0.454 |
| 10rpm | 0.406 | 0.398 | 0.432 | 0.456 | 0.454 |
| 5rpm | 0.395 | 0.389 | 0.426 | 0.451 | 0.449 |

Figure 7.40 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PS.



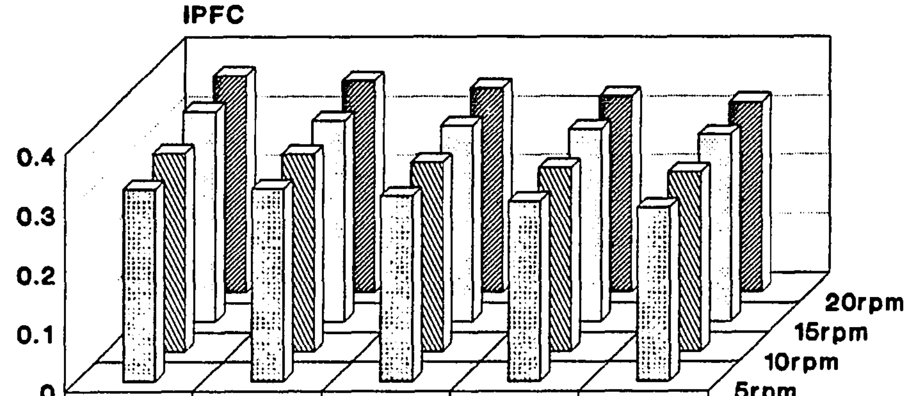
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.32 | 0.332 | 0.346 | 0.333 | 0.324 |
| 15rpm | 0.299 | 0.324 | 0.339 | 0.328 | 0.319 |
| 10rpm | 0.288 | 0.316 | 0.333 | 0.322 | 0.309 |
| 5rpm | 0.278 | 0.308 | 0.326 | 0.316 | 0.309 |

Figure 7.41 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.395 | 0.389 | 0.379 | 0.361 | 0.353 |
| 15rpm | 0.374 | 0.365 | 0.359 | 0.356 | 0.348 |
| 10rpm | 0.352 | 0.34 | 0.333 | 0.328 | 0.324 |
| 5rpm | 0.331 | 0.332 | 0.326 | 0.322 | 0.319 |

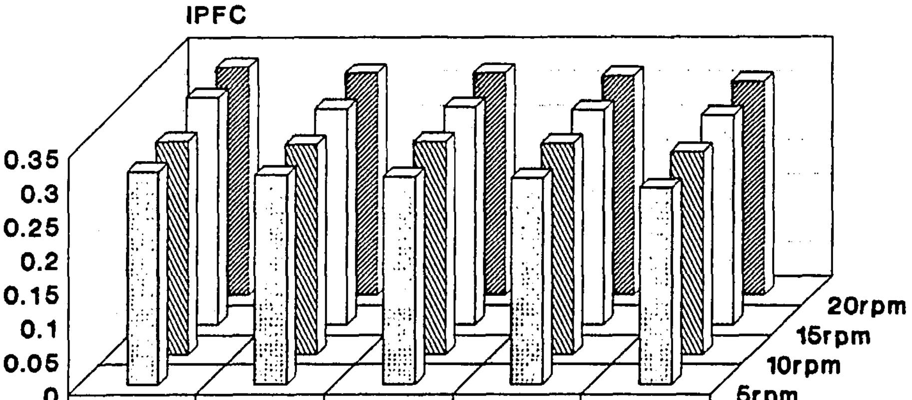
Figure 7.42 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.367 | 0.359 | 0.346 | 0.332 | 0.322 |
| 15rpm | 0.357 | 0.342 | 0.333 | 0.327 | 0.317 |
| 10rpm | 0.335 | 0.334 | 0.32 | 0.31 | 0.303 |
| 5rpm | 0.325 | 0.326 | 0.313 | 0.304 | 0.293 |

Normal Pressure (kPa)

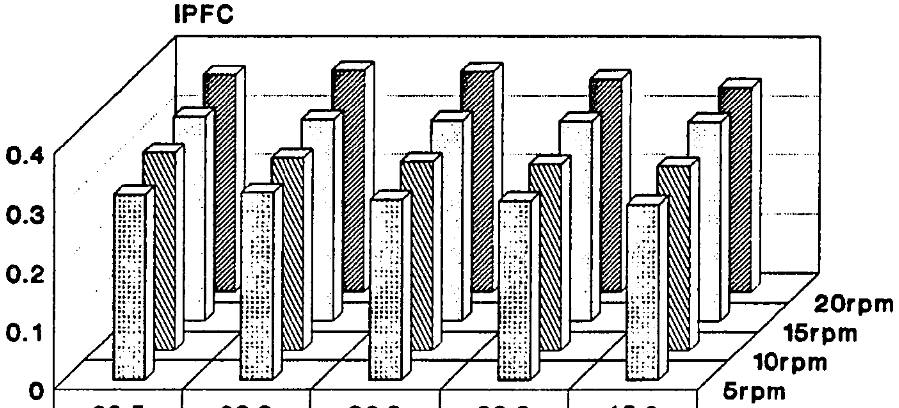
Figure 7.43 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.335 | 0.326 | 0.326 | 0.321 | 0.313 |
| 15rpm | 0.334 | 0.318 | 0.32 | 0.316 | 0.308 |
| 10rpm | 0.314 | 0.309 | 0.313 | 0.31 | 0.298 |
| 5rpm | 0.314 | 0.309 | 0.306 | 0.304 | 0.289 |

Normal Pressure (kPa)

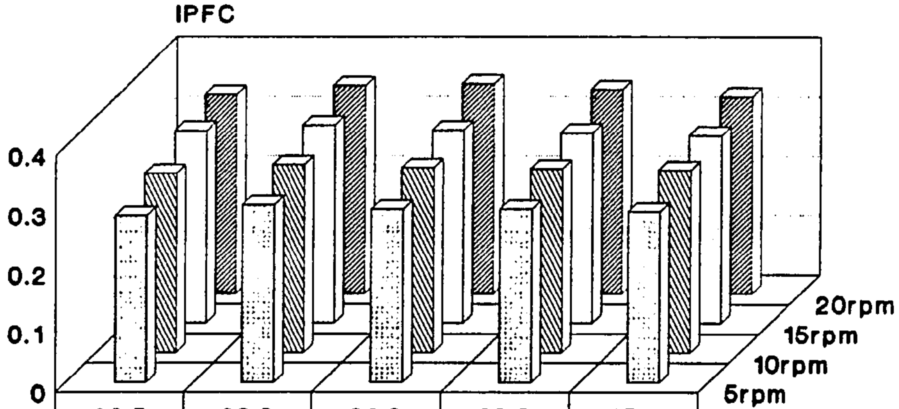
Figure 7.44 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.367 | 0.375 | 0.373 | 0.36 | 0.346 |
| 15rpm | 0.346 | 0.342 | 0.34 | 0.338 | 0.337 |
| 10rpm | 0.335 | 0.326 | 0.32 | 0.316 | 0.313 |
| 5rpm | 0.314 | 0.318 | 0.306 | 0.304 | 0.298 |

Normal Pressure (kPa)

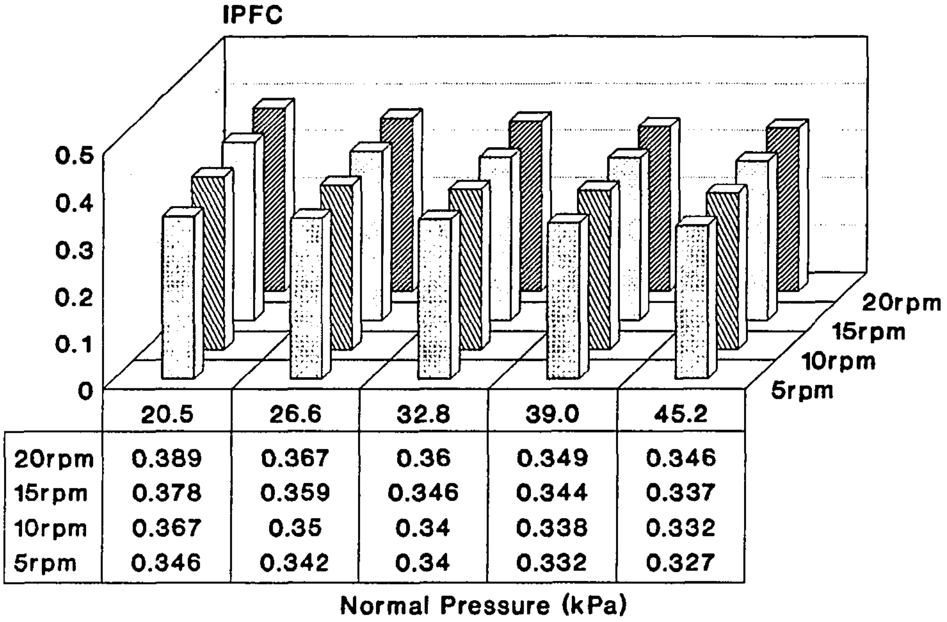
Figure 7.45 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.335 | 0.35 | 0.353 | 0.344 | 0.332 |
| 15rpm | 0.325 | 0.334 | 0.326 | 0.321 | 0.317 |
| 10rpm | 0.303 | 0.318 | 0.313 | 0.31 | 0.308 |
| 5rpm | 0.282 | 0.301 | 0.293 | 0.293 | 0.289 |

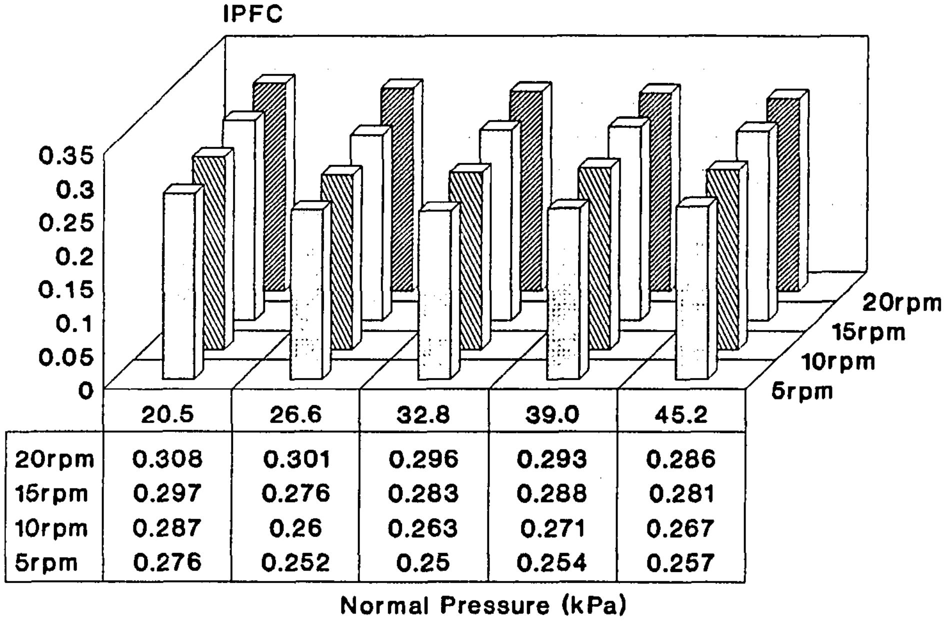
Normal Pressure (kPa)

Figure 7.46 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PA 6.



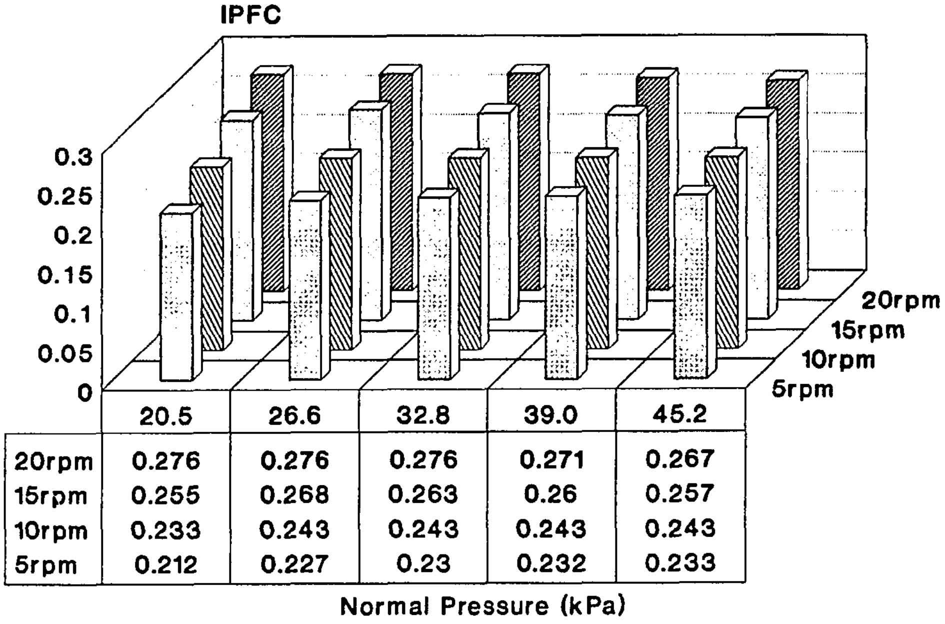
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.389 | 0.367 | 0.36 | 0.349 | 0.346 |
| 15rpm | 0.378 | 0.359 | 0.346 | 0.344 | 0.337 |
| 10rpm | 0.367 | 0.35 | 0.34 | 0.338 | 0.332 |
| 5rpm | 0.346 | 0.342 | 0.34 | 0.332 | 0.327 |

Figure 7.47 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PA 6.



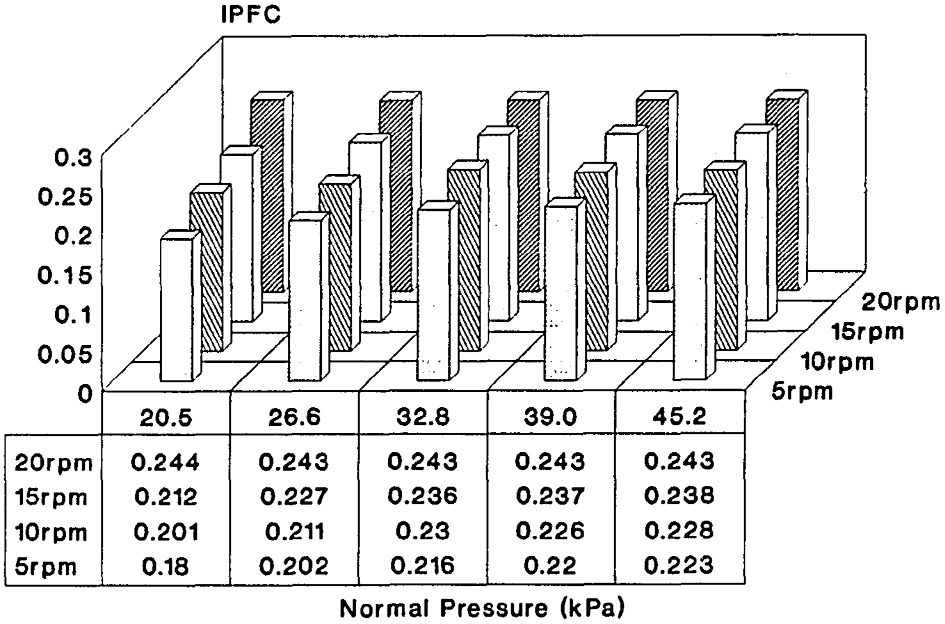
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.308 | 0.301 | 0.296 | 0.293 | 0.286 |
| 15rpm | 0.297 | 0.276 | 0.283 | 0.288 | 0.281 |
| 10rpm | 0.287 | 0.26 | 0.263 | 0.271 | 0.267 |
| 5rpm | 0.276 | 0.252 | 0.25 | 0.254 | 0.257 |

Figure 7.48 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for ABS.



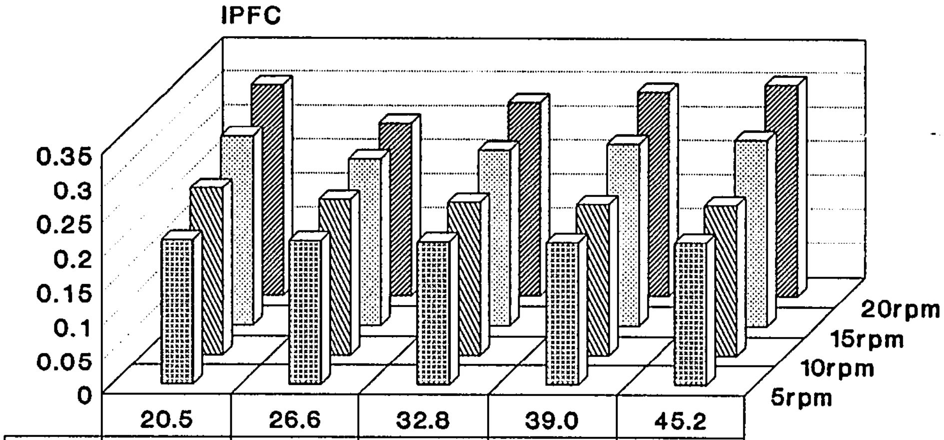
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.276 | 0.276 | 0.276 | 0.271 | 0.267 |
| 15rpm | 0.255 | 0.268 | 0.263 | 0.26 | 0.257 |
| 10rpm | 0.233 | 0.243 | 0.243 | 0.243 | 0.243 |
| 5rpm | 0.212 | 0.227 | 0.23 | 0.232 | 0.233 |

Figure 7.49 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.244 | 0.243 | 0.243 | 0.243 | 0.243 |
| 15rpm | 0.212 | 0.227 | 0.236 | 0.237 | 0.238 |
| 10rpm | 0.201 | 0.211 | 0.23 | 0.226 | 0.228 |
| 5rpm | 0.18 | 0.202 | 0.216 | 0.22 | 0.223 |

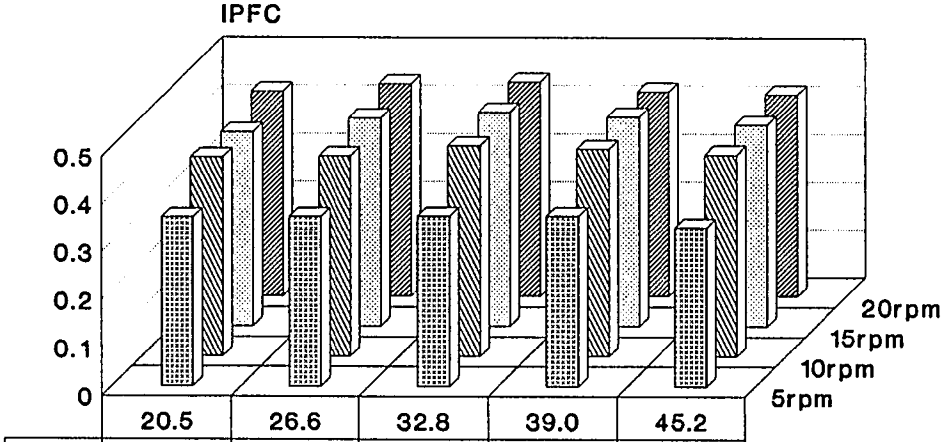
Figure 7.50 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.308 | 0.252 | 0.283 | 0.299 | 0.31 |
| 15rpm | 0.276 | 0.243 | 0.256 | 0.265 | 0.272 |
| 10rpm | 0.244 | 0.227 | 0.223 | 0.22 | 0.219 |
| 5rpm | 0.212 | 0.211 | 0.21 | 0.209 | 0.209 |

Normal Pressure (kPa)

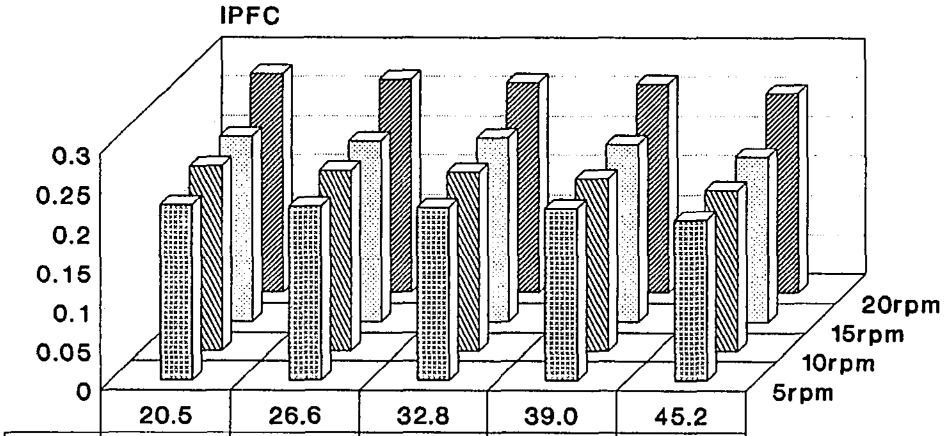
Figure 7.51 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.427 | 0.443 | 0.447 | 0.427 | 0.422 |
| 15rpm | 0.406 | 0.435 | 0.447 | 0.438 | 0.422 |
| 10rpm | 0.416 | 0.419 | 0.44 | 0.433 | 0.422 |
| 5rpm | 0.352 | 0.353 | 0.354 | 0.354 | 0.33 |

Normal Pressure (kPa)

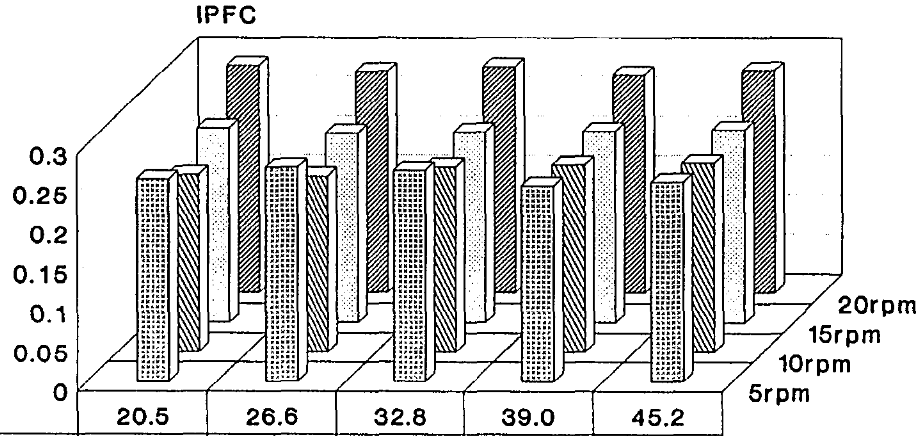
Figure 7.52 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.278 | 0.271 | 0.267 | 0.265 | 0.253 |
| 15rpm | 0.235 | 0.23 | 0.234 | 0.226 | 0.21 |
| 10rpm | 0.235 | 0.23 | 0.228 | 0.22 | 0.205 |
| 5rpm | 0.224 | 0.222 | 0.221 | 0.22 | 0.205 |

Normal Pressure (kPa)

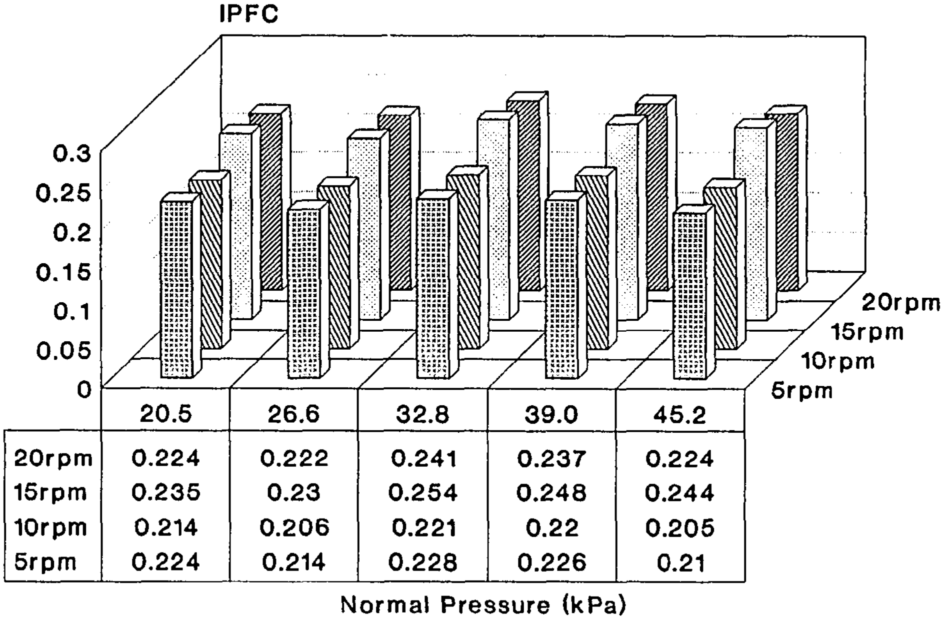
Figure 7.53 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.288 | 0.28 | 0.287 | 0.276 | 0.282 |
| 15rpm | 0.246 | 0.239 | 0.241 | 0.242 | 0.244 |
| 10rpm | 0.224 | 0.222 | 0.234 | 0.237 | 0.239 |
| 5rpm | 0.256 | 0.271 | 0.267 | 0.248 | 0.253 |

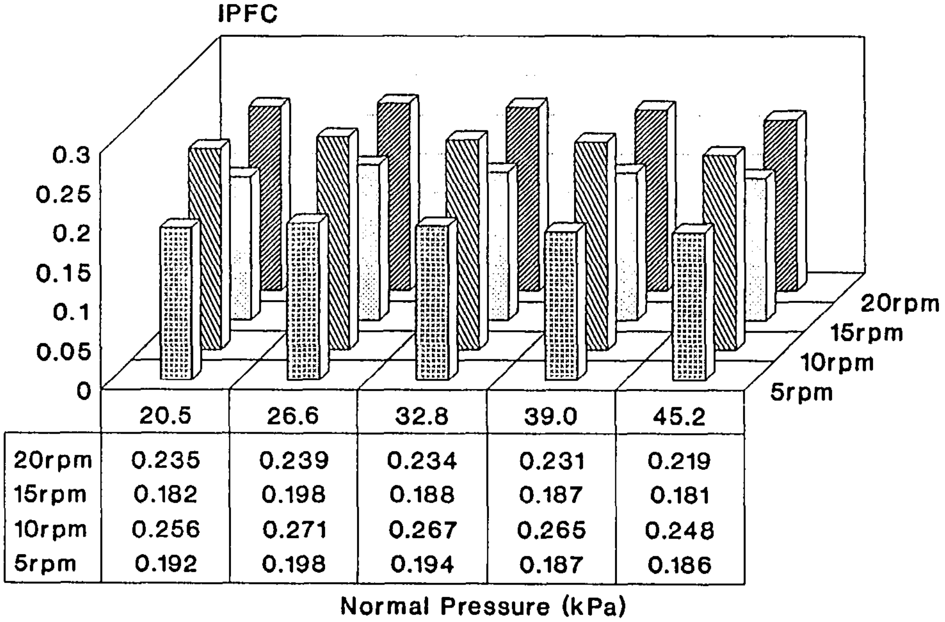
Normal Pressure (kPa)

Figure 7.54 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM3.



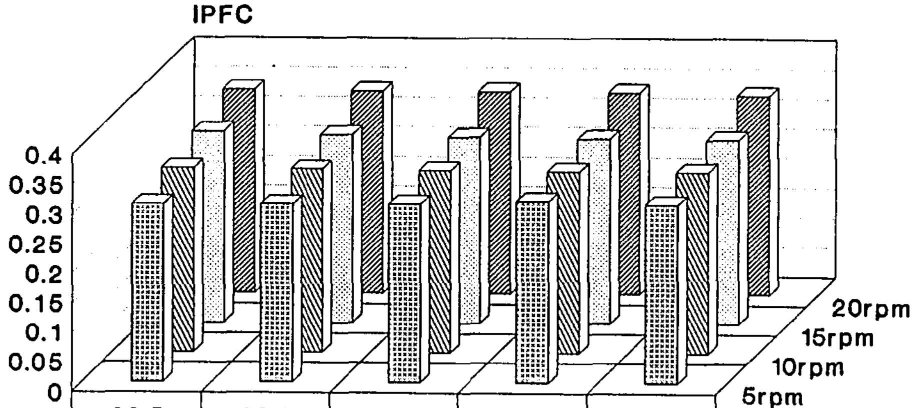
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.224 | 0.222 | 0.241 | 0.237 | 0.224 |
| 15rpm | 0.235 | 0.23 | 0.254 | 0.248 | 0.244 |
| 10rpm | 0.214 | 0.206 | 0.221 | 0.22 | 0.205 |
| 5rpm | 0.224 | 0.214 | 0.228 | 0.226 | 0.21 |

Figure 7.55 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.235 | 0.239 | 0.234 | 0.231 | 0.219 |
| 15rpm | 0.182 | 0.198 | 0.188 | 0.187 | 0.181 |
| 10rpm | 0.256 | 0.271 | 0.267 | 0.265 | 0.248 |
| 5rpm | 0.192 | 0.198 | 0.194 | 0.187 | 0.186 |

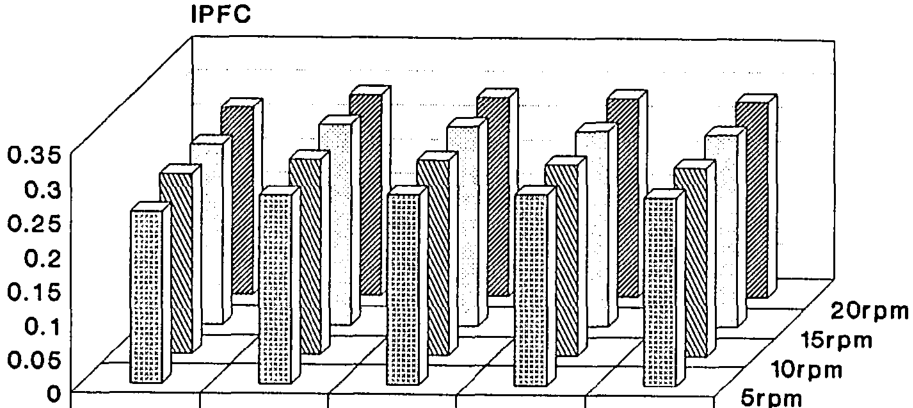
Figure 7.56 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.344 | 0.342 | 0.342 | 0.341 | 0.336 |
| 15rpm | 0.323 | 0.318 | 0.315 | 0.313 | 0.312 |
| 10rpm | 0.312 | 0.31 | 0.308 | 0.307 | 0.307 |
| 5rpm | 0.301 | 0.301 | 0.302 | 0.307 | 0.302 |

Normal Pressure (kPa)

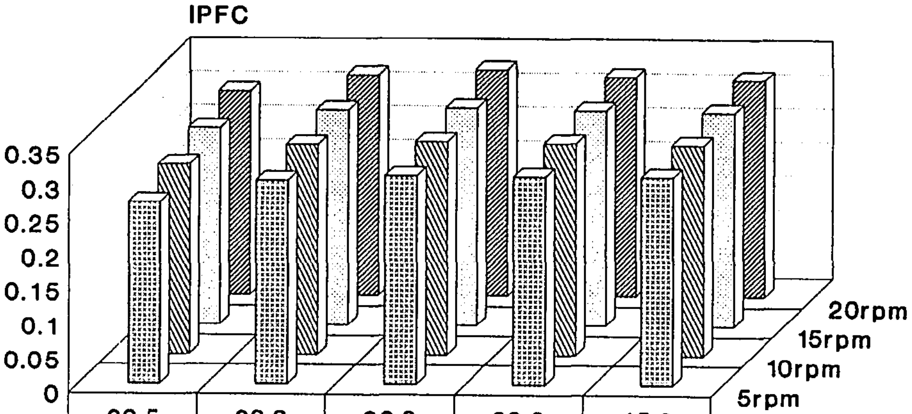
Figure 7.57 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.274 | 0.293 | 0.291 | 0.29 | 0.285 |
| 15rpm | 0.263 | 0.293 | 0.291 | 0.285 | 0.28 |
| 10rpm | 0.263 | 0.285 | 0.285 | 0.279 | 0.275 |
| 5rpm | 0.252 | 0.276 | 0.278 | 0.279 | 0.275 |

Normal Pressure (kPa)

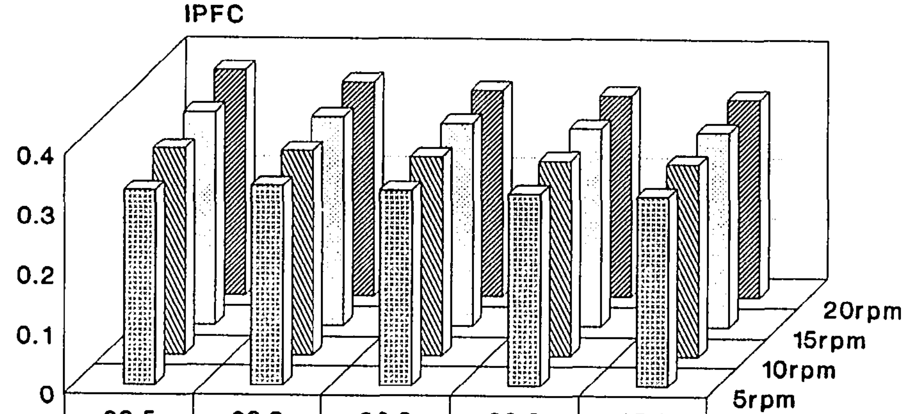
Figure 7.58 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.299 | 0.324 | 0.333 | 0.322 | 0.319 |
| 15rpm | 0.288 | 0.316 | 0.319 | 0.316 | 0.314 |
| 10rpm | 0.278 | 0.308 | 0.313 | 0.311 | 0.309 |
| 5rpm | 0.267 | 0.299 | 0.306 | 0.305 | 0.305 |

Normal Pressure (kPa)

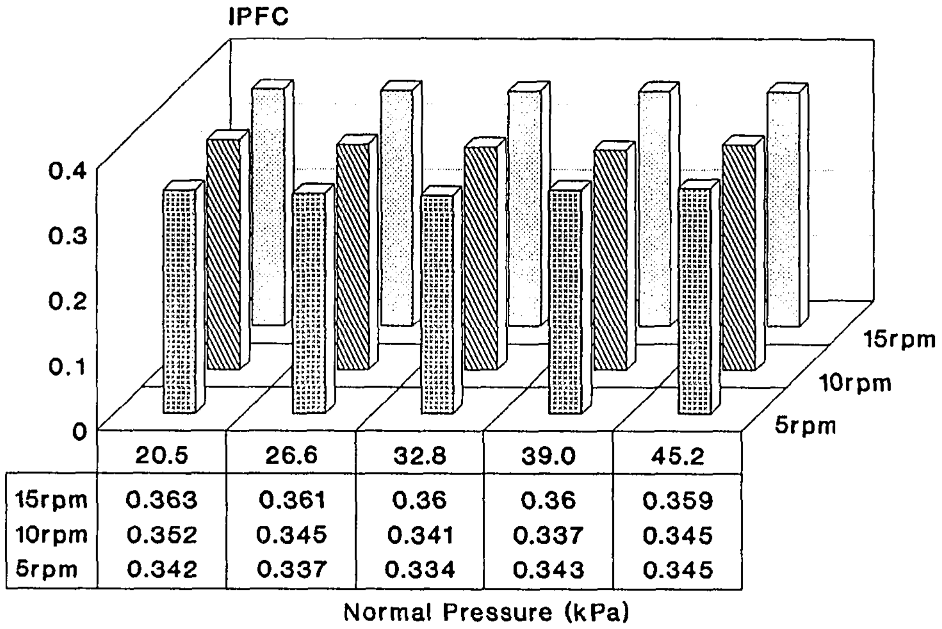
Figure 7.59 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.378 | 0.359 | 0.346 | 0.338 | 0.332 |
| 15rpm | 0.357 | 0.35 | 0.34 | 0.332 | 0.327 |
| 10rpm | 0.346 | 0.342 | 0.333 | 0.327 | 0.322 |
| 5rpm | 0.325 | 0.334 | 0.326 | 0.321 | 0.317 |

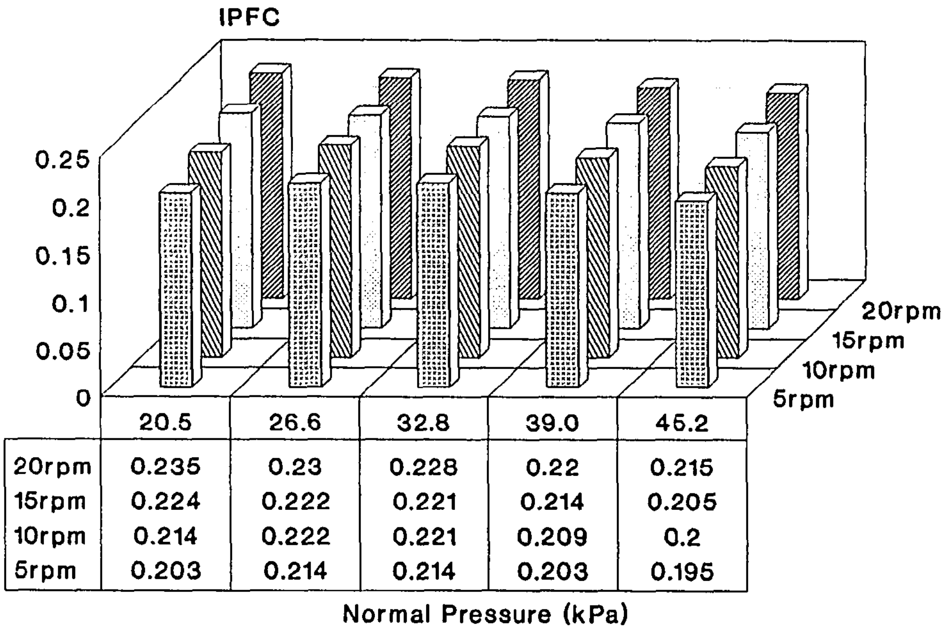
Normal Pressure (kPa)

Figure 7.60 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PA 6.



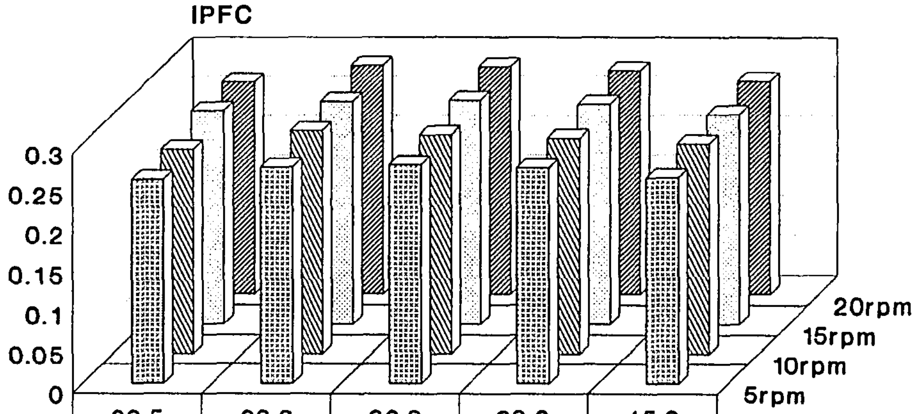
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 15rpm | 0.363 | 0.361 | 0.36 | 0.36 | 0.359 |
| 10rpm | 0.352 | 0.345 | 0.341 | 0.337 | 0.345 |
| 5rpm | 0.342 | 0.337 | 0.334 | 0.343 | 0.345 |

Figure 7.61 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.235 | 0.23 | 0.228 | 0.22 | 0.215 |
| 15rpm | 0.224 | 0.222 | 0.221 | 0.214 | 0.205 |
| 10rpm | 0.214 | 0.222 | 0.221 | 0.209 | 0.2 |
| 5rpm | 0.203 | 0.214 | 0.214 | 0.203 | 0.195 |

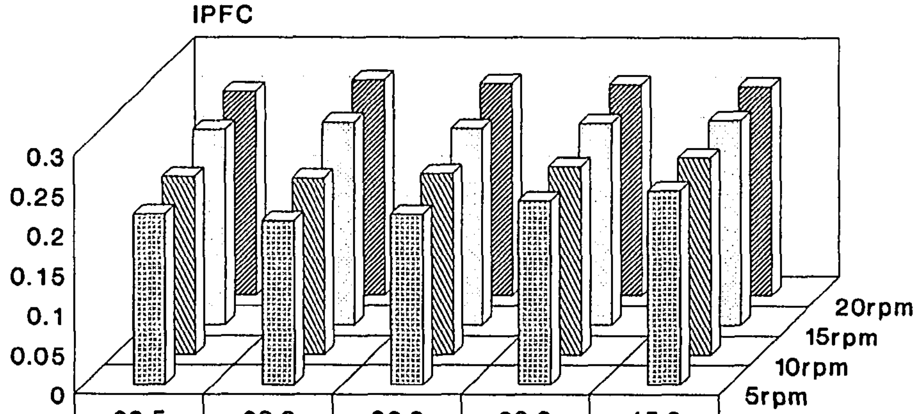
Figure 7.62 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.267 | 0.288 | 0.287 | 0.282 | 0.268 |
| 15rpm | 0.267 | 0.279 | 0.281 | 0.276 | 0.263 |
| 10rpm | 0.256 | 0.279 | 0.274 | 0.27 | 0.263 |
| 5rpm | 0.256 | 0.271 | 0.274 | 0.27 | 0.258 |

Normal Pressure (kPa)

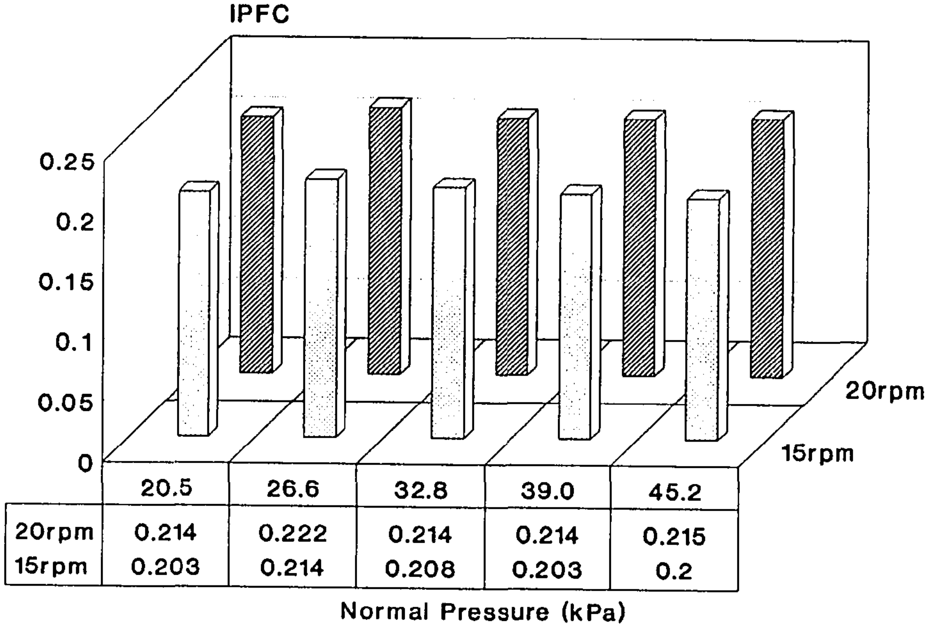
Figure 7.63 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.256 | 0.271 | 0.267 | 0.265 | 0.263 |
| 15rpm | 0.246 | 0.255 | 0.247 | 0.254 | 0.258 |
| 10rpm | 0.224 | 0.222 | 0.228 | 0.237 | 0.248 |
| 5rpm | 0.214 | 0.206 | 0.214 | 0.231 | 0.244 |

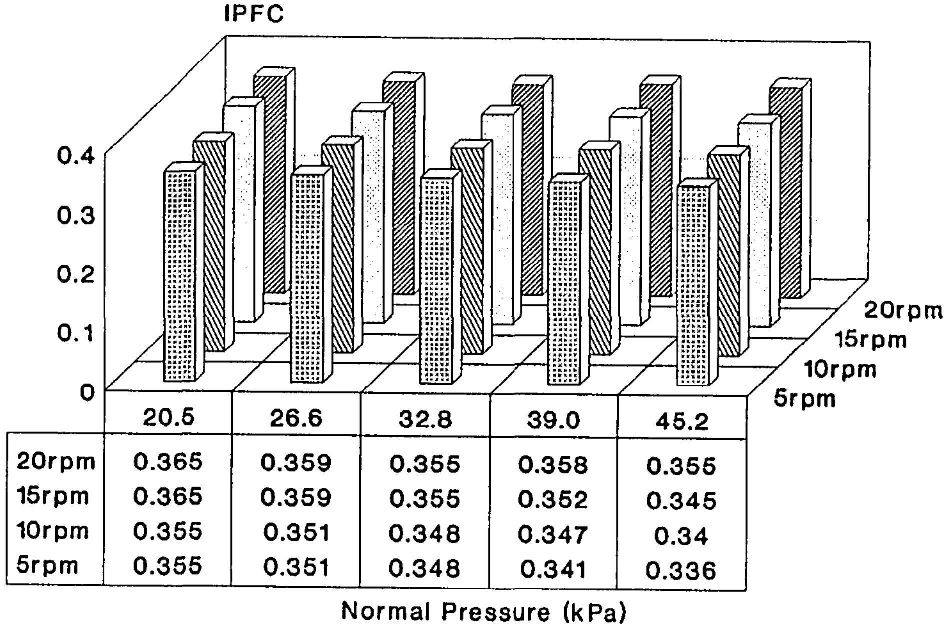
Normal Pressure (kPa)

Figure 7.64 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM4.



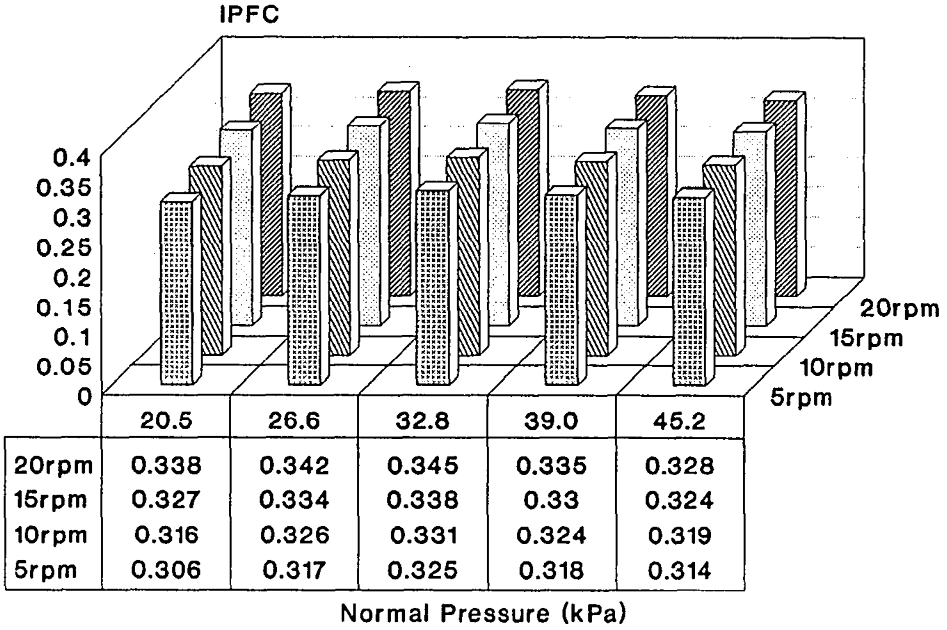
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.214 | 0.222 | 0.214 | 0.214 | 0.215 |
| 15rpm | 0.203 | 0.214 | 0.208 | 0.203 | 0.2 |

Figure 7.65 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM5.



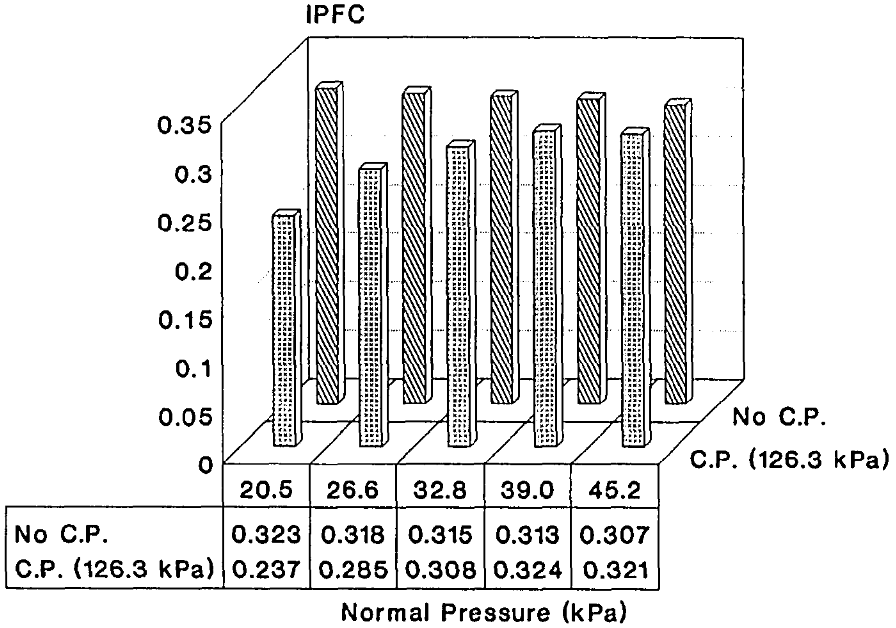
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.365 | 0.359 | 0.355 | 0.358 | 0.355 |
| 15rpm | 0.365 | 0.359 | 0.355 | 0.352 | 0.345 |
| 10rpm | 0.355 | 0.351 | 0.348 | 0.347 | 0.34 |
| 5rpm | 0.355 | 0.351 | 0.348 | 0.341 | 0.336 |

Figure 7.66 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for PE.



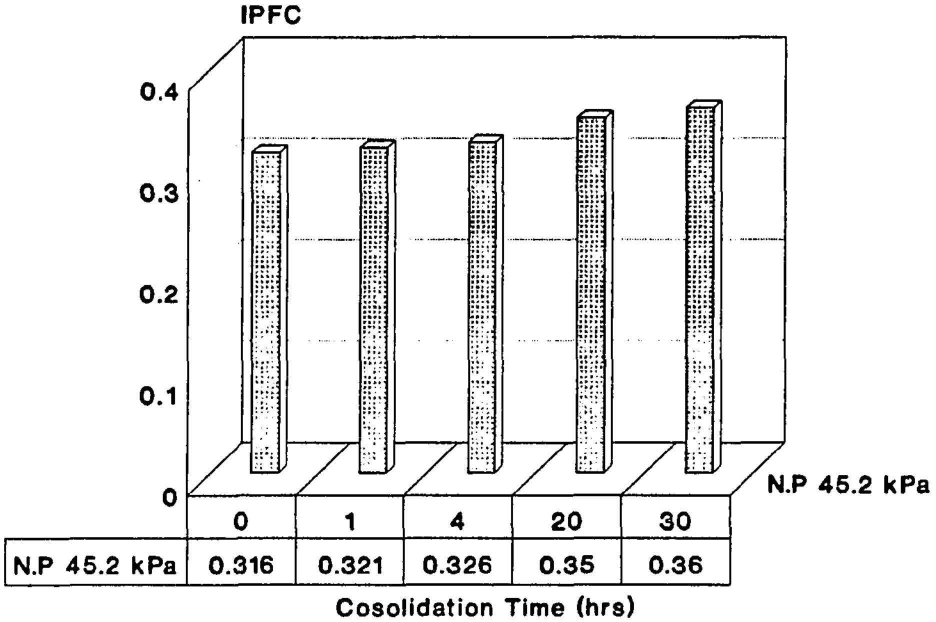
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.338 | 0.342 | 0.345 | 0.335 | 0.328 |
| 15rpm | 0.327 | 0.334 | 0.338 | 0.33 | 0.324 |
| 10rpm | 0.316 | 0.326 | 0.331 | 0.324 | 0.319 |
| 5rpm | 0.306 | 0.317 | 0.325 | 0.318 | 0.314 |

Figure 7.67 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for PP.



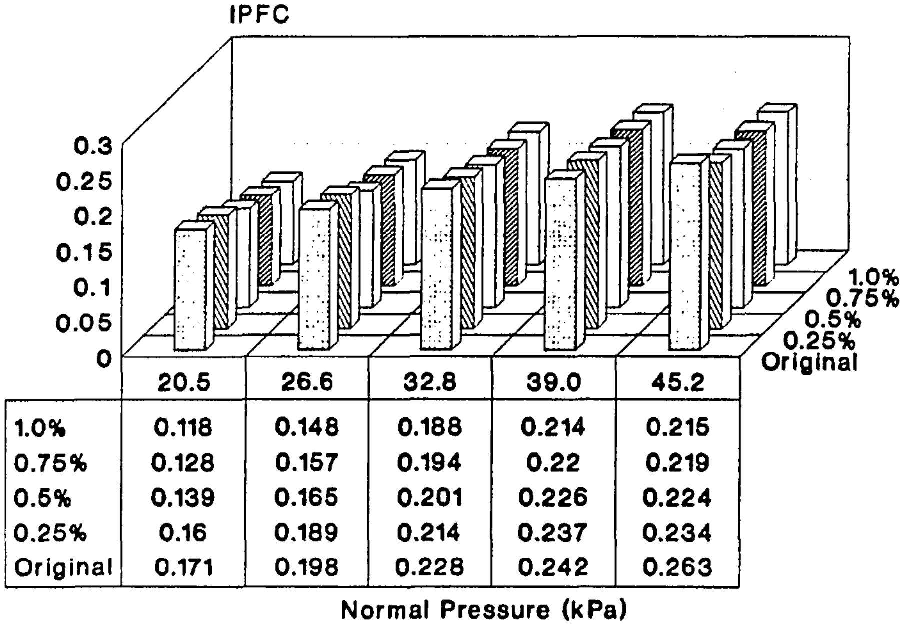
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| No C.P. | 0.323 | 0.318 | 0.315 | 0.313 | 0.307 |
| C.P. (126.3 kPa) | 0.237 | 0.285 | 0.308 | 0.324 | 0.321 |

Figure 7.68 IPFC for the Pellets Manufactured Using Die A211 with Consolidation Pressure as a Function of Normal Pressure for PE.



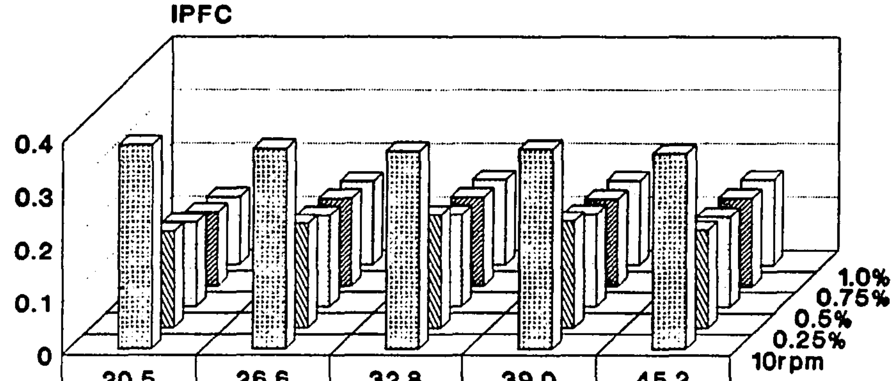
| Cosolidation Time (hrs) | 0 | 1 | 4 | 20 | 30 |
|---|---|---|---|---|---|
| N.P 45.2 kPa | 0.316 | 0.321 | 0.326 | 0.35 | 0.36 |

Figure 7.69 IPFC for the Pellets Manufactured Using Die A211 with Consolidation Time as a Function of Normal Pressure for PE.



| Normal Pressure (kPa) | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 1.0% | 0.118 | 0.148 | 0.188 | 0.214 | 0.215 |
| 0.75% | 0.128 | 0.157 | 0.194 | 0.22 | 0.219 |
| 0.5% | 0.139 | 0.165 | 0.201 | 0.226 | 0.224 |
| 0.25% | 0.16 | 0.189 | 0.214 | 0.237 | 0.234 |
| Original | 0.171 | 0.198 | 0.228 | 0.242 | 0.263 |

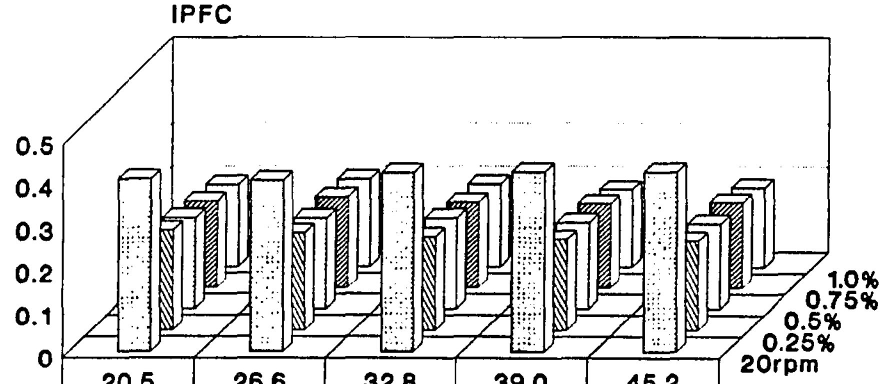
Figure 7.70 IPFC for Pellets with Circular Cross-Sections with Zinc Stearate as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 1.0% | 0.128 | 0.157 | 0.161 | 0.159 | 0.161 |
| 0.75% | 0.139 | 0.165 | 0.168 | 0.164 | 0.166 |
| 0.5% | 0.16 | 0.173 | 0.174 | 0.175 | 0.171 |
| 0.25% | 0.182 | 0.198 | 0.214 | 0.203 | 0.186 |
| 10rpm | 0.384 | 0.378 | 0.374 | 0.377 | 0.369 |

Normal Pressure (kPa)

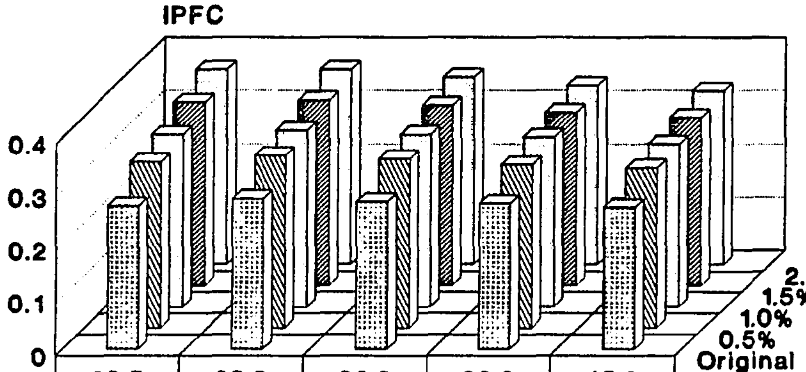
Figure 7.71 IPFC for Pellets Manufactured Using Die A211 with Zinc Stearate as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 1.0% | 0.192 | 0.206 | 0.194 | 0.181 | 0.186 |
| 0.75% | 0.203 | 0.214 | 0.201 | 0.198 | 0.2 |
| 0.5% | 0.214 | 0.214 | 0.214 | 0.203 | 0.2 |
| 0.25% | 0.235 | 0.23 | 0.221 | 0.214 | 0.21 |
| 20rpm | 0.405 | 0.402 | 0.42 | 0.421 | 0.422 |

Normal Pressure (kPa)

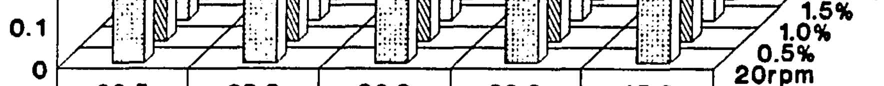
Figure 7.72 IPFC for Pellets Manufactured Using Die A212 with Zinc Stearate as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 0.367 | 0.367 | 0.353 | 0.338 | 0.327 |
| 1.5% | 0.346 | 0.35 | 0.34 | 0.327 | 0.317 |
| 1.0% | 0.325 | 0.334 | 0.326 | 0.321 | 0.308 |
| 0.5% | 0.314 | 0.326 | 0.32 | 0.31 | 0.303 |
| Original | 0.271 | 0.285 | 0.28 | 0.276 | 0.269 |

Normal Pressure (kPa)

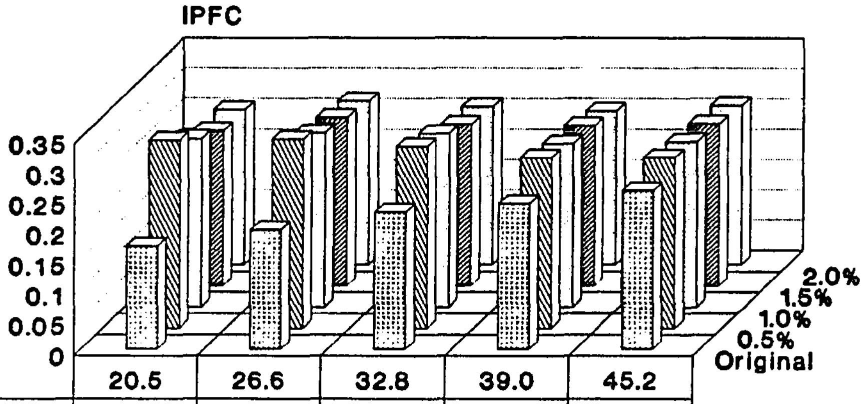
Figure 7.73 IPFC for Pellets with Circular Cross-Section with Mica Clay as a Function of Normal Pressure for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 0.421 | 0.432 | 0.406 | 0.4 | 0.419 |
| 1.5% | 0.41 | 0.424 | 0.4 | 0.388 | 0.395 |
| 1.0% | 0.399 | 0.399 | 0.38 | 0.372 | 0.356 |
| 0.5% | 0.399 | 0.391 | 0.373 | 0.36 | 0.351 |
| 20rpm | 0.389 | 0.367 | 0.36 | 0.349 | 0.346 |

Normal Pressure (kPa)

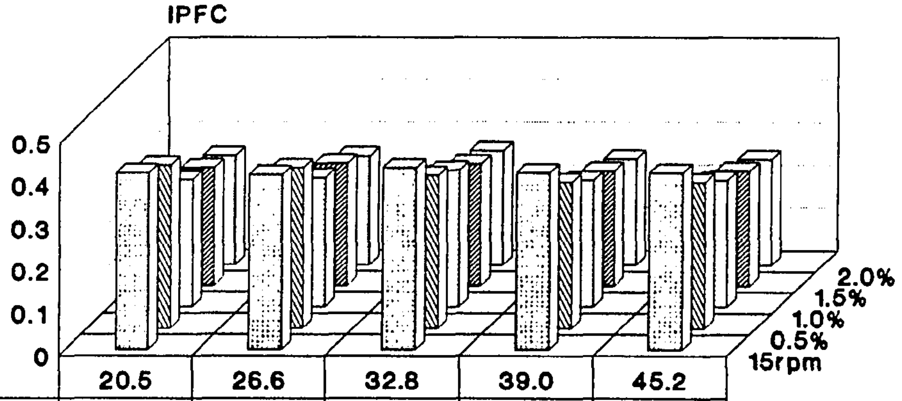
Figure 7.74 IPFC for Pellets Manufactured Using Die A241 with Mica Clay at Extruder Screw Speed 20rpm as a Function of Normal Pressure for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 0.256 | 0.271 | 0.261 | 0.254 | 0.263 |
| 1.5% | 0.256 | 0.279 | 0.267 | 0.265 | 0.268 |
| 1.0% | 0.278 | 0.288 | 0.287 | 0.27 | 0.273 |
| 0.5% | 0.31 | 0.312 | 0.301 | 0.282 | 0.282 |
| Original | 0.171 | 0.198 | 0.228 | 0.242 | 0.263 |

Normal Pressure (kPa)

Figure 7.75 IPFC for Pellets with Circular Cross-Section with PBT Powder as a Function of Normal Pressure for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 0.256 | 0.255 | 0.267 | 0.248 | 0.248 |
| 1.5% | 0.278 | 0.288 | 0.287 | 0.27 | 0.27 |
| 1.0% | 0.299 | 0.304 | 0.321 | 0.298 | 0.298 |
| 0.5% | 0.384 | 0.378 | 0.36 | 0.343 | 0.343 |
| 15rpm | 0.416 | 0.411 | 0.427 | 0.416 | 0.416 |

Normal Pressure (kPa)

Figure 7.76 IPFC for Pellets Manufactured Using Die A212 with PBT Powder at Extruder Screw Speed 15rpm as a Function of Normal Pressure for POM3.

# CHAPTER 8

# DISCUSSION - THE INTERPARTICULATE FRICTION COEFFICIENT

## 8.1 Comparison of the IFPC for Pellets with Circular and Bilobal Cross-Sections

The results presented in Figure 7.1 indicate that the high molecular weight material, U10-01 (POM1), has a markedly greater interparticulate friction coefficient compared to the remaining materials. The medium molecular weight material, M90 (POM3), exhibits a somewhat greater coefficient than the remaining three materials. Thus, there is no real trend which can be isolated with regard to molecular weight. In addition, although the coefficient varies as a function of normal load, there is no single, discernible trend.

The results presented in Figure 7.2 indicate that the material, PE, has a markedly greater interparticulate friction coefficient compared to the remaining materials. The material, PS exhibits a somewhat greater coefficient than the remaining three materials. In addition, although the coefficient varies as a function of normal load, there is no single, discernible trend.

The results presented in Figure 7.3 to Figure 7.51 present the IPFC for the pellets with bilobal cross-section for all test materials for all different dies. The comparison of IPFC between the circular cross-section pellet and bilobal cross-section pellet for all test material with different dies are plotted in Figures 8.1 to 8.40.

In addition to the variation of the normal force and the molecular weight that was measured with the pellets of circular cross-section for acetal copolymer, the multi-lobal pellets also exhibit a variation with extruder screw speed and the die used. These two variables combine to create variations in the size and shape of the pellets.

In Figure 8.1 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 52%-75% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 8%-41% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.2 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 32%-87% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 18%-62% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.3 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 45%-75% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 20%-55% compared to

cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.4 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 35%-87% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 22%-62% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.5 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for acetal copolymer grade M25. .The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 88%-167% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 70%-111% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.6 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for acetal copolymer grade M25. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 165%-185% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 35%-65% compared to

cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.7 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for acetal copolymer grade M25. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 165%-186% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 23%-46% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.8 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for acetal copolymer grade M25. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 142%-176% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 41%-71% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.9 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 48%-106% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 10%-44% compared to

cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.10 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 66%-150% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 17%-62% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.11 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 85%-144% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 17%-62% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.12 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 77%-144% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 25%-87% compared to

cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.13 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 99%-141% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 4%-10% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.14 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 146%-158% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 11%-51% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.15 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 135%-173% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 24%-51% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.16 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 135%-152% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 29%-51% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.17 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 106%-143% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 6%-32% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.18 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 147%-159% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 5%-16% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.19 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 143%-173% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 19%-48% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.20 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A211 is 137%-166% compared to cylindrical pellets. The pellets manufactured with die A211 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 25%-54% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.21 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for PE. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 20%-42% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A211 is 3%-16% compared to cylindrical pellets. The

pellets manufactured with die A211 have the lowest % increase among the bilobal pellets.

In Figure 8.22 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for PE. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 32%-45% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 12%-23% compared to cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.23 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for PE. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 36%-52% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A211 is 16%-29% compared to cylindrical pellets. The pellets manufactured with die A211 have the lowest % increase among the bilobal pellets.

In Figure 8.24 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for PE. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 40%-55% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A211 is 19%-36% compared to cylindrical pellets. The

pellets manufactured with die A211 have the lowest % increase among the bilobal pellets.

In Figure 8.25 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for PP. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 22%-30% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 8%-20% compared to cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.26 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for PP. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 25%-34% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 11%-22% compared to cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.27 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for PP. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 32%-44% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 14%-24% compared to cylindrical pellets. The

pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.28 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for PP. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 34%-49% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 17%-26% compared to cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.29 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for PS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 52%-68% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 4%-23% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.30 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for PS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 49%-73% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 8%-32% compared to cylindrical pellets. The

pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.31 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for PS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 52%-81% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 12%-46% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.32 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for PS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A221 is 52%-82% compared to cylindrical pellets. The pellets manufactured with die A221 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 14%-50% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.33 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for Nylon 6. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 20%-27% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 5%-7% compared to cylindrical pellets. The

pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.34 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for Nylon 6. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 21%-35% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 11%-15% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.35 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for Nylon 6. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 25%-39% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 12%-23% compared to cylindrical pellets. The pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.36 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for Nylon 6. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A241 is 26%-44% compared to cylindrical pellets. The pellets manufactured with die A241 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A212 is 14%-24% compared to cylindrical pellets. The

pellets manufactured with die A212 have the lowest % increase among the bilobal pellets.

In Figure 8.37 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 5 rpm is compared to those with a circular cross-section for ABS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A211 is 32%-74% compared to cylindrical pellets. The pellets manufactured with die A211 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 9%-24% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.38 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 10 rpm is compared to those with a circular cross-section for ABS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A211 is 40%-81% compared to cylindrical pellets. The pellets manufactured with die A211 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 13%-27% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.39 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 15 rpm is compared to those with a circular cross-section for ABS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A211 is 49%-87% compared to cylindrical pellets. The pellets manufactured with die A211 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 22%-33% compared to cylindrical pellets. The

pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

In Figure 8.40 the IPFC % increase for all bilobal pellet cross-sections at an extruder screw speed of 20 rpm is compared to those with a circular cross-section for ABS. The % increase is dependent on the profile die used in their manufacture. The % increase in IPFC for bilobal pellets manufactured with die A211 is 56%-94% compared to cylindrical pellets. The pellets manufactured with die A211 have the largest % increase among the bilobal pellets. On the other hand, the % increase for pellets manufactured with die A231 is 28%-53% compared to cylindrical pellets. The pellets manufactured with die A231 have the lowest % increase among the bilobal pellets.

However, it must be noted that the interparticulate friction coefficient of the pellets with bilobal cross-sections was always greater those for the pellets with circular cross-section. This fact is clearly illustrated in above figures.

### 8.2 Comparison of the IPFC for Pellets with Circular and Trilobal Cross-Sections

The pellets with trilobal cross-sections were all manufactured using the same die, A301-01 (A311) as described in Table 3.1. The effects of molecular weight, normal pressure, and extruder screw speed were determined as shown in Figures 8.41-49. From these graphical results it is difficult to discern any trends. Analysis using Box, Hunter and Hunter techniques [7] produces contradictory conclusions, depending upon the level of the factorial analysis. Enough results were not available to calculate the combined averages data, as was performed with the pellets of bilobal cross-sections. However, it is clear that the interparticulate friction coefficients for pellets with trilobal cross-sections exceeds those for pellets with circular cross-sections as presented in Figures 8.41-49, but are less than those for pellets with bilobal cross-sections.

In Figure 8.41 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 40%-67% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 10%-38% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.42 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M25. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 44%-62% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 18%-30% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.43 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 20%-68% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 10 rpm is 3%-31% compared to cylindrical pellets. The pellets manufactured with a screw speed of 10 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.44 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 15 rpm is 27%-51% compared to cylindrical pellets. The pellets manufactured with a screw speed of 15 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 10 rpm is 12%-28% compared to cylindrical pellets. The pellets manufactured with a screw speed of 10 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.45 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 10 rpm is 50%-68% compared to cylindrical pellets. The pellets manufactured with a screw speed of 10 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 15 rpm is 7%-19% compared to cylindrical pellets. The pellets manufactured with a screw speed of 15 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.46 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for PE. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 28%-

36% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 11%-19% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.47 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for PP. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 24%-28% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 14%-24% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.48 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for PS. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is (5%-5%) compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is (5%-5%) compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.49 the IPFC % increase for trilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for PA 6. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is

24%-39% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 10 rpm is 17%-27% compared to cylindrical pellets. The pellets manufactured with a screw speed of 10 rpm have the lowest % increase among the four different screw speeds.

## 8.3 Comparison of the IFPC for Pellets with Circular and Quadrilobal Cross-Sections

The pellets with quadrilobal cross-sections were all manufactured using the same die, A401-01 (A411) as described in Table 3.1. The effects of molecular weight, normal pressure, and extruder screw speed were determined as shown in Figures 8.50-56. From these graphical results it is difficult to discern any trends. Analysis using Box, Hunter and Hunter techniques [7] produces contradictory conclusions, depending upon the level of the factorial analysis. Sufficient results were not available to calculate the combined averages data, as was performed with the pellets of bilobal cross-section. However, it is clear that the interparticulate friction coefficients for pellets with quadrilobal cross-sections exceeds those for pellets with circular cross-section as presented in Figures 8.50-56, but are less than those for pellets with bilobal cross-sections.

In Figure 8.50 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade U10-01. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 15 rpm is 19%-42% compared to cylindrical pellets. The pellets manufactured with a screw speed of 15 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 14%-34% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.51 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M25. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 22%-37% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 12%-24% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.52 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M90. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 15%-56% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 10%-50% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.53 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M270. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 41%-63% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 14%-50% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.54 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for acetal copolymer grade M450. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 25%-42% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 15 rpm is 18%-32% compared to cylindrical pellets. The pellets manufactured with a screw speed of 15 rpm have the lowest % increase among the four different screw speeds.

In Figure 8.56 the IPFC % increase for quadrilobal pellet cross-sections at four different extruder screw speeds is compared to those with a circular cross-section for PP. The % increase is dependent on the screw speed used in their manufacture. The % increase in IPFC for pellets manufactured with a screw speed of 20 rpm is 45%-54% compared to cylindrical pellets. The pellets manufactured with a screw speed of 20 rpm have the highest % increase among the four different screw speeds. On the other hand, the % increase for pellets manufactured with a screw speed of 5 rpm is 32%-41% compared to cylindrical pellets. The pellets manufactured with a screw speed of 5 rpm have the lowest % increase among the four different screw speeds.

## 8.4 Pellets with Bilobal, Trilobal and Quadrilobal Cross-Sections

### 8.4.1 Effect of Normal Pressure

The normal pressure was found to have only a weak influence on the interparticulate friction coefficient. As seen in Figures 7.1-7.67, the effect is somewhat random. The two level and three level factorial results produced conflicting conclusions which confirms the randomness of the results. So, the results were averaged at fixed values of the normal pressure to dampen the scatter. The averages for acetal copolymer are presented in Table 8.1. The averages for PE, PP, PS, PA 6, and ABS are presented in Table 8.2. As the normal pressure increases, the average IPFC decreases for the pellets with bilobal, trilobal and quadrilobal cross-sections. However, the decrease is only gradual.

### 8.4.2 Effect of Extruder Screw Speed

The extruder screw speed used in the manufacture of the pellets also has a weak influence the interparticulate friction coefficient. As seen in Figures 8.1 - 8.56 the effect is somewhat random. In addition, the two level and three level factorial results produced conflicting conclusions which confirms the randomness of the results. So again, the results were averaged to dampen the scatter, but this time with respect to the extruder screw speed. The averages IPFC for acetal copolymer are presented in Table 8.3. The averages IPFC for PE, PP, PS, PA 6, and ABS are presented in Table 8.4. As the extruder screw speed increases, the average IPFC increases for the pellets with bilobal, trilobal, quadrilobal cross-sections. However the increase is slight.

### 8.4.3 Effect of Molecular Weight

The molecular weight, as represented by the melt index, was found to have a weak influence on the interparticulate friction coefficient. This can be seen from Figures 8.1-8.56. The conflicting conclusions from the two level and three level factorials, and the randomness of the averages for the IPFC of acetal copolymer are presented in Table 8.5 for the pellets with bilobal, trilobal and quadrilobal cross-sections support this statement.

### 8.4.4 Effect of Extrusion Die Geometry

The extrusion die geometry has a distinct effect on the interparticulate friction coefficient. The average IPFC values for acetal copolymer using each die are presented in Table 8.6. The averages for PE, PP, PS, PA 6, and ABS using each die are presented in Table 8.7. It is apparent that die A202-01 produces pellets with superior interparticulate friction coefficients for acetal copolymer, due to the shape of the pellet that it produces.

### 8.4.5 Effect of Agitation of the Particulate Bed

The interparticulate friction coefficient was found to increase for all non-circular pellet geometries after agitation. The increases are clearly seen in Figures 8.57 - 8.121.

Figures 8.57-8.61 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 211 for all five samples of acetal copolymer with agitation. Figure 8.57 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.434 to 0.51. Figure 8.58 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.393 to 0.54. Figure 8.59 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.408 to

0.534. Figure 8.60 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M270. The value of the IPFC is 0.398 to 0.502. Figure 8.61 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer M450. The value of the IPFC is 0.382 to 0.536.

Figures 8.62-8.66 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 212 for all five samples of acetal copolymer with agitation. Figure 8.62 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.438 to 0.642. Figure 8.63 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.46 to 0.568. Figure 8.64 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.416 to 0.517. Figure 8.65 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M270. The value of the IPFC is 0.54 to 0.6. Figure 8.62 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M450. The value of the IPFC is 0.48 to 0.588.

Figures 8.67-8.71 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 212 for all five samples of acetal copolymer with agitation. Figure 8.67 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.474 to 0.562. Figure 8.68 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.384 to 0.459. Figure 8.69 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.445 to 0.517. Figure 8.70 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M270. The value of the IPFC is 0.428 to

0.512. Figure 8.71 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M450. The value of the IPFC is 0.476 to 0.588.

Figures 8.72-8.77 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 231 for all five samples of acetal copolymer with agitation. Figure 8.72 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.408 to 0.546. Figure 8.73 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.298 to 0.434. Figure 8.74 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.309 to 0.386. Figure 8.75 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M270. The value of the IPFC is 0.224 to 0.332. Figure 8.76 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer M450. The value of the IPFC is 0.274 to 0.362.

Figures 8.77-8.81 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 241 for all five samples of acetal copolymer with agitation. Figure 8.77 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.534 to 0.616. Figure 8.78 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.445 to 0.565. Figure 8.79 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.408 to 0.501. Figure 8.80 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M270. The value of the IPFC is 0.386 to 0.514. Figure 8.81 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer M450. The value of the IPFC is 0.438 to 0.598.

Figures 8.82-8.86 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 211 for all five samples of polyethylene, polypropylene, polystyrene, nylon 6, ABS with agitation. The value of the IPFC is presented as described here. Figure 8.82 shows the IPFC as a function of pressure for bilobal pellets manufactured from PE. The value of the IPFC is 0.398 to 0.493. Figure 8.83 shows the IPFC as a function of pressure for bilobal pellets manufactured from PP. The value of the IPFC is 0.28 to 0.37. Figure 8.84 shows the IPFC as a function of pressure for bilobal pellets manufactured from PS. The value of the IPFC is 0.352 to 0.448. Figure 8.85 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6. The value of the IPFC is 0.322 to 0.442. Figure 8.86 shows the IPFC as a function of pressure for bilobal pellets manufactured from ABS. The value of the IPFC is 0.306 to 0.392.

Figures 8.87-8.90 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 212 for all five samples of polyethylene, polypropylene, polystyrene, and nylon 6 with agitation. The value of the IPFC is presented as described here. Figure 8.87 shows the IPFC as a function of pressure for bilobal pellets manufactured from PE. The value of the IPFC is 0.388 to 0.472. Figure 8.88 shows the IPFC as a function of pressure for bilobal pellets manufactured from PP. The value of the IPFC is 0.28 to 0.36. Figure 8.89 shows the IPFC as a function of pressure for bilobal pellets manufactured from PS. The value of the IPFC is 0.344 to 0.406. Figure 8.90 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6. The value of the IPFC is 0.313 to 0.41.

Figures 8.91-8.95 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 221 for all five samples of polyethylene, polypropylene, polystyrene, nylon 6, ABS with agitation. The value of the IPFC is presented as described here. Figure 8.91 shows the IPFC as a function of pressure for bilobal pellets manufactured from PE. The value of the IPFC is 0.408 to 0.492. Figure 8.92

shows the IPFC as a function of pressure for bilobal pellets manufactured from PP. The value of the IPFC is 0.324 to 0.412. Figure 8.93 shows the IPFC as a function of pressure for bilobal pellets manufactured from PS. The value of the IPFC is 0.479 to 0.565. Figure 8.94 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6. The value of the IPFC is 0.35 to 0.483. Figure 8.95 shows the IPFC as a function of pressure for bilobal pellets manufactured from ABS. The value of the IPFC is 0.258 to 0.372.

Figures 8.96-8.100 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 231 for all five samples of polyethylene, polypropylene, polystyrene, nylon 6, and ABS with agitation. The value of the IPFC is presented as described here. Figure 8.96 shows the IPFC as a function of pressure for bilobal pellets manufactured from PE. The value of the IPFC is 0.4 to 0.45. Figure 8.97 shows the IPFC as a function of pressure for bilobal pellets manufactured from PP. The value of the IPFC is 0.319 to 0.438. Figure 8.98 shows the IPFC as a function of pressure for bilobal pellets manufactured from PS. The value of the IPFC is 0.344 to 0.448. Figure 8.99 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6. The value of the IPFC is 0.336 to 0.452. Figure 8.100 shows the IPFC as a function of pressure for bilobal pellets manufactured from ABS. The value of the IPFC is 0.234 to 0.329.

Figures 8.101-8.105 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 241 for all five samples of polyethylene, polypropylene, polystyrene, nylon 6, and ABS with agitation. The value of the IPFC is presented as described here. Figure 8.101 shows the IPFC as a function of pressure for bilobal pellets manufactured from PE. The value of the IPFC is 0.394 to 0.492. Figure 8.102 shows the IPFC as a function of pressure for bilobal pellets manufactured from PP. The value of the IPFC is 0.324 to 0.391. Figure 8.103 shows the IPFC as a function of pressure for bilobal pellets manufactured from PS. The value of the IPFC is 0.350 to 0.62. Figure 8.104 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6. The value of the IPFC is 0.35 to 0.474. Figure 8.105 shows the IPFC as a function of pressure for bilobal pellets manufactured from ABS. The value of the IPFC is 0.242 to 0.414.

Figures 8.106-8.110 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 311 for all five samples of acetal copolymer with agitation. The value of the IPFC is presented as described here. Figure 8.106 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grades U10-01. The value of the IPFC is 0.35 to 0.48. Figure 8.107 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grades M25. The value of the IPFC is 0.242 to 0.309. Figure 8.108 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grades M90. The value of the IPFC is 0.238 to 0.31. Figure 8.109 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grades M270.. The value of the IPFC is 0.24 to 0.309. Figure 8.110 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grades M450. The value of the IPFC is 0.195 to 0.288.

Figures 8.111-8.115 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 411 for all five samples of acetal copolymer with agitation. The value of the IPFC is presented as described here. Figure 8.111 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade U10-01. The value of the IPFC is 0.383 to 0.556. Figure 8.112 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M25. The value of the IPFC is 0.245 to 0.332. Figure 8.113 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer grade M90. The value of the IPFC is 0.31 to 0.385. Figure 8.114 shows the IPFC as a function of pressure for bilobal pellets manufactured from PA 6.

The value of the IPFC is 0.28 to 0.363. Figure 8.115 shows the IPFC as a function of pressure for bilobal pellets manufactured from acetal copolymer. The value of the IPFC is 0.255 to 0.286.

Figures 116-119 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 311 for polyethylene, polypropylene,polystyrene, nylon 6, and ABS with agitation. The value of the IPFC is presented as described here. Figure 8.116 shows the IPFC as a function of pressure for pellets manufactured from PE. The value of the IPFC is 0.375 to 0.462. Figure 8.117 shows the IPFC as a function of pressure for pellets manufactured from PP. The value of the IPFC is 0.298 to 0.36. Figure 8.118 shows the IPFC as a function of pressure for pellets manufactured from PS. The value of the IPFC is 0.348 to 0.422. Figure 8.119 shows the IPFC as a function of pressure for pellets manufactured from PA 6. The value of the IPFC is 0.375 to 0.465.

Figures 120-121 show the IPFC as a function of pressure for the bilobal pellets manufactured using die 411 for polyethylene, polypropylene,polystyrene, nylon 6, and ABS with agitation. The value of the IPFC is presented as described here. Figure 8.120 shows the IPFC as a function of pressure for pellets manufactured from PE. The value of the IPFC is 0.4 to 0.472. Figure 8.121 shows the IPFC as a function of pressure for pellets manufactured from PP. The value of the IPFC is 0.343 to 0.402.

### 8.4.6 Effect of Consolidation Pressure of the Particulate Bed

The pellets manufactured using die A211 from polyethylene were consolidated with a consolidation pressure of 126.3 kPa. In the tests, the static load is applied on the cap of the shear cell. The effect of consolidation pressure on the IPFC is illustrated in Figure 8.122. The consolidation pressure has only a weak, but positive, influence on the IPFC. while the consolidation pressure put on the particulate bed.

### 8.4.7 Effect of Consolidation Time of the Particulate Bed

The specimen of particulates was consolidated at a pressure 126.3 kPa for different time periods. No shear force is applied on the shear cell with a normal force of $N = A \sigma$, where A is the cross-sectional area of the cell and $\sigma$ is the consolidation pressure. After the lapse of the prescribed interval of time, one at a time, the cell is placed on the shear apparatus and the IPFC is measured as described in chapter six. The effect on IPFC for bilobal pellets manufactured using die A211 from polyethylene is shown in Figure 8.123. The consolidation time has a weak, influence on the IPFC values for polyethylene.

### 8.4.8 Effect of Particulate Powders

The influence of additive for cylindrical pellets and bilobal pellets is measured by adding the mica clay into the material nylon 6 as additive in weight percentage from 0.5% to 2%. Both the pellets with circular cross-sections and bilobal cross-sections with adding mica clay is performed. The % increase of IPFC for the pellets with circular cross-sections with mica clay is presented in Figure 8.124. The % increase of IPFC for the pellets with bilobal cross-sections with mica clay is presented in Figure 8.125. The increase is more noteable with the pellets of circular cross-sections than with the pellets of bilobal cross-sections. The fact that an increase in the value of the IPFC occurred at all was surprising. The mica clay powder was expected to destabilize the solid bed by providing rolling contacts with low friction coefficients. In fact, it appears to have acted in an adhesive manner.

In addition, the effect of additive for cylindrical pellets and bilobal pellets are also measured adding PBT powder into the acetal copolymer grade M90 (POM3) in weight percentage from 0.5% to 2%. The % increase for IPFC by adding polyester powder (PBT) into cylindrical pellet are shown in Figure 8.126. The % decrease for IPFC by adding PBT powder into bilobal pellet are shown in Figure 8.127, Here the expected increase in IPFC value was observed with pellets of cylindrical cross-section, especially at low pressure. The addition of polymer powder to polymer pellets is known to improve solids conveying in extrusion, and this effect is expected if the IPFC increases as measured. However, the consistent decrease in the IPFC value for pellets with bilobal cross-sections was unexpected. The PBT powder appears to reverse its role as the pellet geometry changes.

### 8.4.9 Effect of Surface Lubricants

The influence of surface lubricants on the IPFC for cylindrical pellets and bilobal pellets is also measured by adding zinc stearate into the material M90 (POM3) in weight percentage from 0.25% to 1%. However, solid lubricants are frequently added to polymeric pellets among manufacturing. The % decrease of IPFC for the pellets with circular cross-sections by adding zinc stearate are shown in Figure 8.128. The % decrease of IPFC pellets with bilobal cross-sections with zinc stearate are presented in Figures 8.129 and 8.130 respectively for pellets manufactured with different dies and hence possessing different shapes. For all three geometries the IPFC values are significantly reduced, although the decrease with pellets of circular cross-section is significantly loss. Even small amounts of zinc stearate (0.25%) reduce the IPFC over 40%. The measurements are very significant, and explain why materials with external lubricant present convey poorly and cause surging in injection molding, blow molding and extrusion operations.

## 8.5 Comparison of the IPFC for Pellets with Bilobal, Trilobal and Quadrilobal Cross-Sections

Of course the initial hypothesis in this work was those bilobal, trilobal, and quadrilobal pellets would increase the interparticulate friction coefficient. This was found to be the case for all comparable situations. This finding is shown in Figure 8.1 to Figure 8.57 for acetal copolymer, polyethylene, polypropylene, polystyrene, nylon

6 and ABS. These figures indicate the percentage increase in the value of the interparticulate friction coefficient as a function of normal pressure for each of the profile dies used, and all of the extruder screw speeds used. Each and every point in these figures indicates that the interparticulate friction coefficient is improved by the sole action of profiling the pellets. The average IPFC values of bilobal, trilobal, and quadrilobal for all ten samples are presented in Table 8.8.

## 8.6 Effect of the IPFC Increases on the Performance of Plastics Solid Conveying Equipment

The results clearly indicate that the interparticulate friction coefficient is increased with profiled pellets as compared to cylindrical pellets. The hypothesis can readily be drawn that solids beds of profiled pellets will exhibit greater integrity, and not break up readily. However, the profiled pellets must also be conveyed in mechanical systems other than plasticating screws, and in these instances the flexibility is required to be high, and the increased interparticulate friction coefficients may be disadvantageous. It will cause an increase in the coefficient, which reflects the magnitude of the cohesive forces in the solid bed, which must be exceeded if flow is to occur. This, in turn, could lead to arching and piping in bins and hoppers. The solution to these flow anomalies is known to be the use of live bottoms, or hopper stirrers, but this entails an increased cost for the processor, and may limit the use of profiled pellets.

Table 8.1 Effect of Normal Pressure on the Average IPFC for Acetal Copolymer.

| Normal Pressure kPa | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| 20.46 | 0.364 | 0.275 | 0.253 |
| 26.64 | 0.372 | 0.270 | 0.283 |
| 32.82 | 0.369 | 0.269 | 0.259 |
| 39.00 | 0.367 | 0.267 | 0.258 |
| 45.18 | 0.358 | 0.260 | 0.254 |

Table 8.2 Effect of Normal Pressure on the Average IPFC for PE, PP, PS, PA6 and ABS.

| Normal Pressure kPa | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| 20.46 | 0.309 | 0.304 | 0.340 |
| 26.64 | 0.312 | 0.315 | 0.342 |
| 32.82 | 0.313 | 0.314 | 0.343 |
| 39.00 | 0.311 | 0.310 | 0.338 |
| 45.18 | 0.309 | 0.307 | 0.332 |

Table 8.3 Effect of Extruder Screw Speed on the Average IPFC for Acetal Copolymer.

| Extruder screw speed rev/min | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| 5 | 0.339 | 0.247 | 0.259 |
| 10 | 0.360 | 0.267 | 0.264 |
| 15 | 0.367 | 0.271 | 0.262 |
| 20 | 0.375 | 0.288 | 0.270 |

Table 8.4 Effect of Extruder Screw Speed on the Average IPFC for PE, PP, PS, PA6 and ABS.

| Extruder screw speed rev/min | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| 5 | 0.289 | 0.299 | 0.330 |
| 10 | 0.300 | 0.312 | 0.340 |
| 15 | 0.313 | 0.313 | 0.344 |
| 20 | 0.328 | 0.324 | 0.348 |

Table 8.5 Effect of Molecular Weight on the Average IPFC for Acetal Copolymer.

| Melt Index | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| 1.0 | 0.409 | 0.411 | 0.346 |
| 2.5 | 0.371 | 0.234 | 0.235 |
| 9.0 | 0.366 | 0.254 | 0.272 |
| 27.0 | 0.342 | 0.226 | 0.242 |
| 45.0 | 0.341 | 0.225 | 0.211 |

Table 8.6 Effect of Die Geometry on the Average IPFC for Acetal Copolymer.

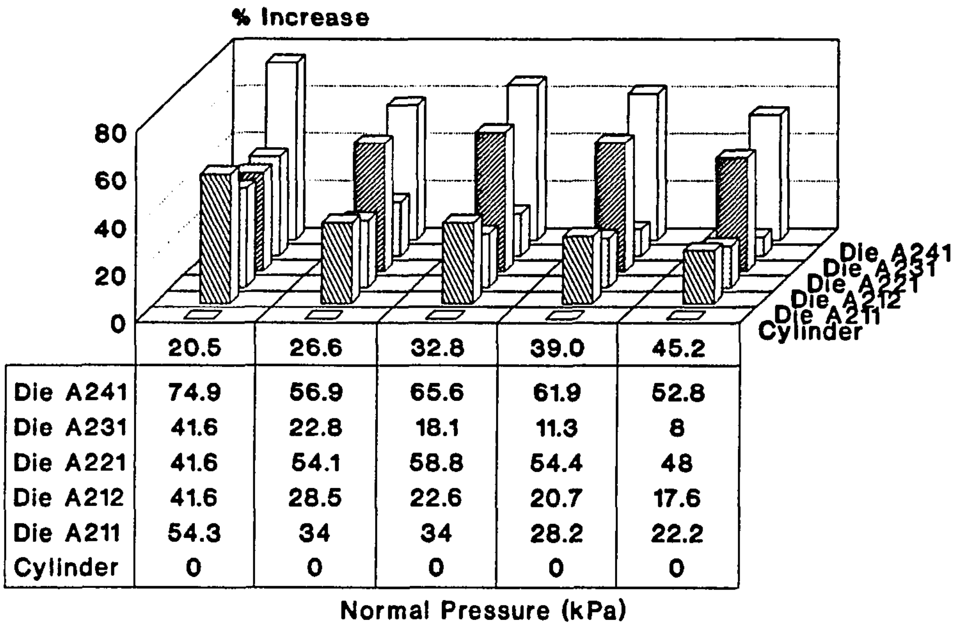
| Profile Die No | Average IPFC |
|---|---|
| A201-01 | 0.381 |
| A201-02 | 0.383 |
| A202-01 | 0.413 |
| A203-01 | 0.274 |
| A204-01 | 0.397 |
| A301-01 | 0.270 |
| A401-01 | 0.261 |

Table 8.7 Effect of Die Geometry on the Average IPFC for PE, PP, PS, PA 6 and ABS.

| Profile Die No | Average IPFC |
|---|---|
| A201-01 | 0.310 |
| A201-02 | 0.304 |
| A202-01 | 0.332 |
| A203-01 | 0.278 |
| A204-01 | 0.323 |
| A301-01 | 0.310 |
| A401-01 | 0.339 |

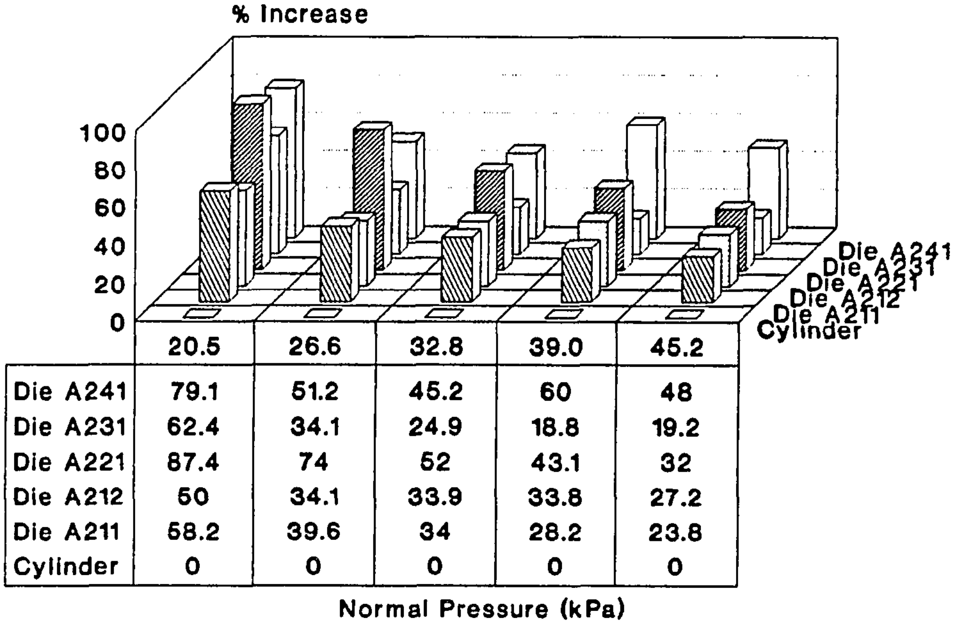
Table 8.8 The Average IPFC values for Pellets with Bilobal, Trilobal and Quadrilobal Cross-Section for Acetal Copolymer, PE, PP, PS, PA 6 and ABS.

| Material | Average IPFC Bilobal | Average IPFC Trilobal | Average IPFC Quadrilobal |
|---|---|---|---|
| U10-01 | 0.409 | 0.411 | 0.346 |
| M25 | 0.371 | 0.234 | 0.235 |
| M90 | 0.366 | 0.254 | 0.272 |
| M270 | 0.342 | 0.226 | 0.242 |
| M450 | 0.341 | 0.225 | 0.211 |
| PE | 0.337 | 0.317 | 0.352 |
| PP | 0.289 | 0.280 | 0.327 |
| PS | 0.351 | 0.308 | N/A |
| PA 6 | 0.329 | 0.338 | N/A |
| ABS | 0.250 | N/A | N/A |



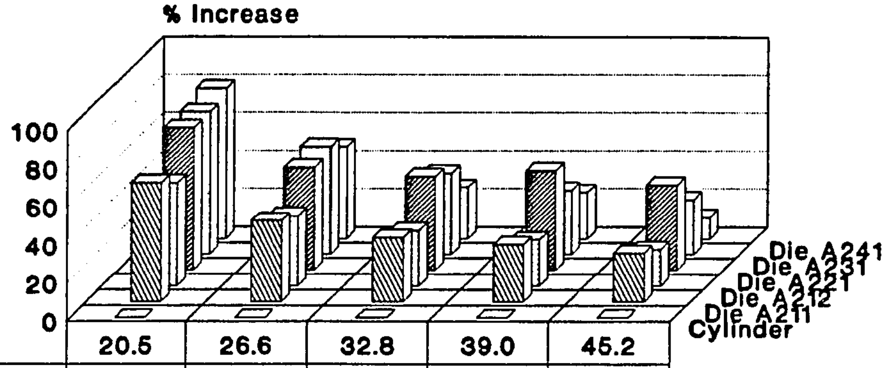
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 74.9 | 56.9 | 65.6 | 61.9 | 52.8 |
| Die A231 | 41.6 | 22.8 | 18.1 | 11.3 | 8 |
| Die A221 | 41.6 | 54.1 | 58.8 | 54.4 | 48 |
| Die A212 | 41.6 | 28.5 | 22.6 | 20.7 | 17.6 |
| Die A211 | 54.3 | 34 | 34 | 28.2 | 22.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Figure 8.1 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 79.1 | 51.2 | 45.2 | 60 | 48 |
| Die A231 | 62.4 | 34.1 | 24.9 | 18.8 | 19.2 |
| Die A221 | 87.4 | 74 | 52 | 43.1 | 32 |
| Die A212 | 50 | 34.1 | 33.9 | 33.8 | 27.2 |
| Die A211 | 58.2 | 39.6 | 34 | 28.2 | 23.8 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

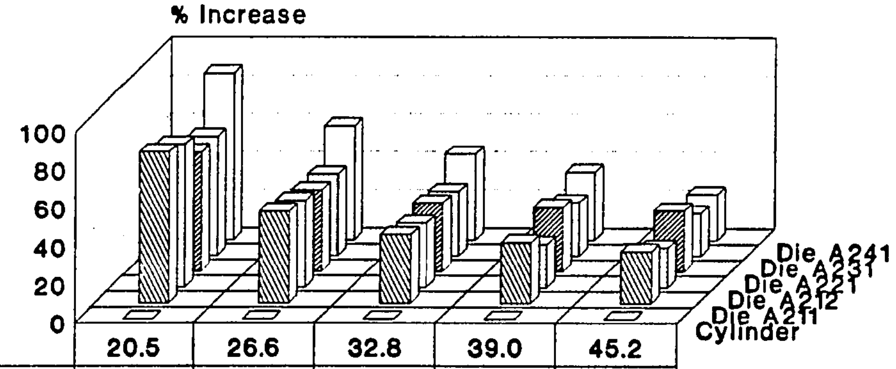
Figure 8.2 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 79.1 | 48.4 | 27 | 24.4 | 11.2 |
| Die A231 | 74.9 | 56.9 | 42.8 | 33.8 | 28.8 |
| Die A221 | 74.9 | 54.1 | 49.5 | 52.5 | 44.8 |
| Die A212 | 54.1 | 37 | 29.2 | 24.4 | 19.2 |
| Die A211 | 62.5 | 42.7 | 34 | 30.2 | 25.5 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

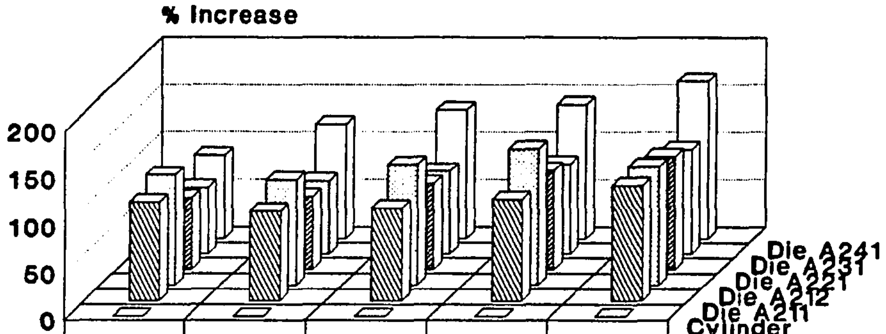
Figure 8.3 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 87.4 | 59.8 | 45 | 35.6 | 24 |
| Die A231 | 62.4 | 42.7 | 33.7 | 28.1 | 22.4 |
| Die A221 | 62.4 | 42.7 | 36 | 33.8 | 32 |
| Die A212 | 74.9 | 45.5 | 33.7 | 22.5 | 20.8 |
| Die A211 | 79.3 | 48.3 | 36.1 | 31.9 | 27.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

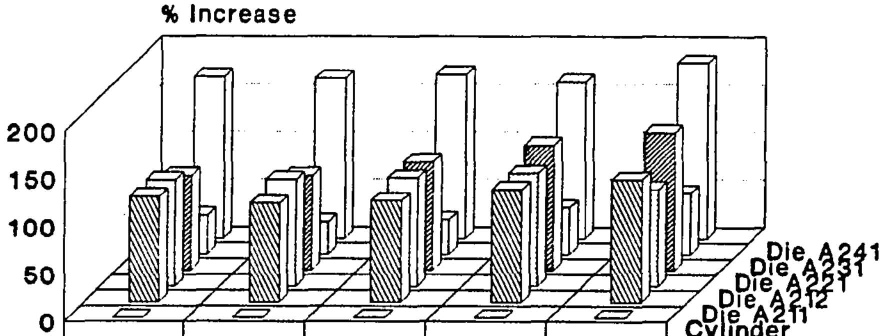
Figure 8.4 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 88.1 | 121.1 | 135.9 | 141.7 | 166.5 |
| Die A231 | 70.4 | 77.8 | 88.1 | 95.6 | 111 |
| Die A221 | 76.3 | 77.8 | 91.8 | 105.5 | 120.2 |
| Die A212 | 117.4 | 112.4 | 128.6 | 145 | 126.4 |
| Die A211 | 104.9 | 95.8 | 98.9 | 108.2 | 122.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

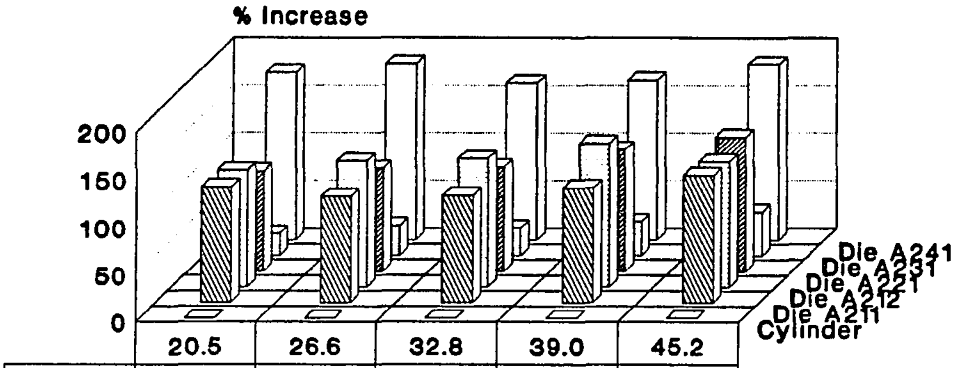
Figure 8.5 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 170.3 | 168.6 | 172.6 | 164.8 | 185 |
| Die A231 | 41.1 | 34.6 | 36.7 | 49.4 | 64.8 |
| Die A221 | 99.8 | 99.5 | 113.9 | 131.8 | 145 |
| Die A212 | 111.6 | 112.4 | 113.9 | 118.6 | 101.8 |
| Die A211 | 111 | 104.2 | 106.6 | 118.2 | 128.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

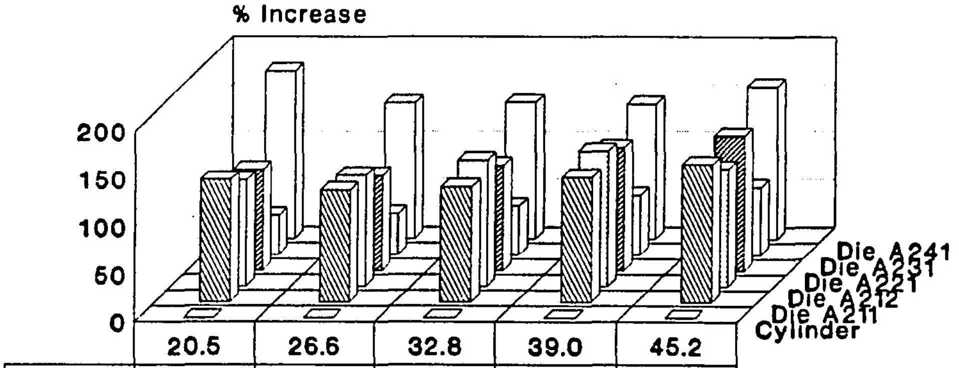
Figure 8.6 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 176.1 | 185.6 | 165.2 | 168 | 185 |
| Die A231 | 23.5 | 31.8 | 29.4 | 36.2 | 46.3 |
| Die A221 | 105.7 | 108.7 | 110.2 | 128.5 | 141.8 |
| Die A212 | 123.3 | 133.3 | 135.9 | 151.6 | 132.6 |
| Die A211 | 122.5 | 112.7 | 113.8 | 121.8 | 135 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

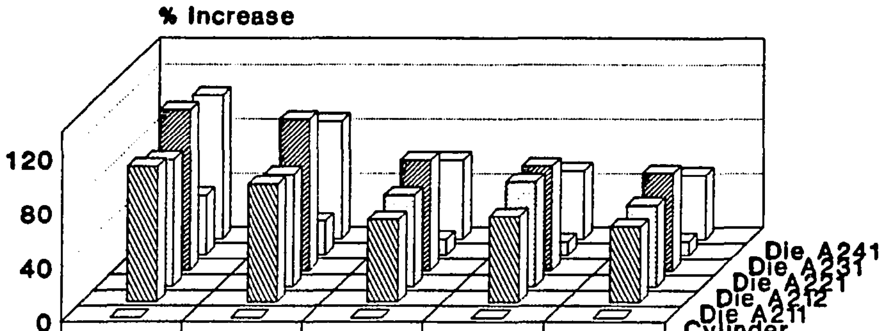
Figure 8.7 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 176.1 | 142.6 | 143.2 | 141.7 | 160.3 |
| Die A231 | 41.1 | 43.2 | 51.4 | 62.6 | 70.9 |
| Die A221 | 105.7 | 99.5 | 110.2 | 128.5 | 141.8 |
| Die A212 | 111.6 | 116.7 | 132.2 | 141.7 | 123.4 |
| Die A211 | 128.6 | 117.5 | 121 | 131.2 | 144.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

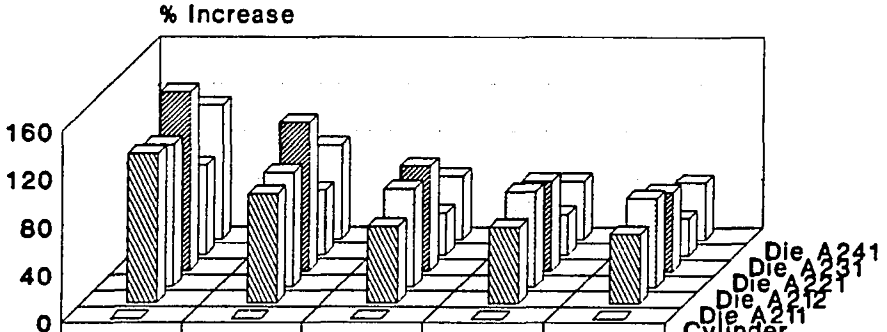
Figure 8.8 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 106.1 | 87 | 58.5 | 50.8 | 47.5 |
| Die A231 | 43.7 | 24.8 | 11.7 | 9.7 | 10.3 |
| Die A221 | 118.5 | 111.9 | 81.8 | 77.4 | 72.3 |
| Die A212 | 93.6 | 82.9 | 67.2 | 77.4 | 59.9 |
| Die A211 | 100 | 86.9 | 61 | 63.2 | 55.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

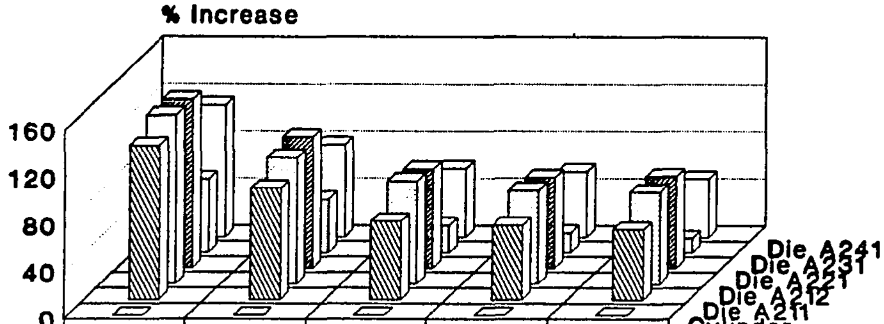
Figure 8.9 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 112.3 | 78.7 | 52.6 | 48.4 | 47.6 |
| Die A231 | 74.9 | 53.9 | 35.1 | 33.9 | 31 |
| Die A221 | 149.7 | 124.3 | 87.6 | 75 | 66.1 |
| Die A212 | 118.5 | 95.3 | 81.8 | 79.8 | 74.3 |
| Die A211 | 124.6 | 90.9 | 64 | 63.2 | 57.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

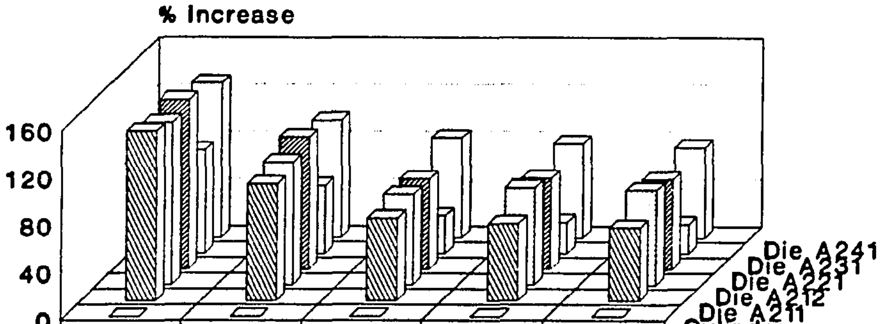
Figure 8.10 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 112.3 | 78.7 | 58.5 | 55.7 | 49.6 |
| Die A231 | 62.4 | 45.6 | 23.4 | 17 | 12.4 |
| Die A221 | 143.5 | 111.9 | 84.7 | 77.4 | 78.5 |
| Die A212 | 143.5 | 107.7 | 87.6 | 79.8 | 78.5 |
| Die A211 | 131 | 94.9 | 66.7 | 63.2 | 59.8 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

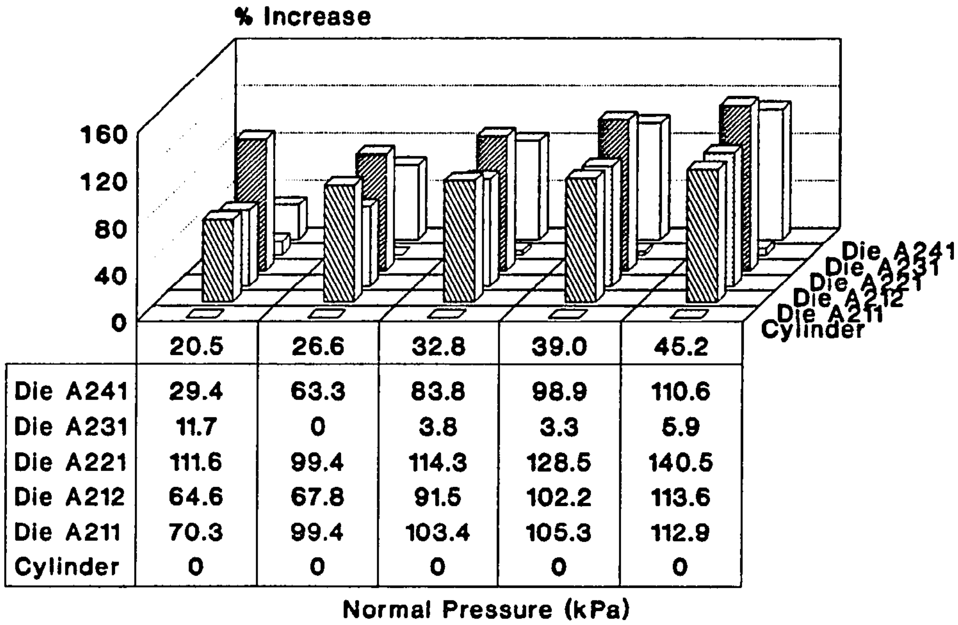
Figure 8.11 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 131 | 99.4 | 84.7 | 79.8 | 76.4 |
| Die A231 | 87.4 | 58 | 32.2 | 26.6 | 24.8 |
| Die A221 | 143.5 | 111.9 | 76.8 | 77.4 | 76.4 |
| Die A212 | 137.3 | 103.6 | 76.8 | 82.3 | 80.5 |
| Die A211 | 143.3 | 99 | 69.7 | 65.4 | 62 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

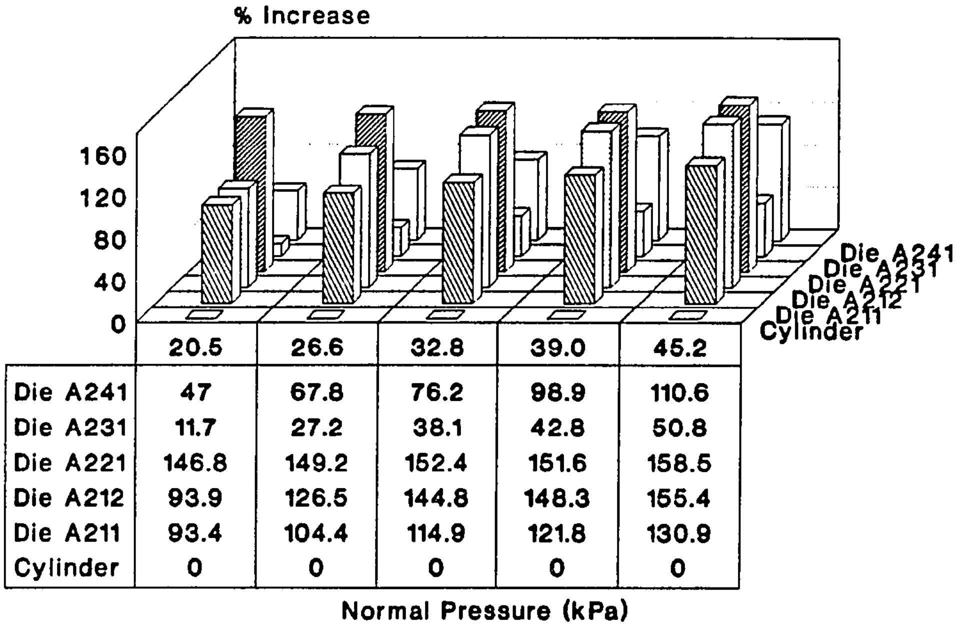
Figure 8.12 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 29.4 | 63.3 | 83.8 | 98.9 | 110.6 |
| Die A231 | 11.7 | 0 | 3.8 | 3.3 | 5.9 |
| Die A221 | 111.6 | 99.4 | 114.3 | 128.5 | 140.5 |
| Die A212 | 64.6 | 67.8 | 91.5 | 102.2 | 113.6 |
| Die A211 | 70.3 | 99.4 | 103.4 | 105.3 | 112.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

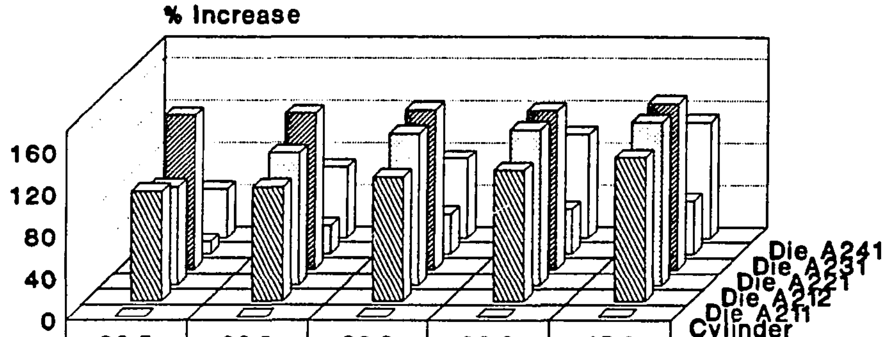
Figure 8.13 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 47 | 67.8 | 76.2 | 98.9 | 110.6 |
| Die A231 | 11.7 | 27.2 | 38.1 | 42.8 | 50.8 |
| Die A221 | 146.8 | 149.2 | 152.4 | 151.6 | 158.5 |
| Die A212 | 93.9 | 126.5 | 144.8 | 148.3 | 155.4 |
| Die A211 | 93.4 | 104.4 | 114.9 | 121.8 | 130.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

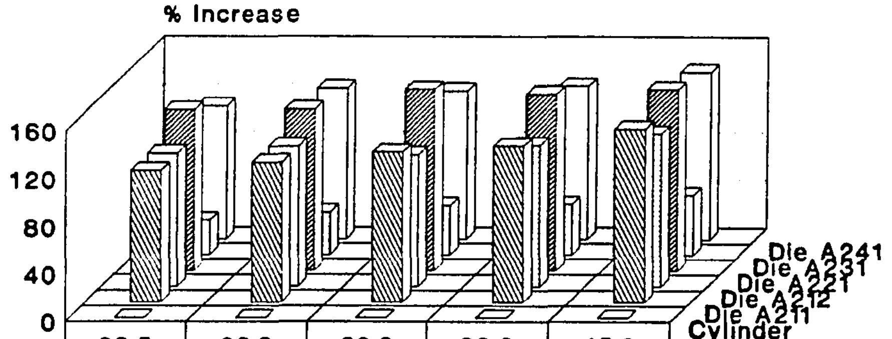
Figure 8.14 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 47 | 67.8 | 76.2 | 98.9 | 110.6 |
| Die A231 | 11.7 | 27.2 | 38.1 | 42.8 | 50.8 |
| Die A221 | 146.8 | 149.2 | 152.4 | 151.6 | 158.5 |
| Die A212 | 93.9 | 126.5 | 144.8 | 148.3 | 155.4 |
| Die A211 | 104.9 | 108.8 | 118.4 | 124.7 | 137 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

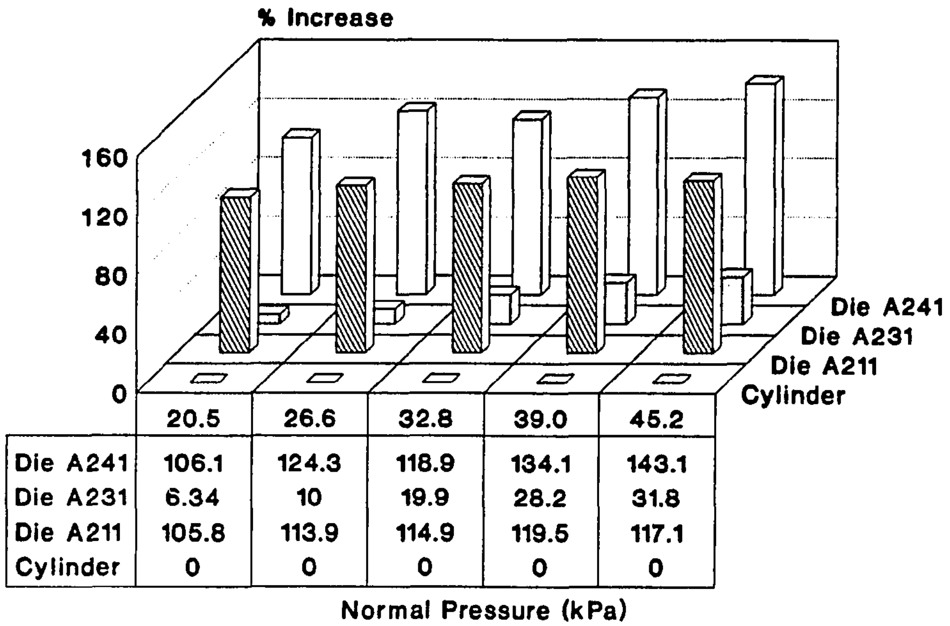
Figure 8.15 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 111.6 | 126.5 | 124.3 | 128.5 | 140.5 |
| Die A231 | 29.4 | 36.1 | 41.9 | 42.8 | 50.8 |
| Die A221 | 135 | 135.6 | 152.4 | 148.3 | 152.4 |
| Die A212 | 111.6 | 117.5 | 110.5 | 118.6 | 128.5 |
| Die A211 | 111 | 117.7 | 126.4 | 131.2 | 145.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

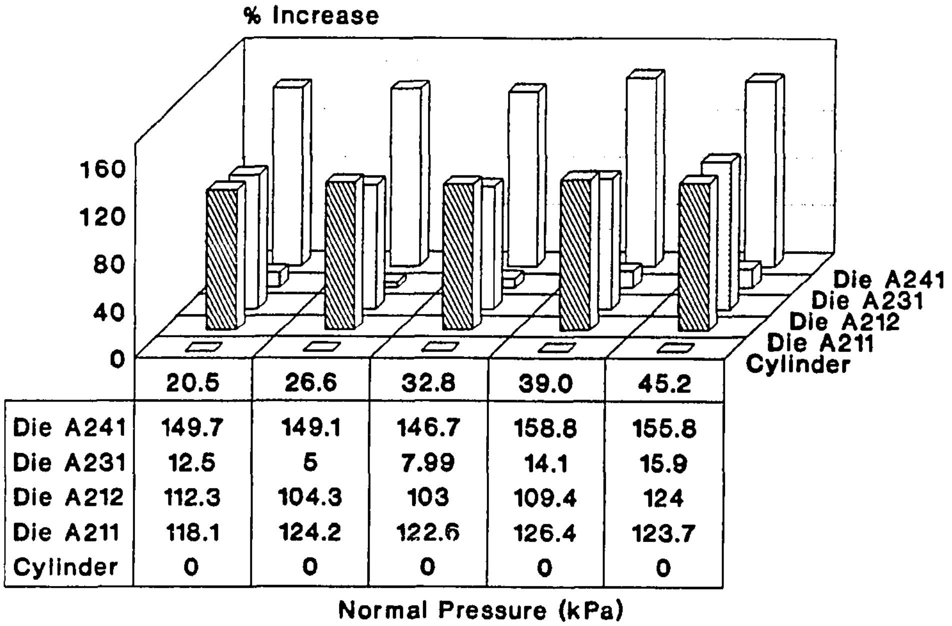
Normal Pressure (kPa)

Figure 8.16 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for POM4.



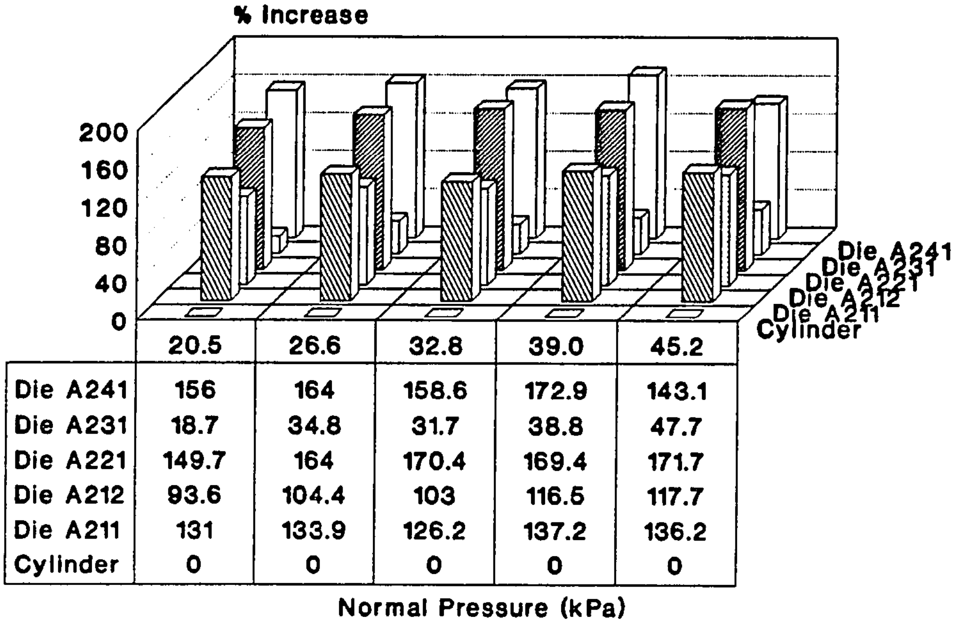
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 106.1 | 124.3 | 118.9 | 134.1 | 143.1 |
| Die A231 | 6.34 | 10 | 19.9 | 28.2 | 31.8 |
| Die A211 | 105.8 | 113.9 | 114.9 | 119.5 | 117.1 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Figure 8.17 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for POM5.



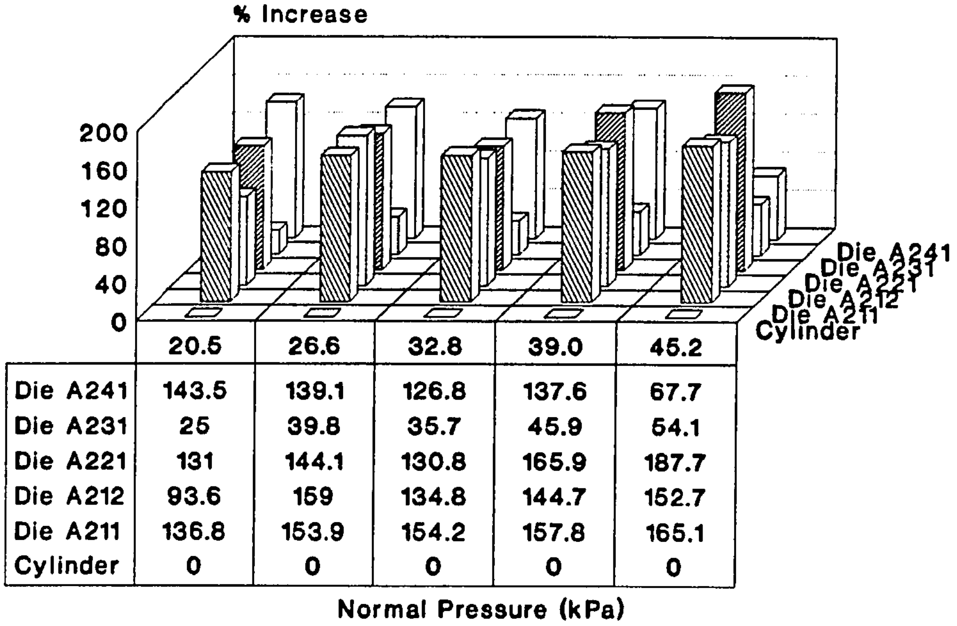
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 149.7 | 149.1 | 146.7 | 158.8 | 155.8 |
| Die A231 | 12.5 | 5 | 7.99 | 14.1 | 15.9 |
| Die A212 | 112.3 | 104.3 | 103 | 109.4 | 124 |
| Die A211 | 118.1 | 124.2 | 122.6 | 126.4 | 123.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Figure 8.18 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for POM5.



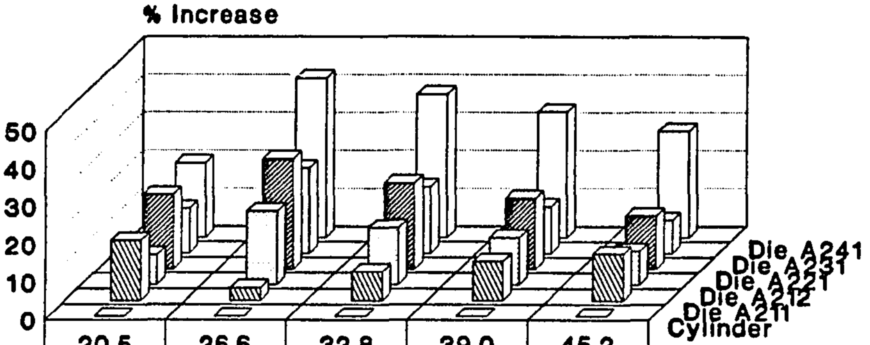
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 156 | 164 | 158.6 | 172.9 | 143.1 |
| Die A231 | 18.7 | 34.8 | 31.7 | 38.8 | 47.7 |
| Die A221 | 149.7 | 164 | 170.4 | 169.4 | 171.7 |
| Die A212 | 93.6 | 104.4 | 103 | 116.5 | 117.7 |
| Die A211 | 131 | 133.9 | 126.2 | 137.2 | 136.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Figure 8.19 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 143.5 | 139.1 | 126.8 | 137.6 | 67.7 |
| Die A231 | 25 | 39.8 | 35.7 | 45.9 | 54.1 |
| Die A221 | 131 | 144.1 | 130.8 | 165.9 | 187.7 |
| Die A212 | 93.6 | 159 | 134.8 | 144.7 | 152.7 |
| Die A211 | 136.8 | 153.9 | 154.2 | 157.8 | 165.1 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

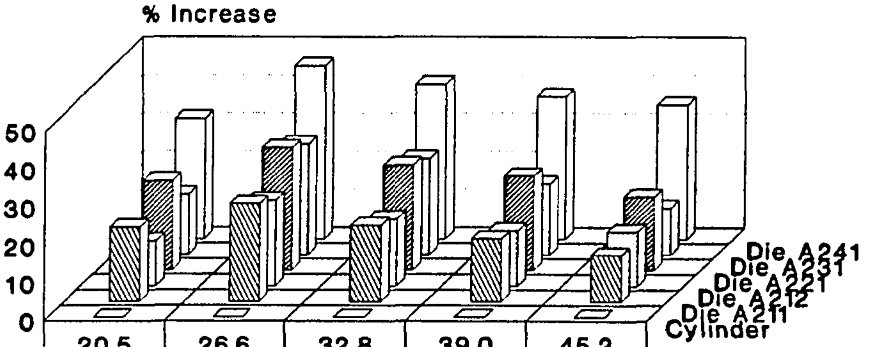
Figure 8.20 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 19.8 | 42.2 | 38.1 | 33.4 | 28.3 |
| Die A231 | 11.9 | 22.7 | 17.8 | 12.5 | 8.9 |
| Die A221 | 19.8 | 29.2 | 22.9 | 18.8 | 14.2 |
| Die A212 | 7.9 | 19.5 | 15.2 | 12.5 | 8.9 |
| Die A211 | 15.9 | 3.3 | 7.6 | 10.4 | 12.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

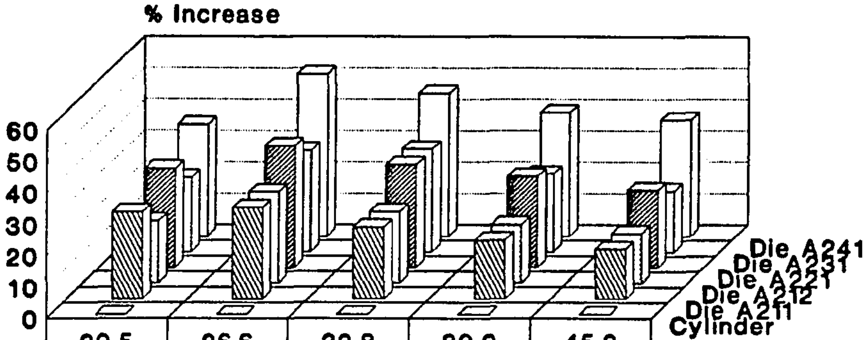
Figure 8.21 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 31.7 | 45.5 | 40.7 | 37.5 | 35.4 |
| Die A231 | 15.9 | 29.2 | 25.4 | 18.8 | 12.4 |
| Die A221 | 23.8 | 32.5 | 27.9 | 25 | 19.5 |
| Die A212 | 11.9 | 22.7 | 17.8 | 14.6 | 14.4 |
| Die A211 | 19.8 | 26 | 20.3 | 16.7 | 12.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

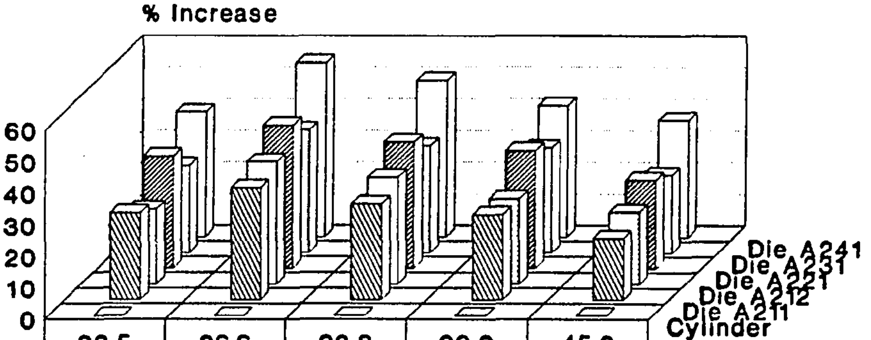
Figure 8.22 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 35.7 | 51.9 | 45.7 | 39.6 | 37.2 |
| Die A231 | 23.8 | 32.5 | 33 | 25 | 19.5 |
| Die A221 | 31.7 | 39 | 33 | 29.2 | 24.8 |
| Die A212 | 19.8 | 29.2 | 22.9 | 18.8 | 16 |
| Die A211 | 27.7 | 29.2 | 22.9 | 18.8 | 15.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

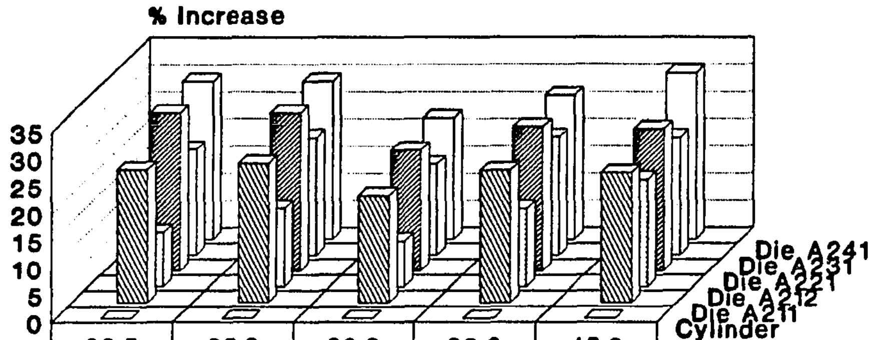
Figure 8.23 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 39.6 | 55.2 | 49.6 | 41.7 | 37.2 |
| Die A231 | 27.7 | 39 | 34 | 33.4 | 24.8 |
| Die A221 | 35.7 | 45.5 | 40.2 | 37.5 | 28.3 |
| Die A212 | 23.8 | 39 | 34 | 27.1 | 23 |
| Die A211 | 27.7 | 35.7 | 30.5 | 27.1 | 19.5 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

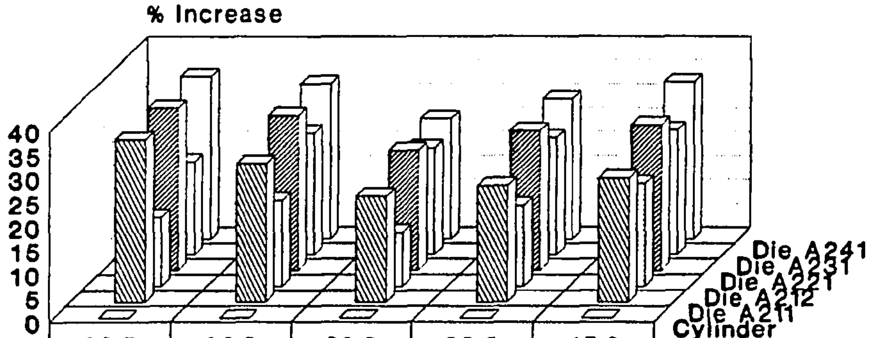
Figure 8.24 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 29.1 | 29.1 | 22.3 | 26.6 | 30.6 |
| Die A231 | 19.5 | 21.6 | 16.8 | 21.8 | 21.6 |
| Die A221 | 29.1 | 29.1 | 22.3 | 26.6 | 26.1 |
| Die A212 | 10 | 14.5 | 8.4 | 14.4 | 19.8 |
| Die A211 | 24.5 | 25.6 | 19.7 | 24.4 | 23.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

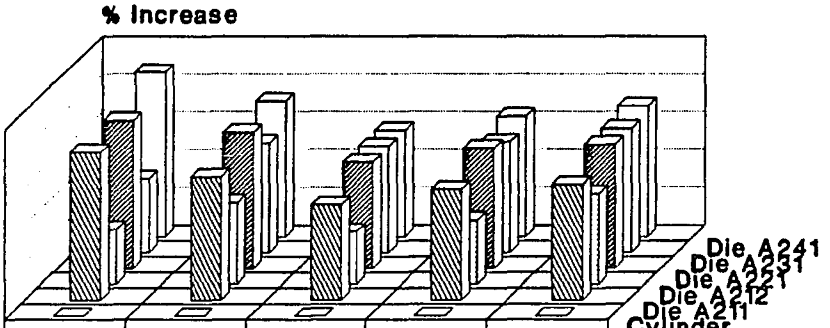
Figure 8.25 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 34.1 | 32.6 | 25.2 | 29.3 | 32.9 |
| Die A231 | 19.5 | 25.5 | 22.3 | 24.5 | 26.1 |
| Die A221 | 34.1 | 32.6 | 25.2 | 29.3 | 30.6 |
| Die A212 | 14.5 | 18.1 | 11.3 | 17 | 21.6 |
| Die A211 | 34.1 | 29.1 | 22.3 | 24.5 | 26.1 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

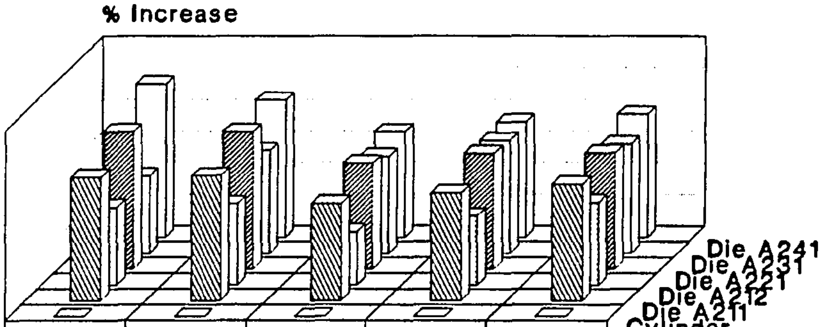
Figure 8.26 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 43.6 | 36.1 | 28.2 | 31.9 | 34.7 |
| Die A231 | 19.6 | 29.1 | 28.2 | 29.3 | 32.9 |
| Die A221 | 39.1 | 36.1 | 28.2 | 31.9 | 32.9 |
| Die A212 | 14.5 | 21.6 | 13.9 | 17 | 23.9 |
| Die A211 | 39.1 | 32.6 | 25.2 | 29.3 | 30.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

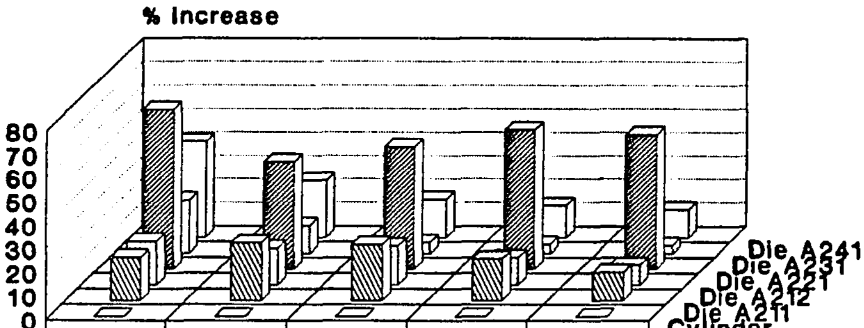
Figure 8.27 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 48.6 | 43.6 | 33.6 | 36.7 | 39.2 |
| Die A231 | 24.5 | 32.6 | 30.7 | 35.8 | 34.7 |
| Die A221 | 43.6 | 43.6 | 33.6 | 36.7 | 36.9 |
| Die A212 | 24.5 | 25.6 | 16.8 | 21.8 | 26.1 |
| Die A211 | 39.1 | 39.6 | 30.7 | 34.1 | 36.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

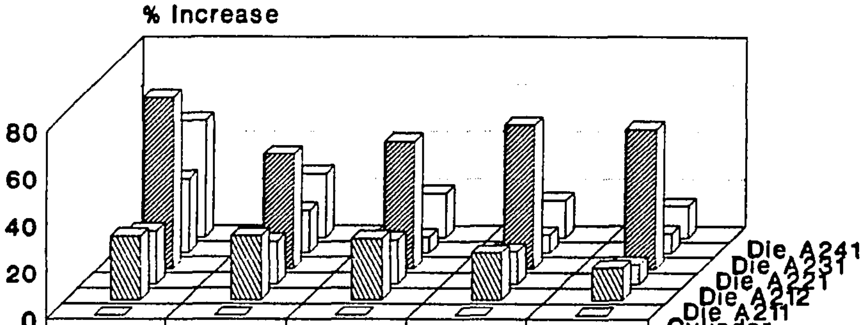
Figure 8.28 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 40.9 | 24.3 | 16.4 | 13.8 | 11.9 |
| Die A231 | 22.6 | 12 | 4.67 | 3.9 | 3.5 |
| Die A221 | 68.1 | 45.7 | 52.1 | 59.4 | 57.5 |
| Die A212 | 18.3 | 15.4 | 16.4 | 11.6 | 8.4 |
| Die A211 | 18.3 | 24.3 | 23.6 | 17.7 | 11.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

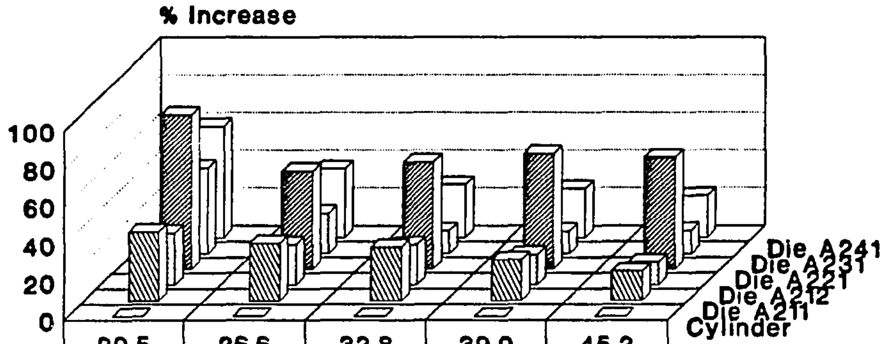
Figure 8.29 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 49.8 | 27.3 | 18.9 | 15.9 | 13.7 |
| Die A231 | 31.9 | 18.4 | 6.87 | 7.8 | 8.4 |
| Die A221 | 72.8 | 49.1 | 54.3 | 61.1 | 59.3 |
| Die A212 | 22.6 | 18.4 | 18.9 | 13.8 | 8.4 |
| Die A211 | 27.2 | 27.3 | 26.1 | 19.8 | 13.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

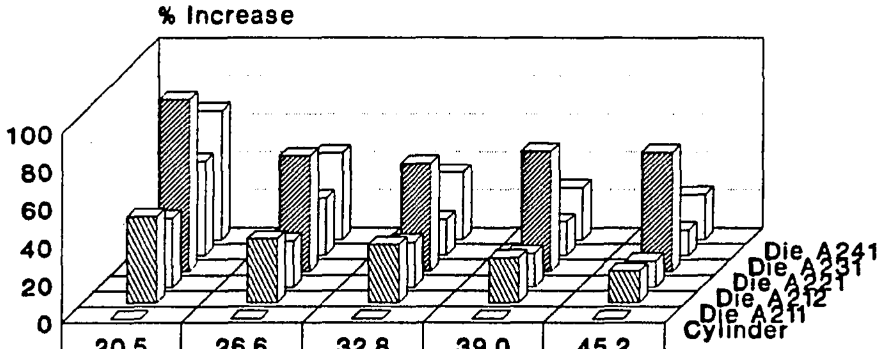
Figure 8.30 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 59.1 | 36.7 | 28.2 | 25.8 | 22.1 |
| Die A231 | 45.5 | 21.3 | 11.8 | 11.7 | 11.9 |
| Die A221 | 81.7 | 52.1 | 56.8 | 61.1 | 59.3 |
| Die A212 | 27.2 | 21.3 | 21.1 | 15.9 | 11.9 |
| Die A211 | 36.2 | 30.3 | 28.2 | 21.6 | 15.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

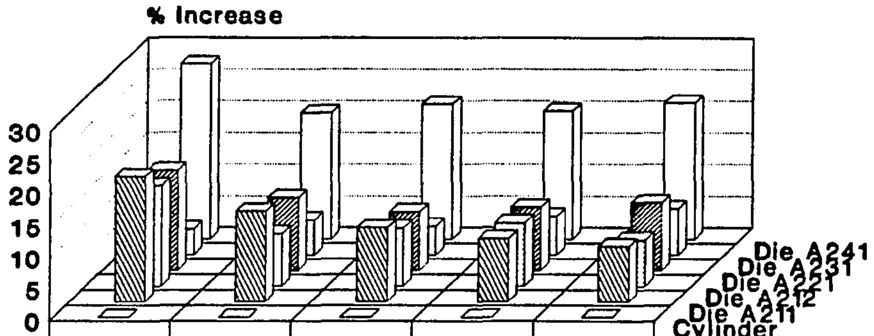
Figure 8.31 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 68.1 | 45.7 | 35.4 | 27.6 | 23.9 |
| Die A231 | 49.8 | 30.3 | 18.9 | 17.7 | 13.7 |
| Die A221 | 90.6 | 61 | 56.8 | 63.3 | 62.8 |
| Die A212 | 36.2 | 24.3 | 23.6 | 17.7 | 13.7 |
| Die A211 | 45.5 | 33.7 | 30.7 | 23.7 | 16.8 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

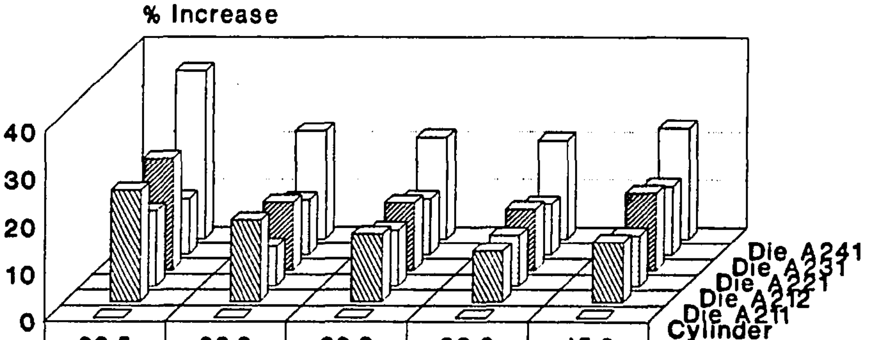
Normal Pressure (kPa)

Figure 8.32 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for PS.



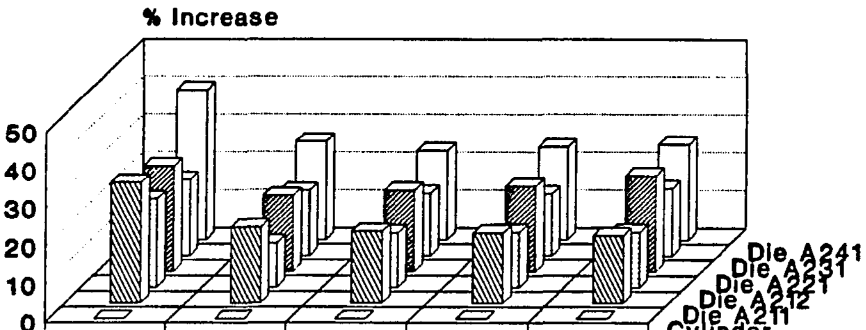
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 27.7 | 20 | 21.4 | 20.3 | 21.6 |
| Die A231 | 4.1 | 5.6 | 4.6 | 6.2 | 7.4 |
| Die A221 | 15.9 | 11.6 | 9.38 | 10.1 | 10.8 |
| Die A212 | 15.9 | 8.4 | 9.3 | 10.1 | 7.4 |
| Die A211 | 19.9 | 14.4 | 11.8 | 10.1 | 8.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Figure 8.33 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 35.4 | 22.8 | 21.4 | 20.7 | 23.4 |
| Die A231 | 11.8 | 11.6 | 11.8 | 10.7 | 14.5 |
| Die A221 | 23.6 | 14.4 | 14.3 | 12.9 | 16.4 |
| Die A212 | 15.9 | 8.4 | 11.8 | 10.7 | 10.8 |
| Die A211 | 23.6 | 17.2 | 14.3 | 10.7 | 12.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

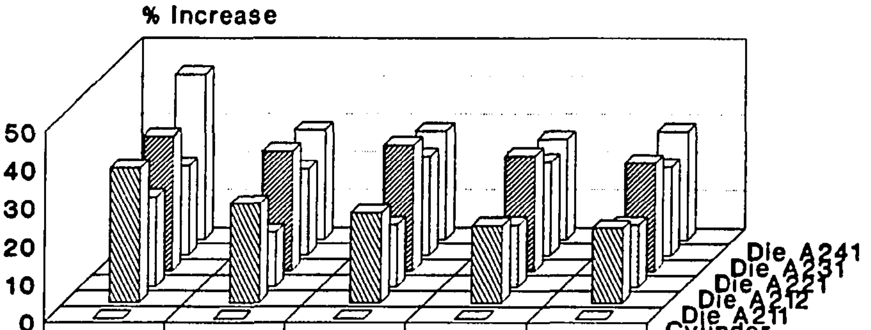
Figure 8.34 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 39.5 | 26 | 23.6 | 24.6 | 25.3 |
| Die A231 | 20 | 17.2 | 16.4 | 16.3 | 17.8 |
| Die A221 | 27.7 | 20 | 21.4 | 22.5 | 25.3 |
| Die A212 | 23.2 | 11.6 | 14.3 | 14.5 | 14.5 |
| Die A211 | 31.7 | 20 | 18.9 | 18.5 | 17.8 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

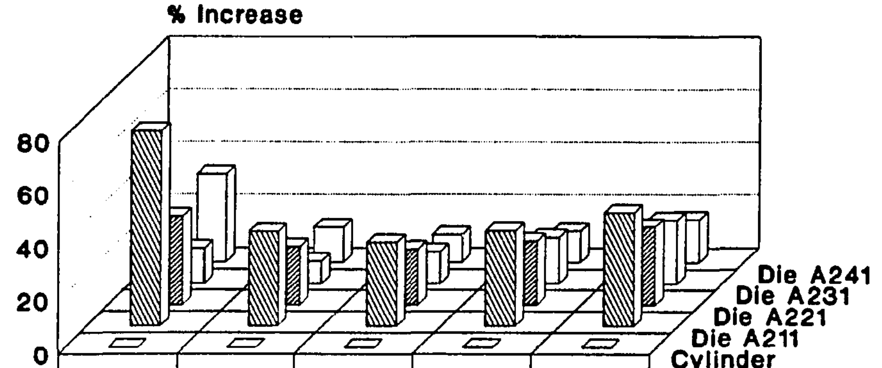
Figure 8.35 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 43.5 | 28.8 | 28.6 | 26.4 | 28.6 |
| Die A231 | 23.6 | 22.8 | 26.1 | 24.6 | 23.4 |
| Die A221 | 35.4 | 31.6 | 33.2 | 30.4 | 28.6 |
| Die A212 | 23.6 | 14.4 | 16.4 | 16.3 | 16.4 |
| Die A211 | 35.4 | 26 | 23.6 | 20.3 | 19.7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

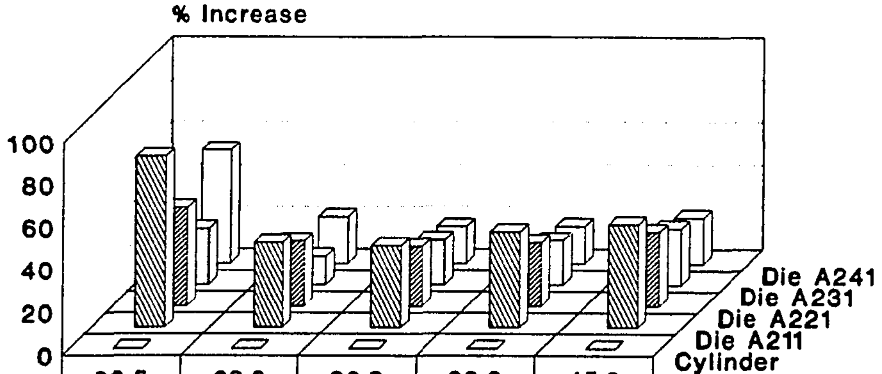
Figure 8.36 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 33.3 | 13.4 | 10.5 | 11.8 | 16.1 |
| Die A231 | 13.2 | 8.6 | 12.1 | 17.6 | 23.9 |
| Die A221 | 33.3 | 22 | 21.1 | 24.1 | 29.4 |
| Die A211 | 73.6 | 35.5 | 31.6 | 35.8 | 42.8 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

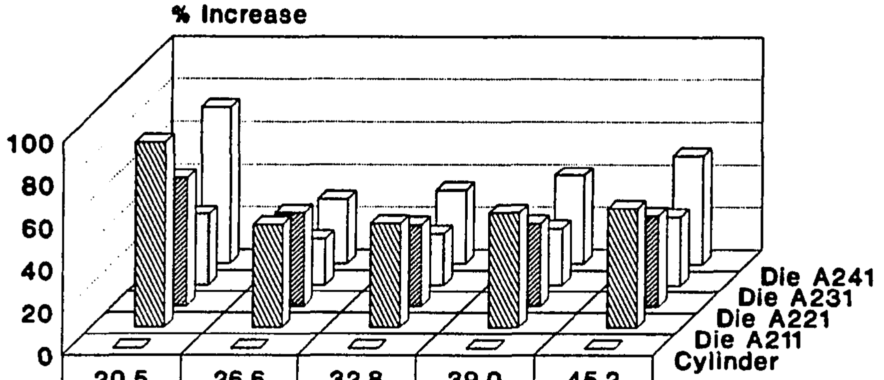
Figure 8.37 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 5rpm for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 53.5 | 22 | 17.4 | 17.6 | 21.7 |
| Die A231 | 26.4 | 13.4 | 21.1 | 20.9 | 26.7 |
| Die A221 | 46.5 | 30.6 | 27.9 | 29.9 | 35 |
| Die A211 | 80.5 | 39.8 | 38.4 | 44.9 | 48.3 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

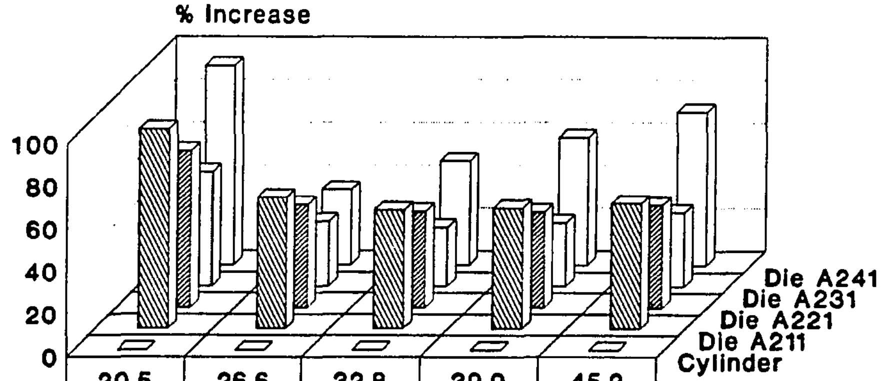
Figure 8.38 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 10rpm for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 73.6 | 30.6 | 34.7 | 41.7 | 51.1 |
| Die A231 | 33.3 | 22 | 24.2 | 26.7 | 32.2 |
| Die A221 | 60.4 | 44.1 | 38.4 | 39 | 42.8 |
| Die A211 | 86.8 | 48.4 | 48.9 | 54 | 56.1 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

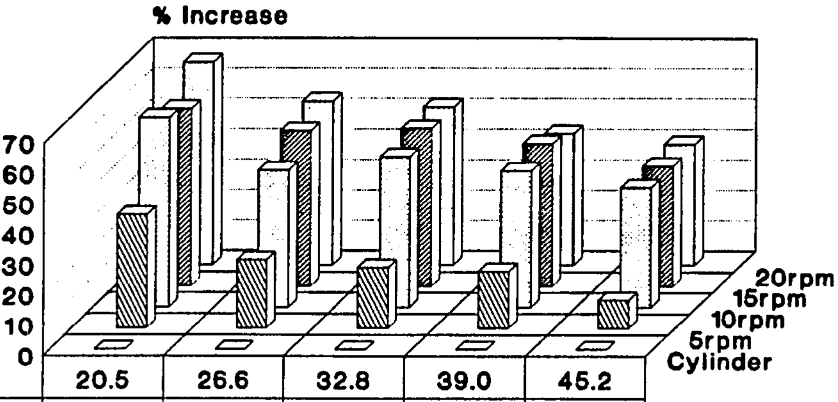
Figure 8.39 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 15rpm for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| Die A241 | 93.7 | 35.5 | 48.9 | 59.9 | 72.2 |
| Die A231 | 53.5 | 30.6 | 27.9 | 29.9 | 35 |
| Die A221 | 73.6 | 48.4 | 45.3 | 44.9 | 48.3 |
| Die A211 | 93.7 | 61.8 | 55.8 | 56.7 | 58.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

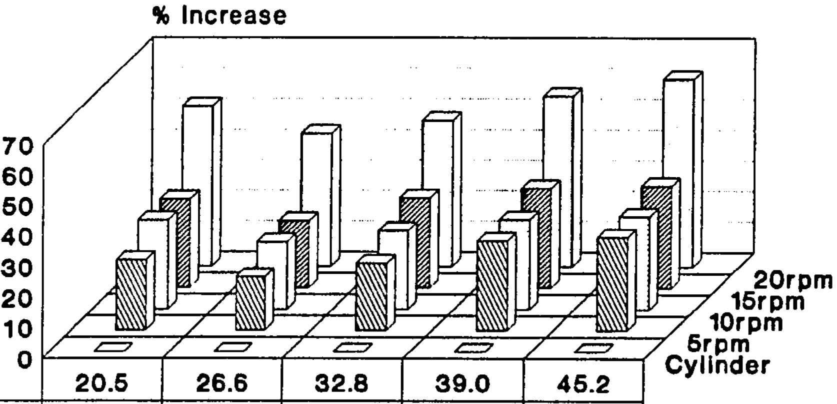
Figure 8.40 % Increase for all Bilobal Pellets Compared to Circular Pellets at an Extruder Screw Speed 20rpm for ABS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 66.7 | 53.9 | 52 | 43.3 | 39.8 |
| 15rpm | 58.4 | 51.1 | 52 | 47 | 39.8 |
| 10rpm | 62.5 | 45.4 | 49.7 | 45.2 | 39.8 |
| 5rpm | 37.6 | 22.6 | 20.3 | 18.9 | 9.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

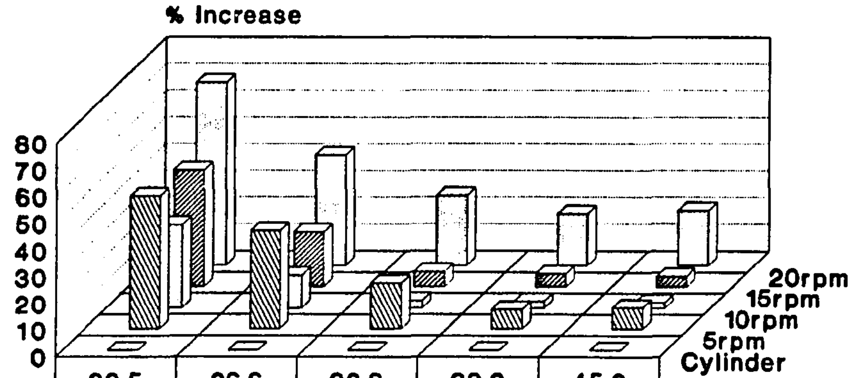
Figure 8.41 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 52.5 | 43.5 | 47.7 | 55.8 | 61.3 |
| 15rpm | 29.1 | 21.9 | 29.4 | 32.7 | 33.6 |
| 10rpm | 29.1 | 21.9 | 25.7 | 29.4 | 30.5 |
| 5rpm | 23.2 | 17.6 | 22 | 29.4 | 30.5 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

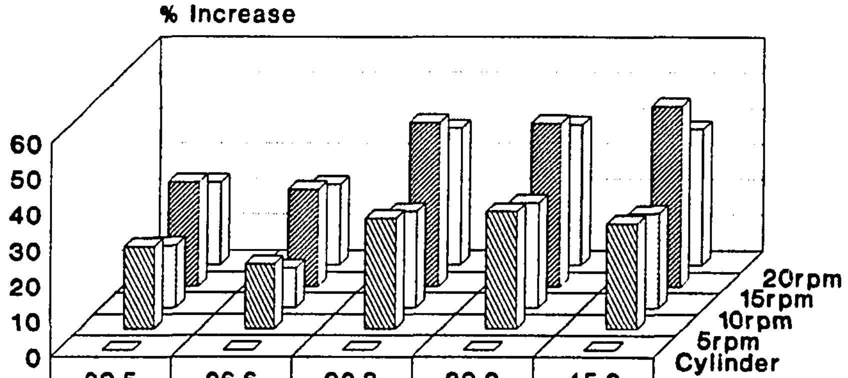
Figure 8.42 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 68.5 | 41.2 | 26.1 | 19.5 | 20.6 |
| 15rpm | 43.6 | 20.5 | 5.64 | 4.97 | 4.1 |
| 10rpm | 31.1 | 12.2 | 2.7 | 2.5 | 2.05 |
| 5rpm | 49.8 | 37 | 17.3 | 7.4 | 8.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

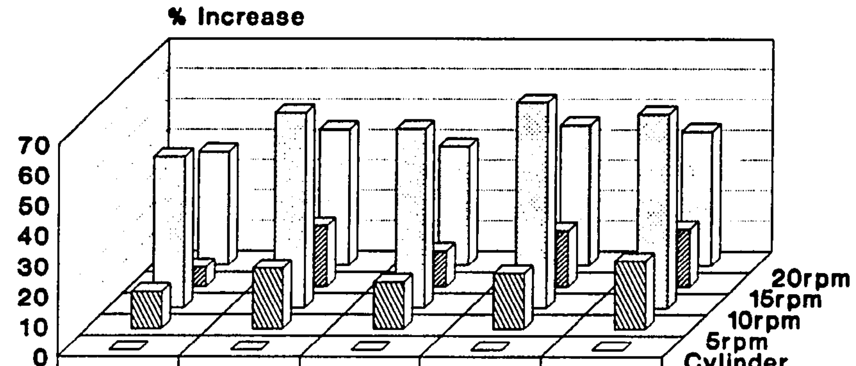
Figure 8.43 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 23.1 | 22.6 | 38.5 | 39.4 | 38.3 |
| 15rpm | 29.1 | 27.1 | 46 | 45.9 | 50.6 |
| 10rpm | 17.6 | 11.1 | 27 | 29.4 | 26.5 |
| 5rpm | 23.1 | 18.2 | 31 | 32.9 | 29.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

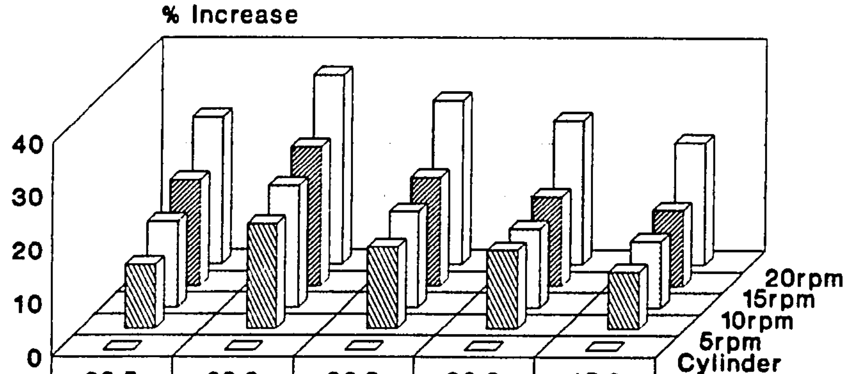
Figure 8.44 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 37.4 | 44.8 | 39.3 | 46.2 | 44.1 |
| 15rpm | 6.41 | 20 | 11.9 | 18.4 | 19.1 |
| 10rpm | 49.7 | 64.2 | 58.9 | 67.7 | 63.8 |
| 5rpm | 12.3 | 20 | 15.5 | 18.4 | 22.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

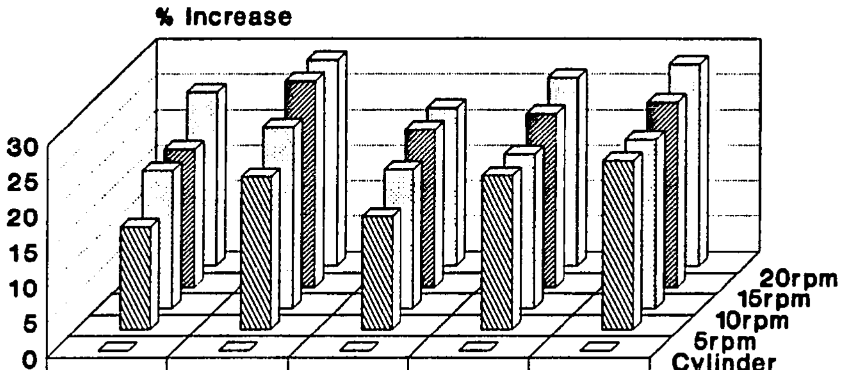
Figure 8.45 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 27.7 | 35.7 | 30.8 | 27.1 | 23 |
| 15rpm | 19.8 | 26 | 20.3 | 16.7 | 14.2 |
| 10rpm | 15.9 | 22.7 | 17.8 | 14.6 | 12.4 |
| 5rpm | 11.9 | 19.5 | 15.2 | 14.6 | 10.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

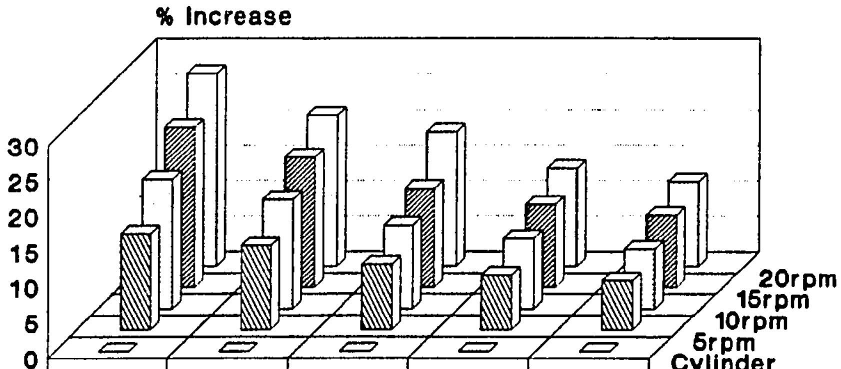
Figure 8.46 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 24.5 | 29.1 | 22.3 | 26.6 | 28.4 |
| 15rpm | 19.5 | 29.1 | 22.3 | 24.5 | 26.1 |
| 10rpm | 19.5 | 25.6 | 19.7 | 21.8 | 23.9 |
| 5rpm | 14.5 | 21.6 | 16 | 21.8 | 23.9 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

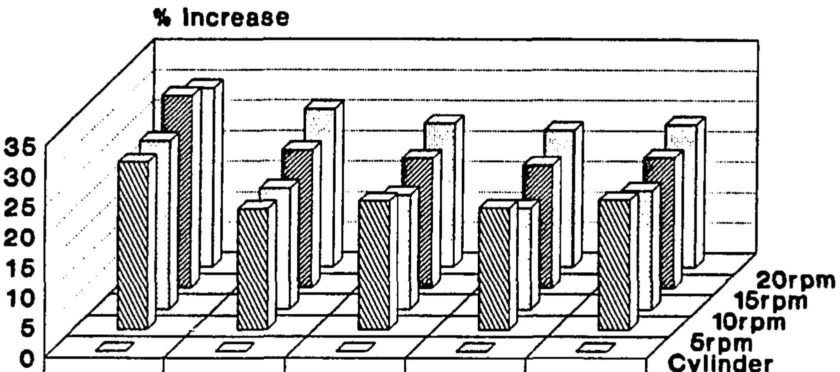
Figure 8.47 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PP.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 27.2 | 21.3 | 18.9 | 13.8 | 11.9 |
| 15rpm | 22.6 | 18.4 | 13.9 | 11.7 | 10.2 |
| 10rpm | 18.3 | 15.4 | 11.8 | 9.9 | 8.4 |
| 5rpm | 13.6 | 11.9 | 9.3 | 7.8 | 7 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

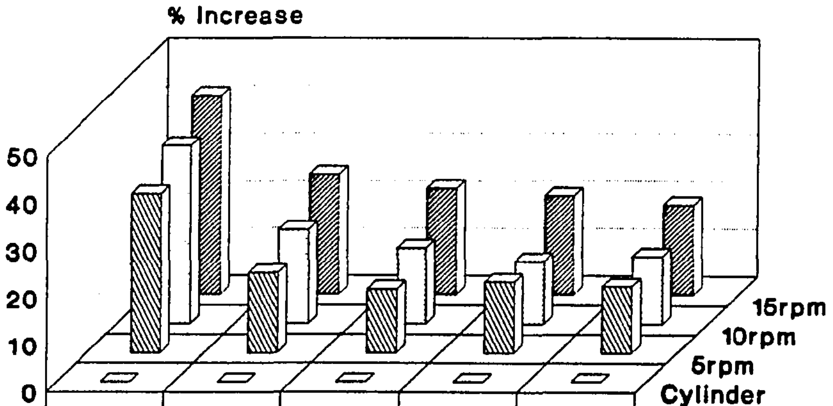
Figure 8.48 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PS.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 29.5 | 26 | 23.6 | 22.5 | 23.4 |
| 15rpm | 31.7 | 22.8 | 21.4 | 20.3 | 21.6 |
| 10rpm | 27.7 | 20 | 18.9 | 16.8 | 19.7 |
| 5rpm | 27.7 | 20 | 21.4 | 20.3 | 21.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

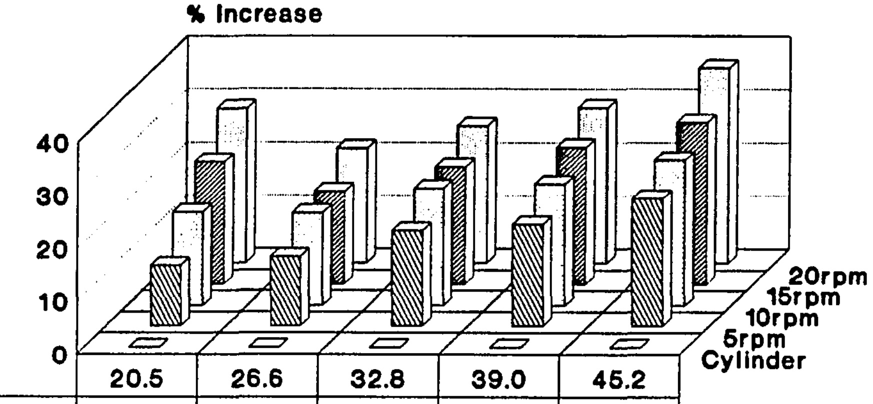
Figure 8.49 % Increase for Trilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PA 6.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 15rpm | 41.8 | 25.3 | 22.4 | 20.8 | 18.9 |
| 10rpm | 37.5 | 19.8 | 15.9 | 13.1 | 14.2 |
| 5rpm | 33.6 | 17 | 13.6 | 15.1 | 14.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

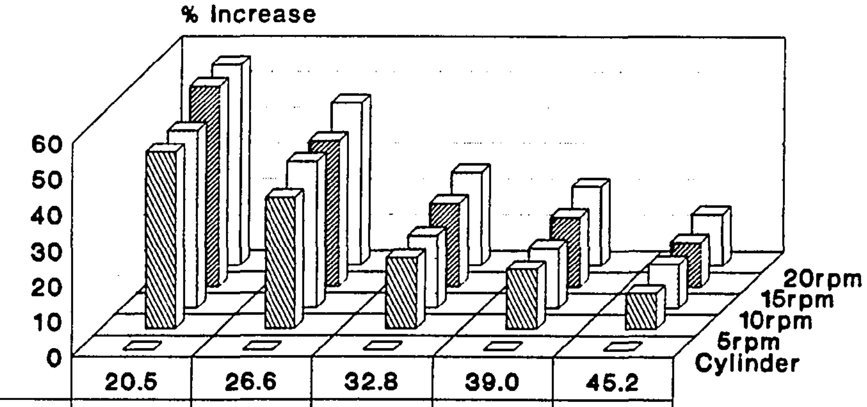
Figure 8.50 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM1.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 29.1 | 21.7 | 25.9 | 29.4 | 36.9 |
| 15rpm | 23.1 | 17.5 | 22.1 | 25.9 | 30.6 |
| 10rpm | 17.6 | 17.5 | 22.1 | 22.9 | 27.4 |
| 5rpm | 11.5 | 13.2 | 18.2 | 19.4 | 24.2 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

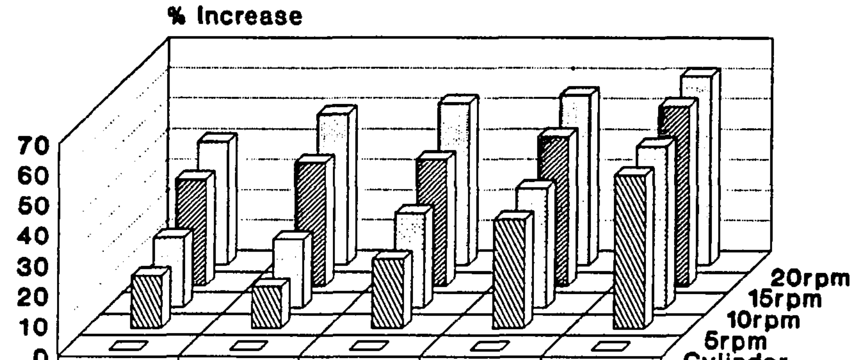
Figure 8.51 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM2.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 56.1 | 45.5 | 25.9 | 22.1 | 14.5 |
| 15rpm | 56.1 | 40.9 | 23.2 | 19.5 | 12.4 |
| 10rpm | 49.7 | 40.9 | 20.2 | 16.9 | 12.4 |
| 5rpm | 49.7 | 36.9 | 20.2 | 16.9 | 10.3 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

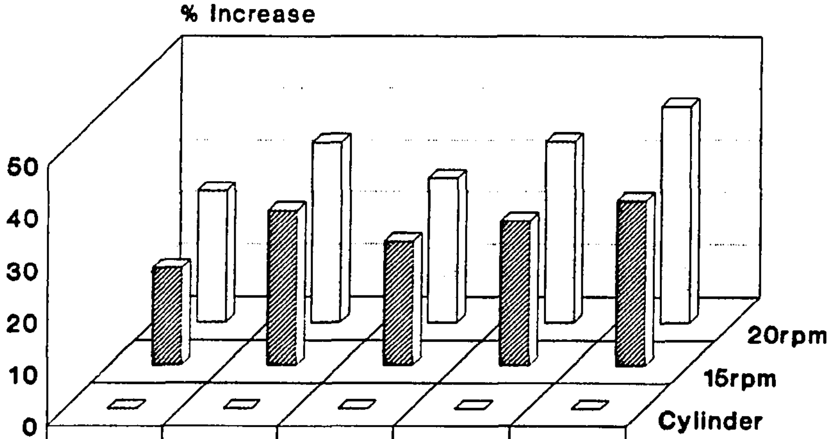
Figure 8.52 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM3.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 40.7 | 49.7 | 53.4 | 55.9 | 62.3 |
| 15rpm | 35.2 | 40.9 | 41.9 | 49.4 | 59.3 |
| 10rpm | 23.1 | 22.6 | 31 | 39.4 | 53.1 |
| 5rpm | 17.6 | 13.8 | 22.9 | 35.9 | 50.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

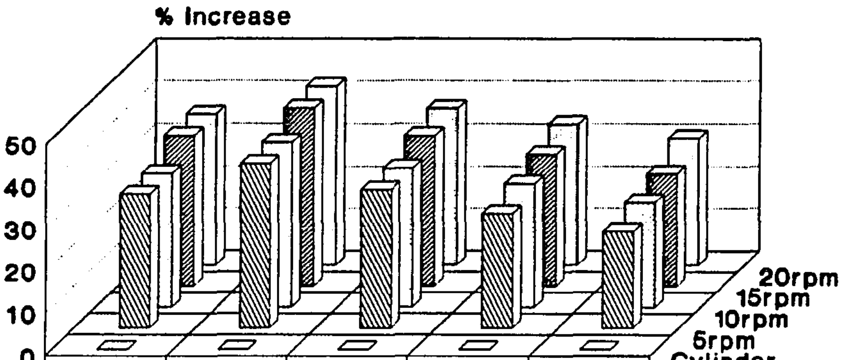
Figure 8.53 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM4.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 25.1 | 34.5 | 27.6 | 34.6 | 41.4 |
| 15rpm | 18.7 | 29.7 | 23.8 | 27.7 | 31.6 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

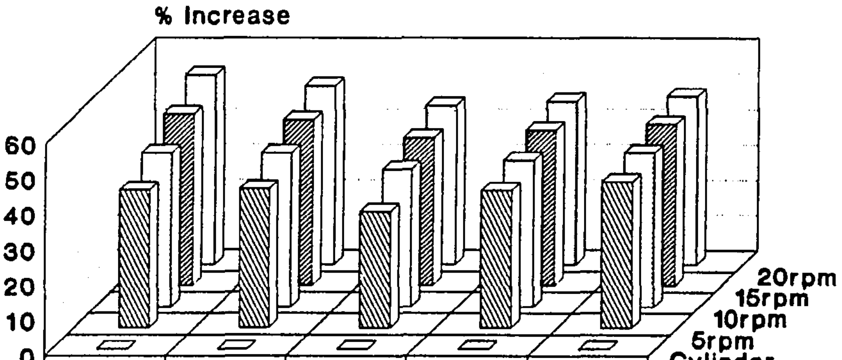
Figure 8.54 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for POM5.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 35.7 | 42.2 | 37.1 | 33.4 | 30.1 |
| 15rpm | 35.7 | 42.2 | 35.6 | 31.3 | 26.6 |
| 10rpm | 31.7 | 39 | 33 | 29.2 | 24.8 |
| 5rpm | 31.7 | 39 | 33 | 27.1 | 23 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

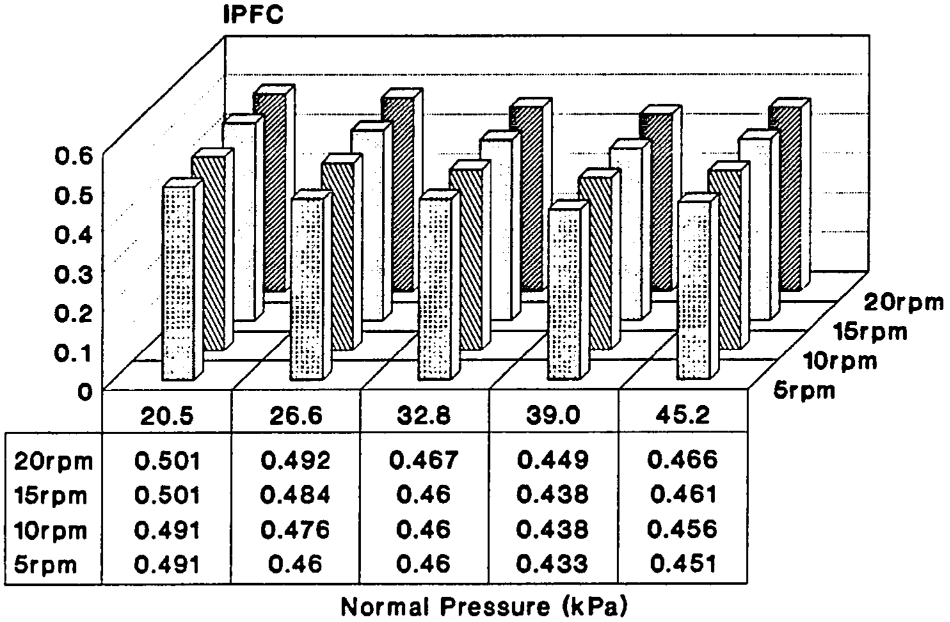
Figure 8.55 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PE.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 53.6 | 50.7 | 44.9 | 46.3 | 47.7 |
| 15rpm | 48.6 | 47.1 | 42 | 44.1 | 45.9 |
| 10rpm | 43.6 | 43.6 | 39.1 | 41.5 | 43.7 |
| 5rpm | 39.1 | 39.6 | 33.2 | 38.9 | 41.4 |
| Cylinder | 0 | 0 | 0 | 0 | 0 |

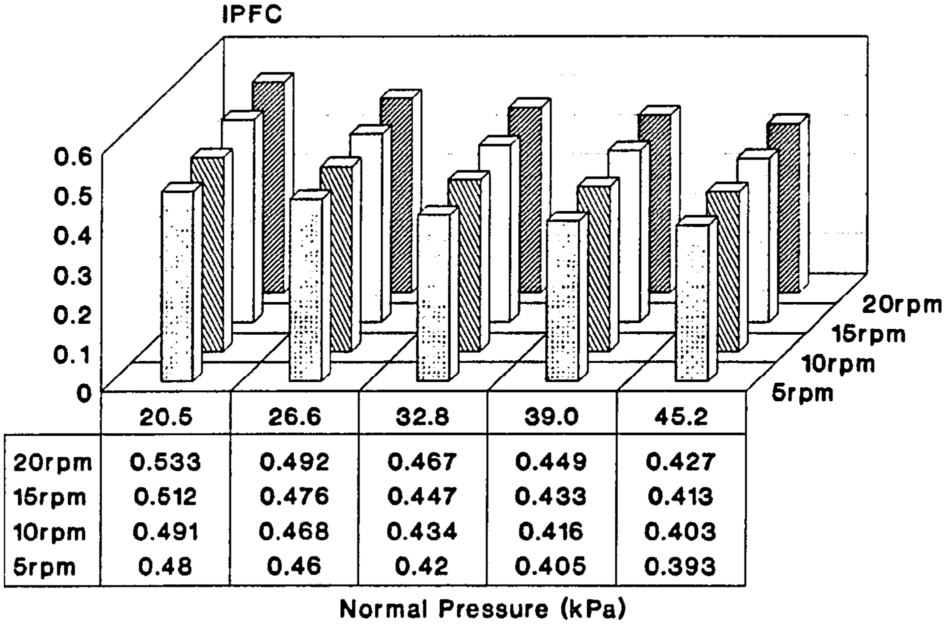
Normal Pressure (kPa)

Figure 8.56 % Increase for Quadrilobal Pellets Compared to Circular Pellets at Four Different Extruder Screw Speed for PP.



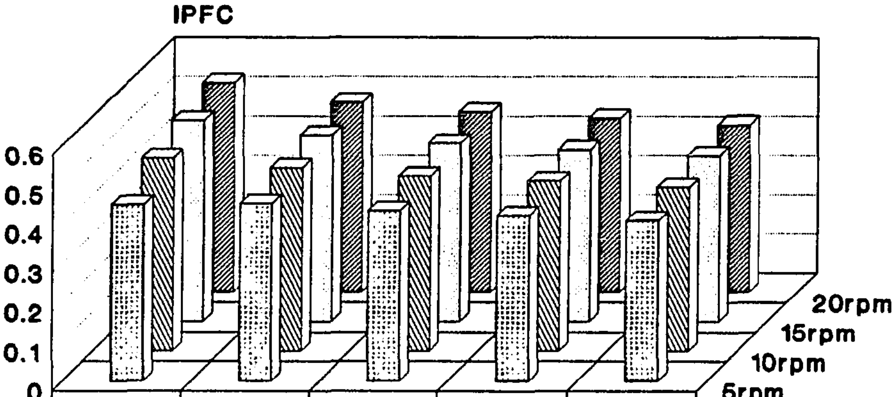
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.501 | 0.492 | 0.467 | 0.449 | 0.466 |
| 15rpm | 0.501 | 0.484 | 0.46 | 0.438 | 0.461 |
| 10rpm | 0.491 | 0.476 | 0.46 | 0.438 | 0.456 |
| 5rpm | 0.491 | 0.46 | 0.46 | 0.433 | 0.451 |

Figure 8.57 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.533 | 0.492 | 0.467 | 0.449 | 0.427 |
| 15rpm | 0.512 | 0.476 | 0.447 | 0.433 | 0.413 |
| 10rpm | 0.491 | 0.468 | 0.434 | 0.416 | 0.403 |
| 5rpm | 0.48 | 0.46 | 0.42 | 0.405 | 0.393 |

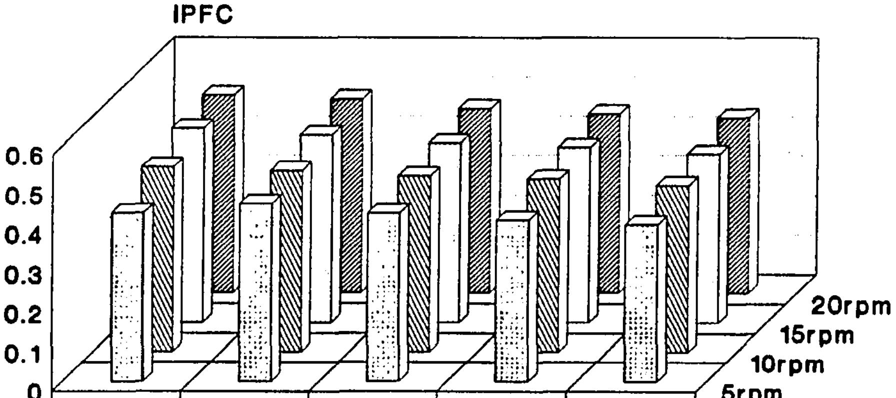
Figure 8.58 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM2 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.533 | 0.484 | 0.46 | 0.444 | 0.427 |
| 15rpm | 0.512 | 0.476 | 0.454 | 0.438 | 0.422 |
| 10rpm | 0.491 | 0.468 | 0.447 | 0.433 | 0.417 |
| 5rpm | 0.448 | 0.451 | 0.434 | 0.421 | 0.408 |

Normal Pressure (kPa)

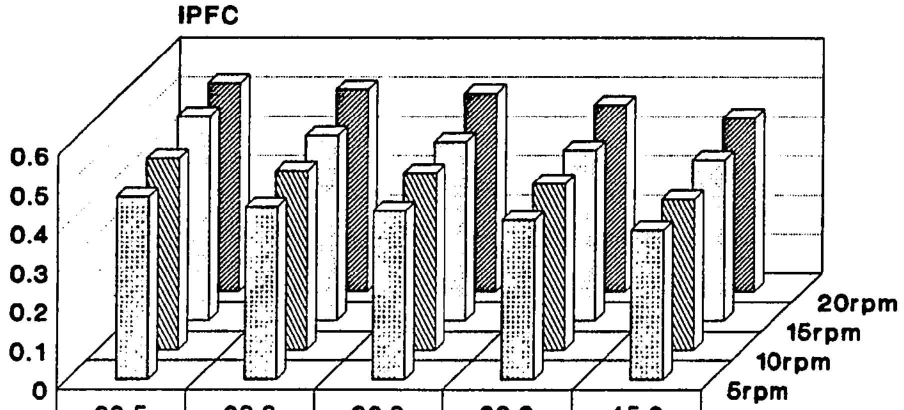
Figure 8.59 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM3 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.501 | 0.492 | 0.467 | 0.455 | 0.446 |
| 15rpm | 0.491 | 0.476 | 0.454 | 0.444 | 0.427 |
| 10rpm | 0.469 | 0.46 | 0.447 | 0.438 | 0.422 |
| 5rpm | 0.427 | 0.451 | 0.427 | 0.41 | 0.398 |

Normal Pressure (kPa)

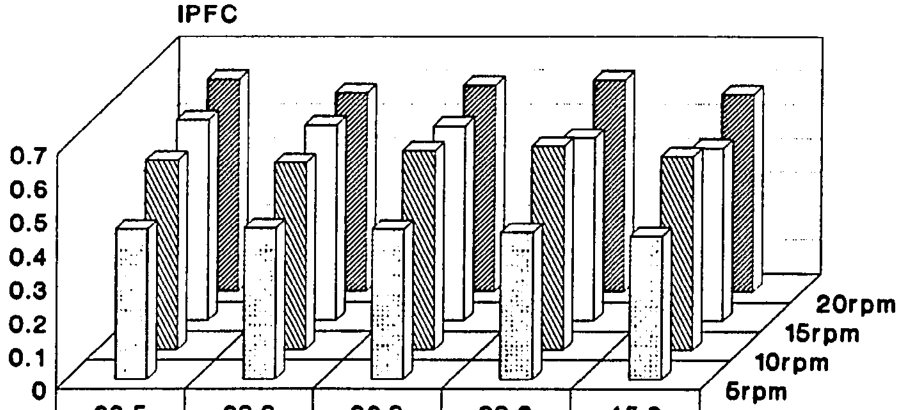
Figure 8.60 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM4 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.533 | 0.517 | 0.507 | 0.477 | 0.446 |
| 15rpm | 0.523 | 0.476 | 0.46 | 0.438 | 0.413 |
| 10rpm | 0.491 | 0.46 | 0.454 | 0.427 | 0.388 |
| 5rpm | 0.469 | 0.443 | 0.434 | 0.41 | 0.384 |

Normal Pressure (kPa)

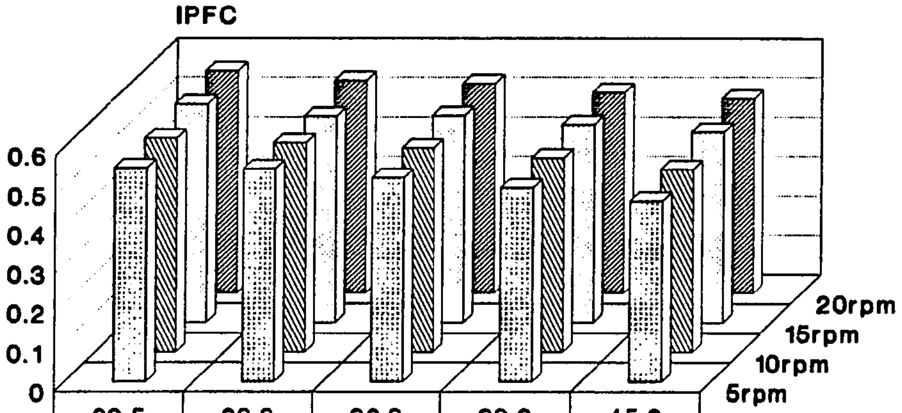
Figure 8.61 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for POM5 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.629 | 0.591 | 0.613 | 0.628 | 0.586 |
| 15rpm | 0.597 | 0.583 | 0.58 | 0.544 | 0.514 |
| 10rpm | 0.565 | 0.558 | 0.593 | 0.606 | 0.577 |
| 5rpm | 0.448 | 0.452 | 0.447 | 0.438 | 0.427 |

Normal Pressure (kPa)

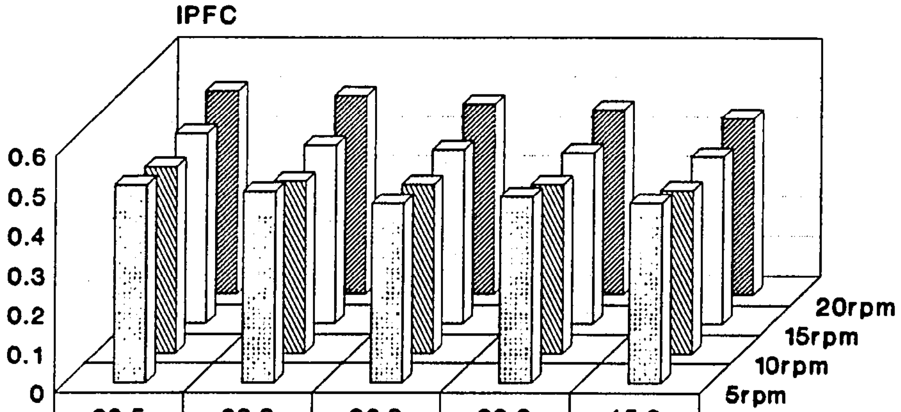
Figure 8.62 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM1 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.565 | 0.542 | 0.533 | 0.511 | 0.495 |
| 15rpm | 0.555 | 0.525 | 0.527 | 0.505 | 0.485 |
| 10rpm | 0.544 | 0.533 | 0.52 | 0.494 | 0.466 |
| 5rpm | 0.544 | 0.542 | 0.52 | 0.494 | 0.461 |

Normal Pressure (kPa)

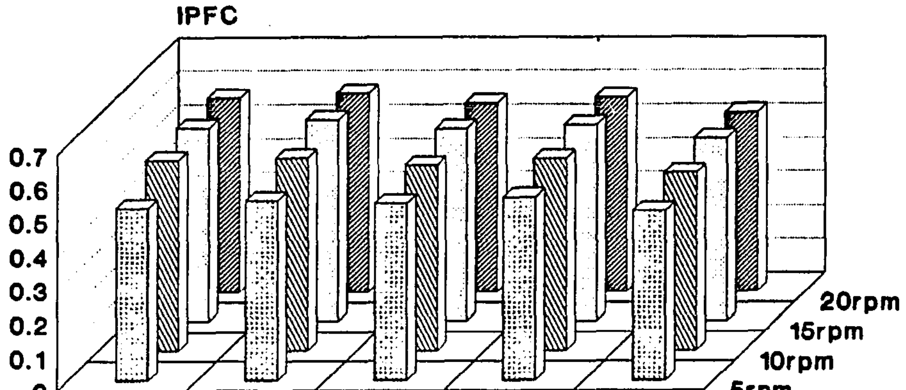
Figure 8.63 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM2 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.512 | 0.501 | 0.48 | 0.466 | 0.446 |
| 15rpm | 0.48 | 0.452 | 0.44 | 0.433 | 0.422 |
| 10rpm | 0.47 | 0.435 | 0.427 | 0.427 | 0.413 |
| 5rpm | 0.501 | 0.484 | 0.454 | 0.472 | 0.456 |

Normal Pressure (kPa)

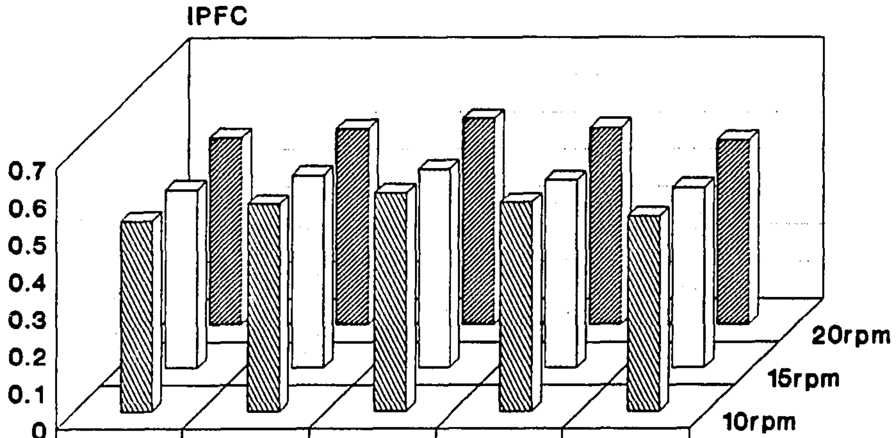
Figure 8.64 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM3 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.576 | 0.591 | 0.56 | 0.578 | 0.533 |
| 15rpm | 0.576 | 0.599 | 0.573 | 0.584 | 0.543 |
| 10rpm | 0.565 | 0.574 | 0.553 | 0.572 | 0.528 |
| 5rpm | 0.512 | 0.533 | 0.527 | 0.544 | 0.504 |

Normal Pressure (kPa)

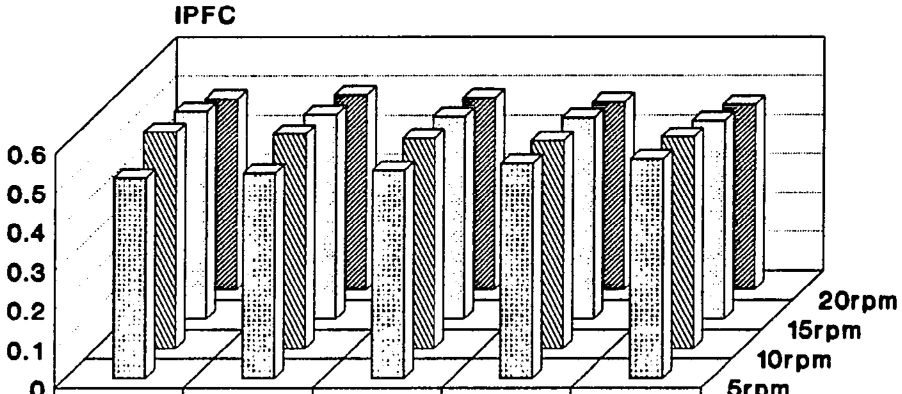
Figure 8.65 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM4 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.501 | 0.525 | 0.553 | 0.528 | 0.495 |
| 15rpm | 0.48 | 0.517 | 0.533 | 0.505 | 0.485 |
| 10rpm | 0.512 | 0.558 | 0.587 | 0.561 | 0.524 |

Normal Pressure (kPa)

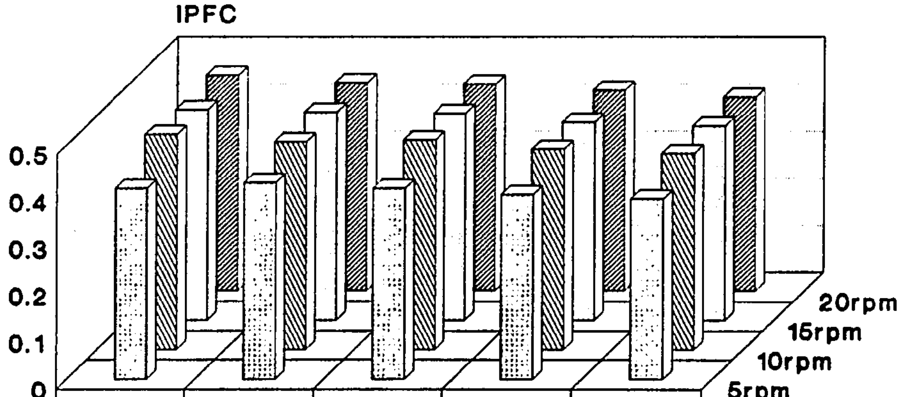
Figure 8.66 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for POM5 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.491 | 0.501 | 0.493 | 0.483 | 0.475 |
| 15rpm | 0.533 | 0.525 | 0.52 | 0.517 | 0.509 |
| 10rpm | 0.555 | 0.55 | 0.54 | 0.533 | 0.543 |
| 5rpm | 0.512 | 0.525 | 0.533 | 0.55 | 0.562 |

Normal Pressure (kPa)

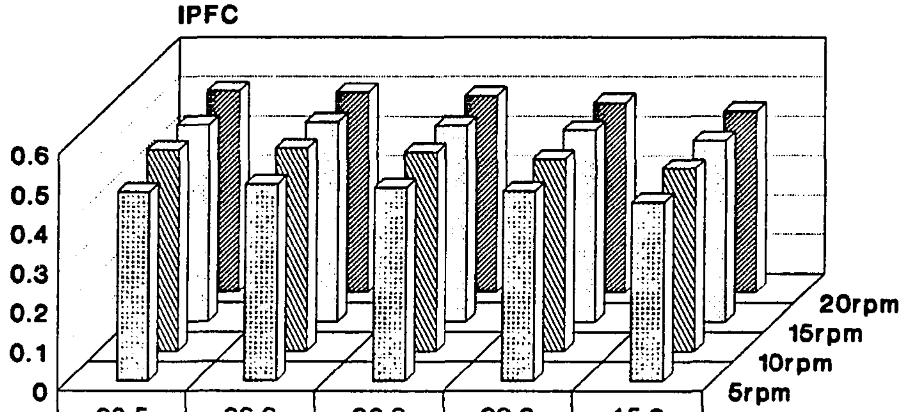
Figure 8.67 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.459 | 0.443 | 0.44 | 0.427 | 0.413 |
| 15rpm | 0.448 | 0.443 | 0.44 | 0.421 | 0.413 |
| 10rpm | 0.459 | 0.443 | 0.447 | 0.427 | 0.417 |
| 5rpm | 0.406 | 0.419 | 0.407 | 0.393 | 0.384 |

Normal Pressure (kPa)

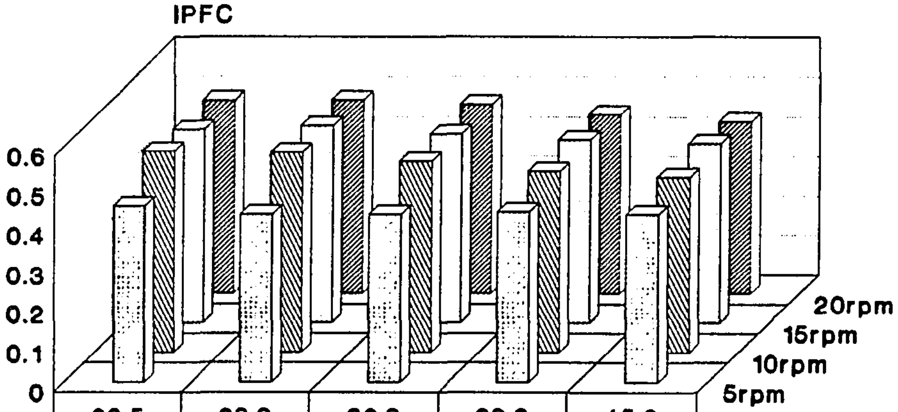
Figure 8.68 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM2 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.512 | 0.509 | 0.5 | 0.483 | 0.461 |
| 15rpm | 0.501 | 0.509 | 0.5 | 0.489 | 0.461 |
| 10rpm | 0.512 | 0.517 | 0.507 | 0.489 | 0.466 |
| 5rpm | 0.48 | 0.501 | 0.493 | 0.483 | 0.456 |

Normal Pressure (kPa)

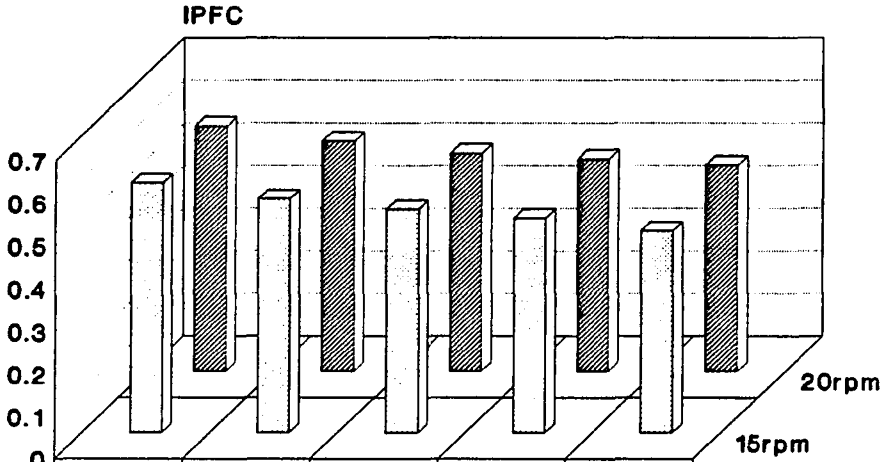
Figure 8.69 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM3 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.491 | 0.492 | 0.48 | 0.455 | 0.437 |
| 15rpm | 0.491 | 0.501 | 0.48 | 0.466 | 0.456 |
| 10rpm | 0.512 | 0.509 | 0.487 | 0.461 | 0.446 |
| 5rpm | 0.448 | 0.427 | 0.427 | 0.433 | 0.427 |

Normal Pressure (kPa)

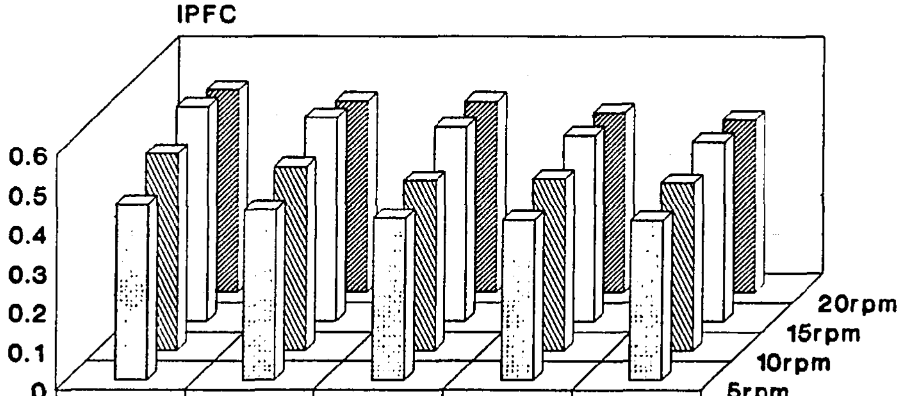
Figure 8.70 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM4 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.576 | 0.542 | 0.513 | 0.5 | 0.485 |
| 15rpm | 0.587 | 0.55 | 0.527 | 0.505 | 0.475 |

Normal Pressure (kPa)

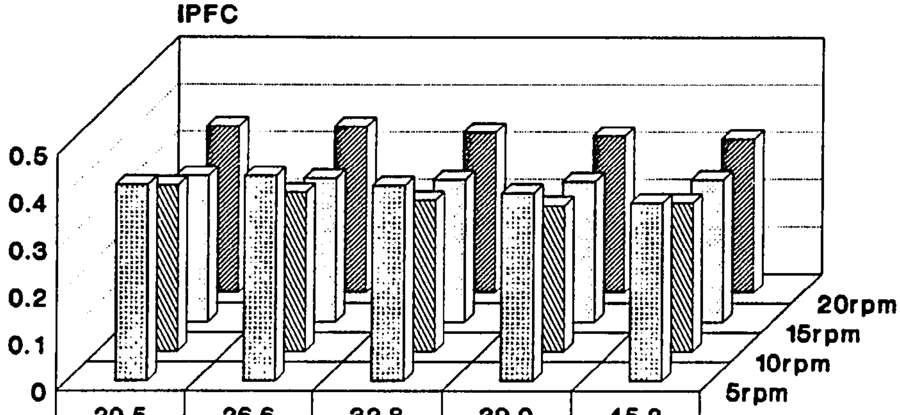
Figure 8.71 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for POM5 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.512 | 0.484 | 0.483 | 0.455 | 0.437 |
| 15rpm | 0.544 | 0.517 | 0.493 | 0.472 | 0.456 |
| 10rpm | 0.501 | 0.468 | 0.434 | 0.438 | 0.427 |
| 5rpm | 0.448 | 0.435 | 0.414 | 0.41 | 0.408 |

Normal Pressure (kPa)

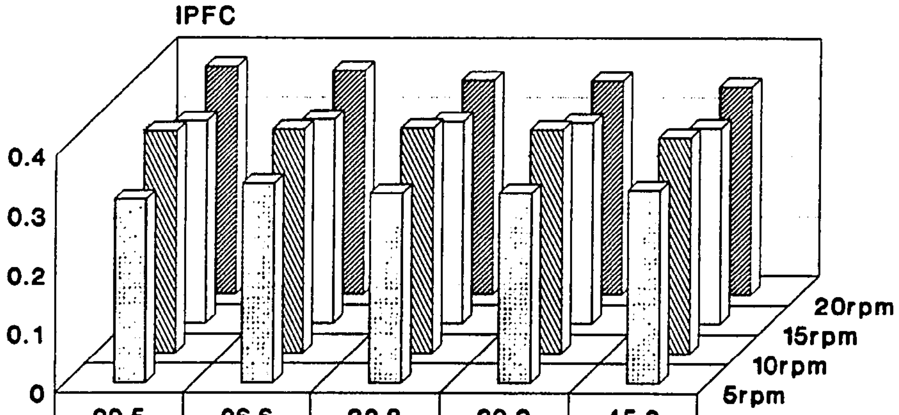
Figure 8.72 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.352 | 0.353 | 0.341 | 0.332 | 0.326 |
| 15rpm | 0.31 | 0.304 | 0.301 | 0.298 | 0.302 |
| 10rpm | 0.352 | 0.337 | 0.321 | 0.31 | 0.316 |
| 5rpm | 0.416 | 0.435 | 0.414 | 0.399 | 0.379 |

Normal Pressure (kPa)

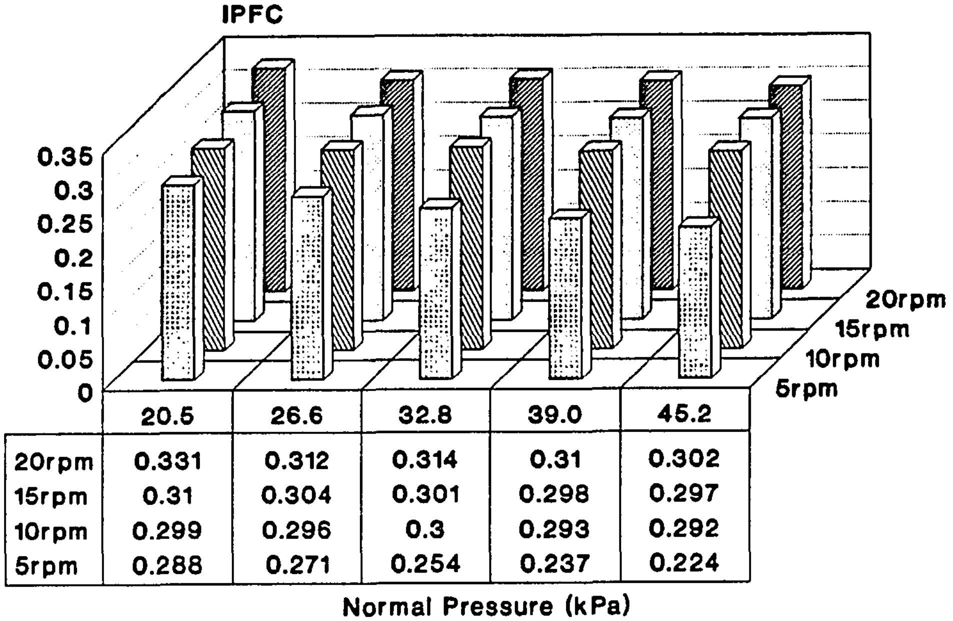
Figure 8.73 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM2 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.378 | 0.361 | 0.36 | 0.35 |
| 15rpm | 0.342 | 0.345 | 0.341 | 0.338 | 0.33 |
| 10rpm | 0.374 | 0.378 | 0.38 | 0.377 | 0.364 |
| 5rpm | 0.31 | 0.337 | 0.321 | 0.321 | 0.326 |

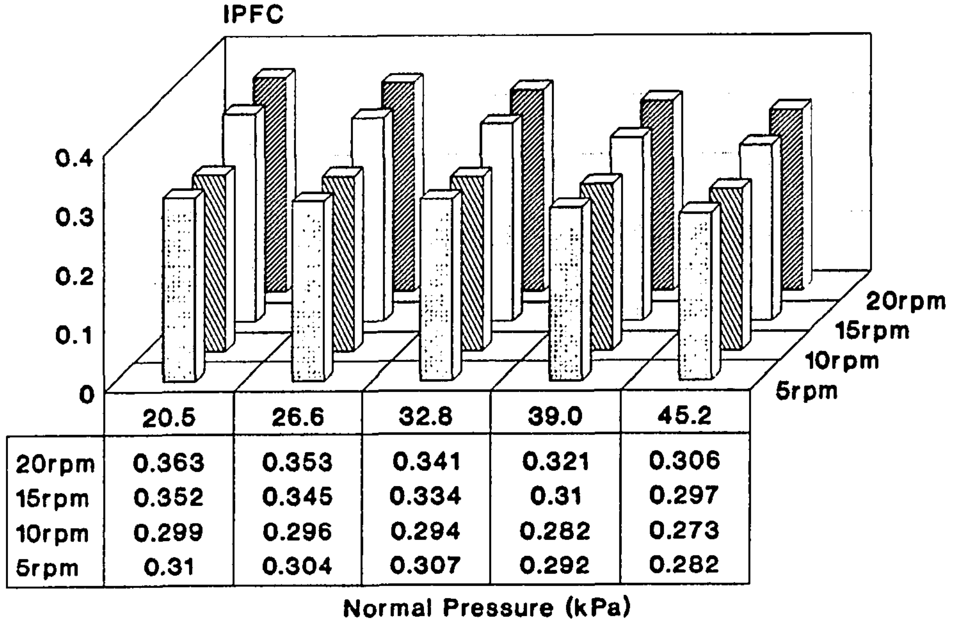
Normal Pressure (kPa)

Figure 8.74 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM3 with Agitation.



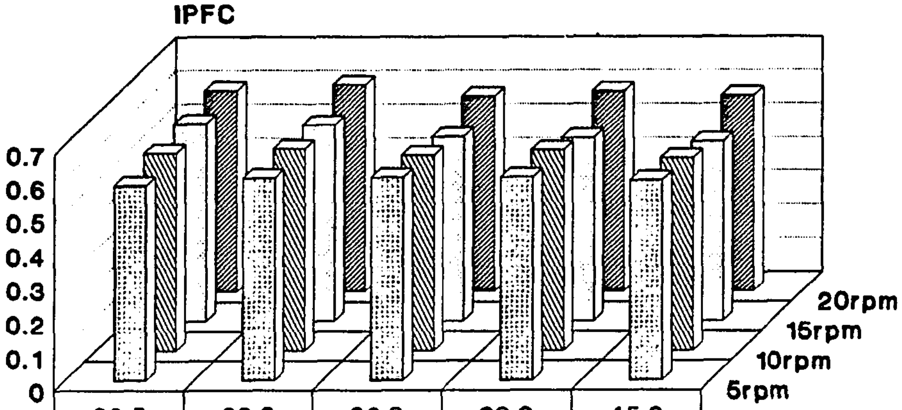
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.331 | 0.312 | 0.314 | 0.31 | 0.302 |
| 15rpm | 0.31 | 0.304 | 0.301 | 0.298 | 0.297 |
| 10rpm | 0.299 | 0.296 | 0.3 | 0.293 | 0.292 |
| 5rpm | 0.288 | 0.271 | 0.254 | 0.237 | 0.224 |

Figure 8.75 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM4 with Agitation.



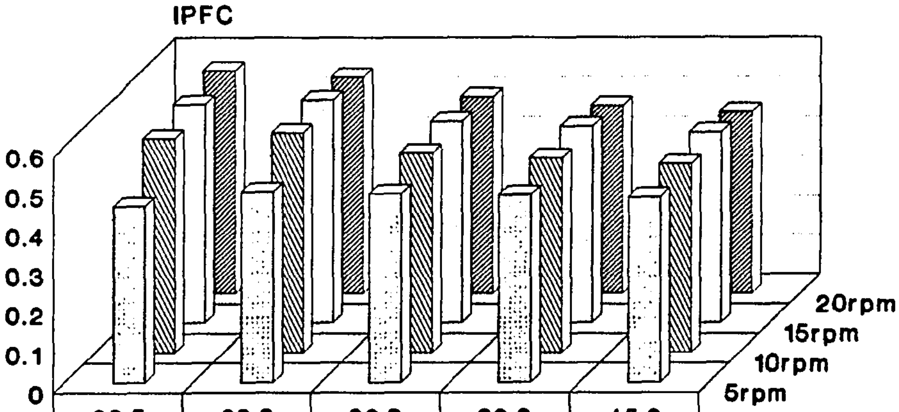
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.363 | 0.353 | 0.341 | 0.321 | 0.306 |
| 15rpm | 0.352 | 0.345 | 0.334 | 0.31 | 0.297 |
| 10rpm | 0.299 | 0.296 | 0.294 | 0.282 | 0.273 |
| 5rpm | 0.31 | 0.304 | 0.307 | 0.292 | 0.282 |

Figure 8.76 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for POM5 with Agitation.



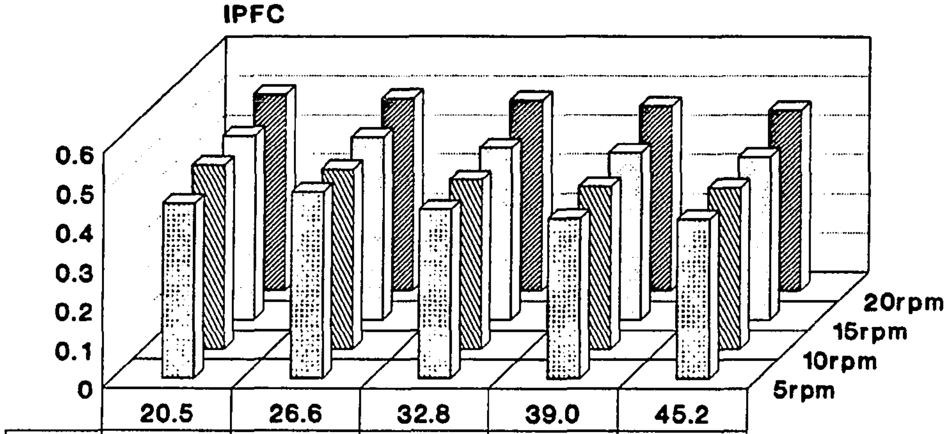
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.597 | 0.615 | 0.58 | 0.595 | 0.582 |
| 15rpm | 0.587 | 0.583 | 0.547 | 0.544 | 0.533 |
| 10rpm | 0.587 | 0.599 | 0.58 | 0.595 | 0.572 |
| 5rpm | 0.576 | 0.599 | 0.6 | 0.6 | 0.591 |

Figure 8.77 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.565 | 0.55 | 0.5 | 0.477 | 0.461 |
| 15rpm | 0.555 | 0.566 | 0.513 | 0.5 | 0.485 |
| 10rpm | 0.544 | 0.558 | 0.507 | 0.494 | 0.48 |
| 5rpm | 0.448 | 0.484 | 0.48 | 0.477 | 0.471 |

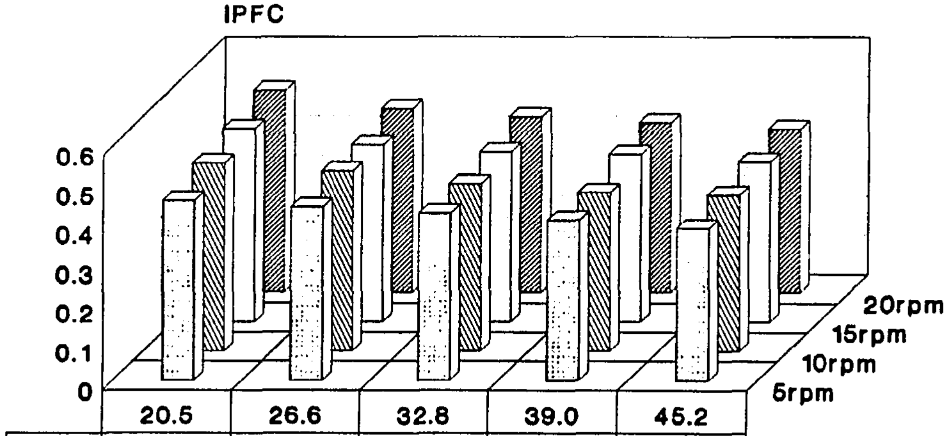
Figure 8.78 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM2 with Agitation..



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.501 | 0.492 | 0.487 | 0.472 | 0.461 |
| 15rpm | 0.47 | 0.468 | 0.44 | 0.427 | 0.417 |
| 10rpm | 0.47 | 0.46 | 0.434 | 0.416 | 0.413 |
| 5rpm | 0.448 | 0.476 | 0.434 | 0.41 | 0.408 |

Normal Pressure (kPa)

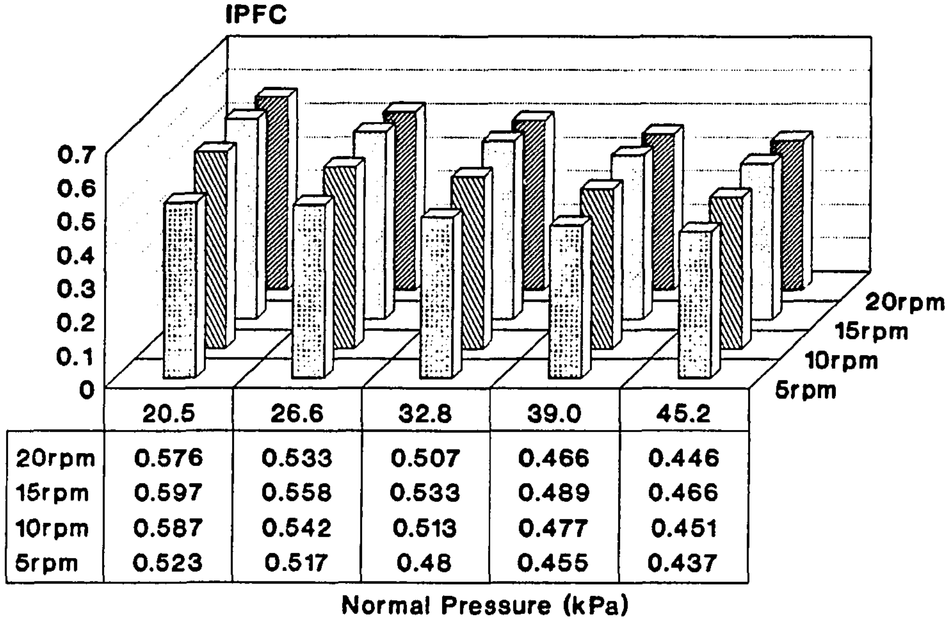
Figure 8.79 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM3 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.512 | 0.468 | 0.447 | 0.433 | 0.417 |
| 15rpm | 0.491 | 0.452 | 0.434 | 0.427 | 0.408 |
| 10rpm | 0.48 | 0.46 | 0.427 | 0.405 | 0.398 |
| 5rpm | 0.459 | 0.443 | 0.427 | 0.41 | 0.388 |

Normal Pressure (kPa)

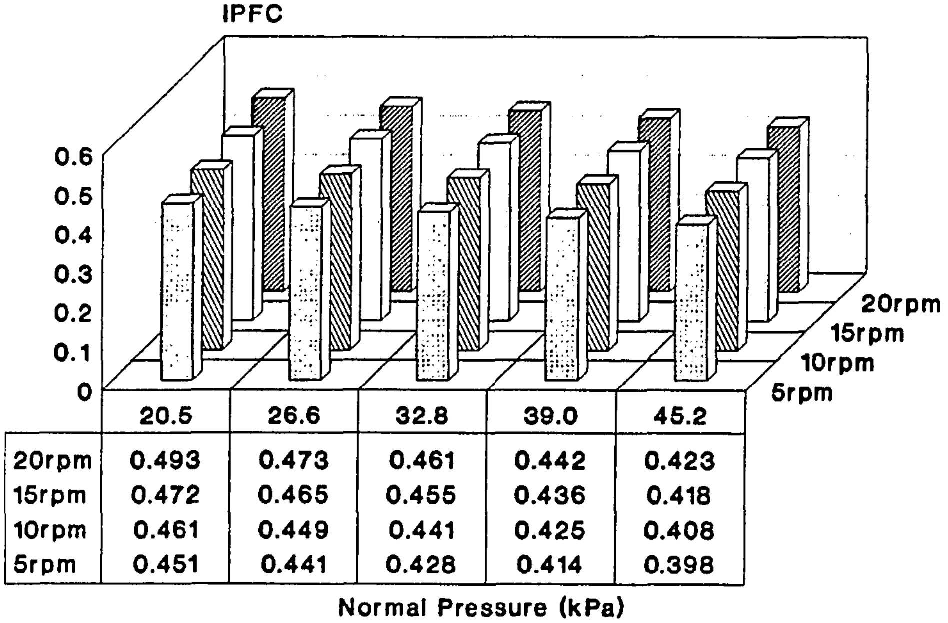
Figure 8.80 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM4 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.576 | 0.533 | 0.507 | 0.466 | 0.446 |
| 15rpm | 0.597 | 0.558 | 0.533 | 0.489 | 0.466 |
| 10rpm | 0.587 | 0.542 | 0.513 | 0.477 | 0.451 |
| 5rpm | 0.523 | 0.517 | 0.48 | 0.455 | 0.437 |

Normal Pressure (kPa)

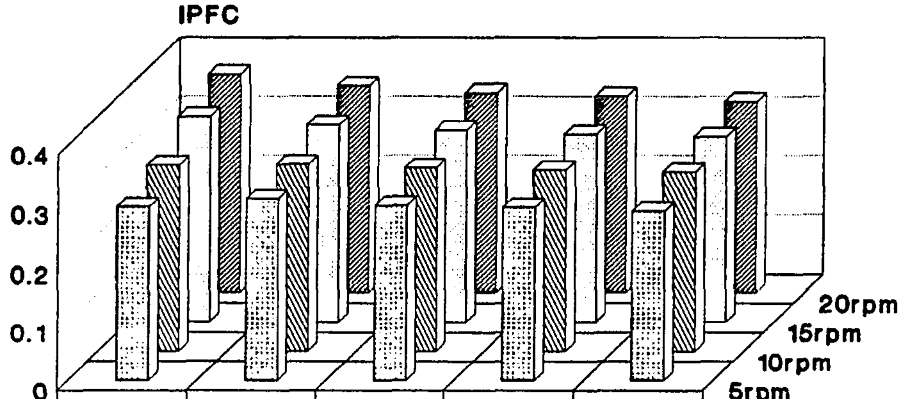
Figure 8.81 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for POM5 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.493 | 0.473 | 0.461 | 0.442 | 0.423 |
| 15rpm | 0.472 | 0.465 | 0.455 | 0.436 | 0.418 |
| 10rpm | 0.461 | 0.449 | 0.441 | 0.425 | 0.408 |
| 5rpm | 0.451 | 0.441 | 0.428 | 0.414 | 0.398 |

Normal Pressure (kPa)

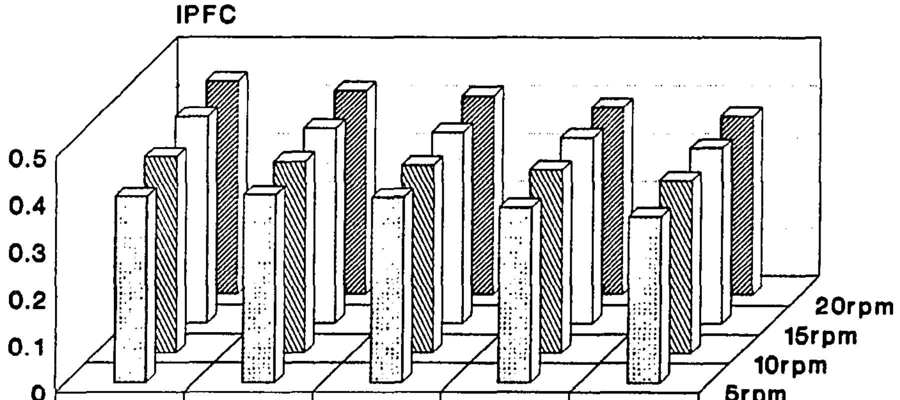
Figure 8.82 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PE with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.37 | 0.35 | 0.338 | 0.332 | 0.324 |
| 15rpm | 0.348 | 0.334 | 0.325 | 0.318 | 0.314 |
| 10rpm | 0.316 | 0.317 | 0.311 | 0.307 | 0.304 |
| 5rpm | 0.295 | 0.309 | 0.298 | 0.294 | 0.288 |

Normal Pressure (kPa)

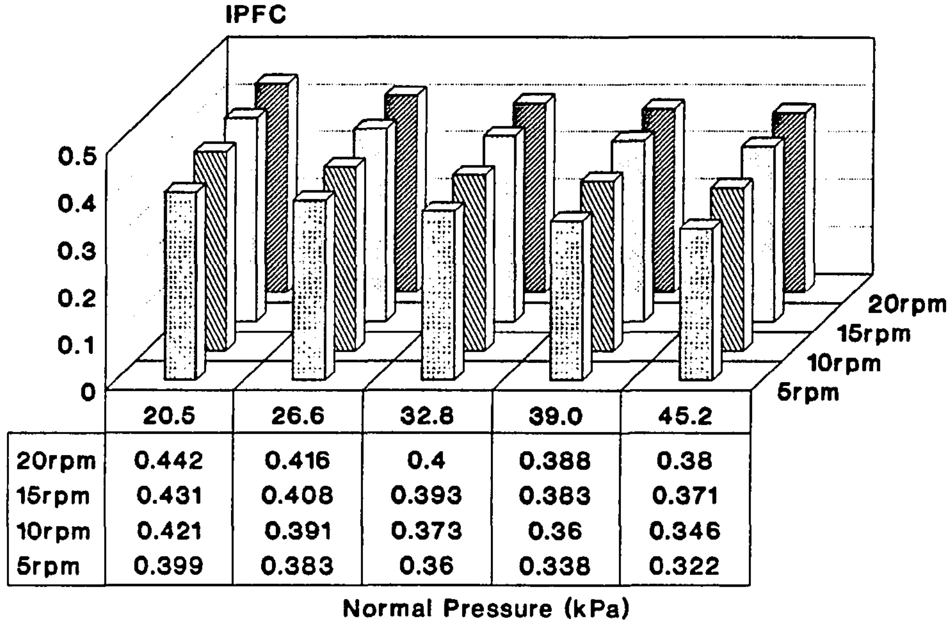
Figure 8.83 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PP with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.448 | 0.43 | 0.419 | 0.395 | 0.377 |
| 15rpm | 0.438 | 0.414 | 0.406 | 0.395 | 0.372 |
| 10rpm | 0.416 | 0.406 | 0.399 | 0.389 | 0.367 |
| 5rpm | 0.395 | 0.398 | 0.393 | 0.372 | 0.353 |

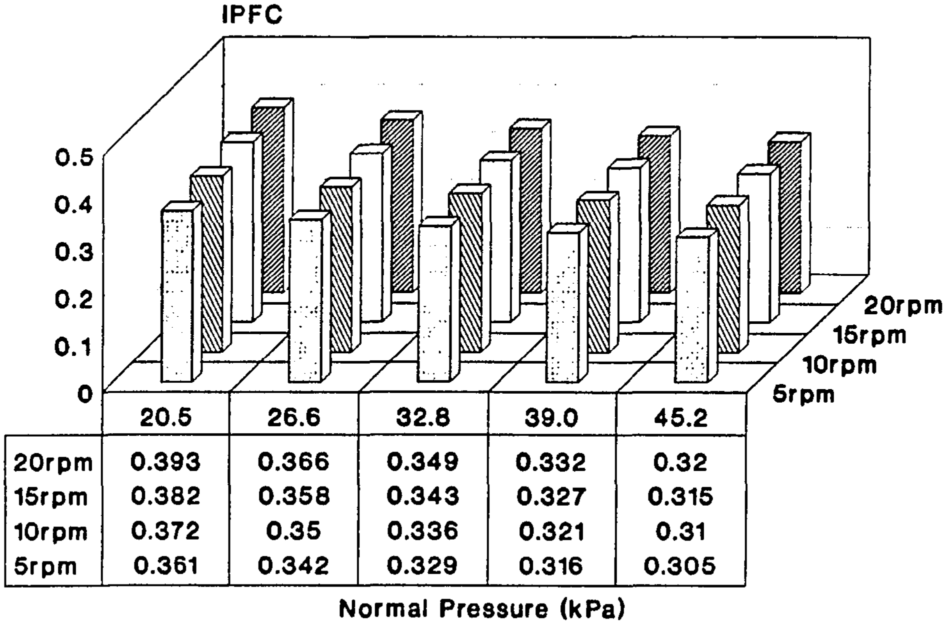
Normal Pressure (kPa)

Figure 8.84 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PS with Agitation.



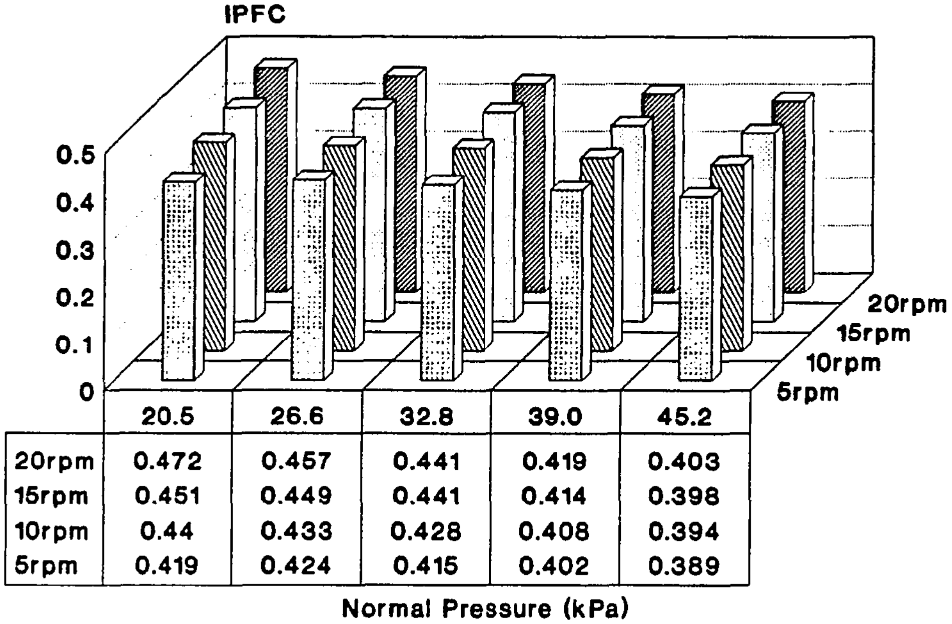
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.442 | 0.416 | 0.4 | 0.388 | 0.38 |
| 15rpm | 0.431 | 0.408 | 0.393 | 0.383 | 0.371 |
| 10rpm | 0.421 | 0.391 | 0.373 | 0.36 | 0.346 |
| 5rpm | 0.399 | 0.383 | 0.36 | 0.338 | 0.322 |

Figure 8.85 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for PA 6 with Agitation.



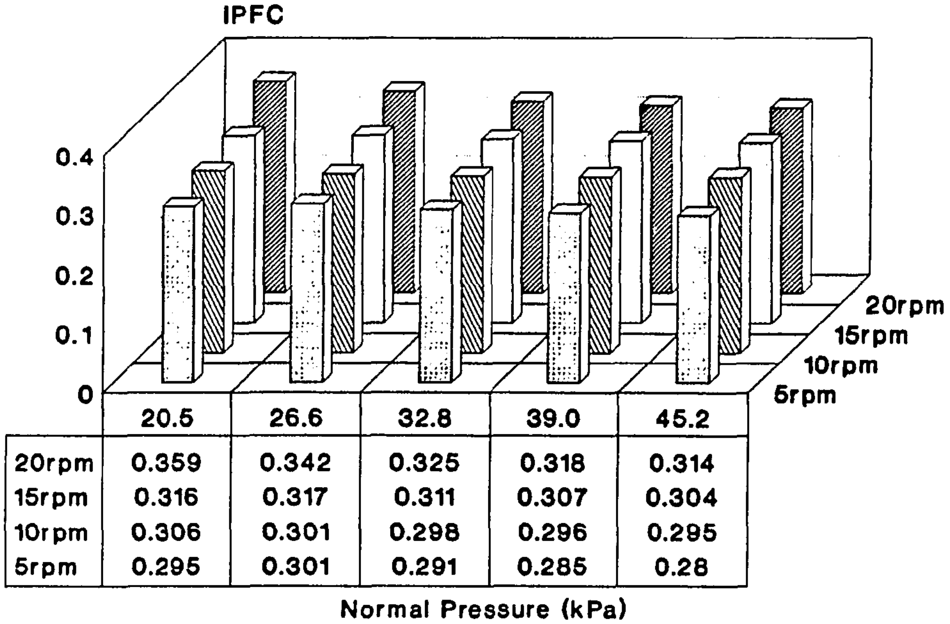
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.393 | 0.366 | 0.349 | 0.332 | 0.32 |
| 15rpm | 0.382 | 0.358 | 0.343 | 0.327 | 0.315 |
| 10rpm | 0.372 | 0.35 | 0.336 | 0.321 | 0.31 |
| 5rpm | 0.361 | 0.342 | 0.329 | 0.316 | 0.305 |

Figure 8.86 IPFC for Pellets Manufactured Using Die A211 as a Function of Normal Pressure for ABS with Agitation.



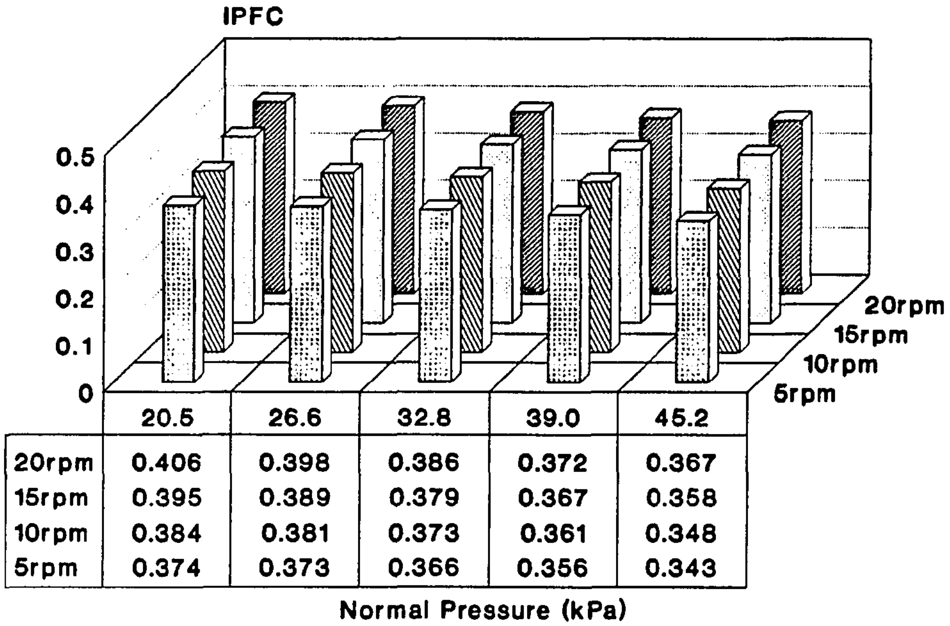
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.472 | 0.457 | 0.441 | 0.419 | 0.403 |
| 15rpm | 0.451 | 0.449 | 0.441 | 0.414 | 0.398 |
| 10rpm | 0.44 | 0.433 | 0.428 | 0.408 | 0.394 |
| 5rpm | 0.419 | 0.424 | 0.415 | 0.402 | 0.389 |

Figure 8.87 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PE with Agitation.



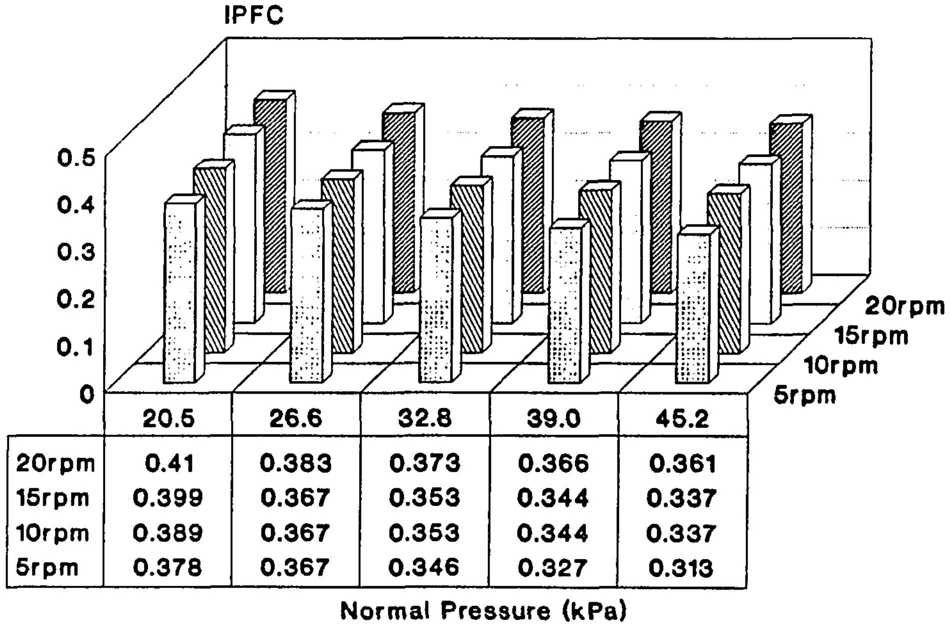
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.359 | 0.342 | 0.325 | 0.318 | 0.314 |
| 15rpm | 0.316 | 0.317 | 0.311 | 0.307 | 0.304 |
| 10rpm | 0.306 | 0.301 | 0.298 | 0.296 | 0.295 |
| 5rpm | 0.295 | 0.301 | 0.291 | 0.285 | 0.28 |

Figure 8.88 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PP with Agitation.



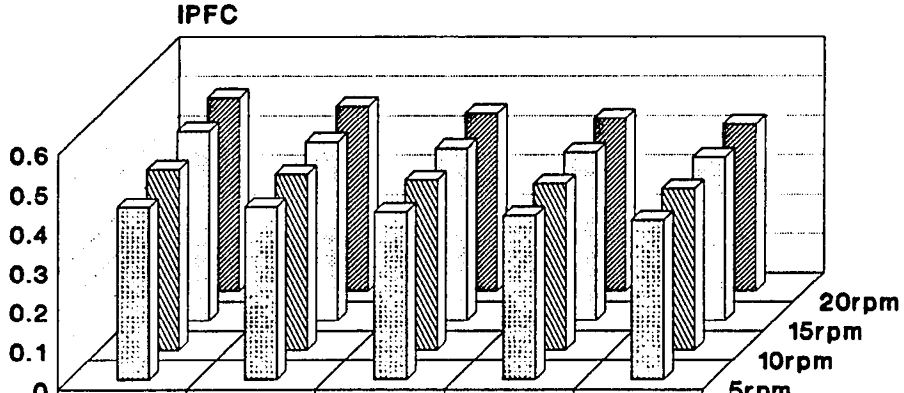
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.406 | 0.398 | 0.386 | 0.372 | 0.367 |
| 15rpm | 0.395 | 0.389 | 0.379 | 0.367 | 0.358 |
| 10rpm | 0.384 | 0.381 | 0.373 | 0.361 | 0.348 |
| 5rpm | 0.374 | 0.373 | 0.366 | 0.356 | 0.343 |

Figure 8.89 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.41 | 0.383 | 0.373 | 0.366 | 0.361 |
| 15rpm | 0.399 | 0.367 | 0.353 | 0.344 | 0.337 |
| 10rpm | 0.389 | 0.367 | 0.353 | 0.344 | 0.337 |
| 5rpm | 0.378 | 0.367 | 0.346 | 0.327 | 0.313 |

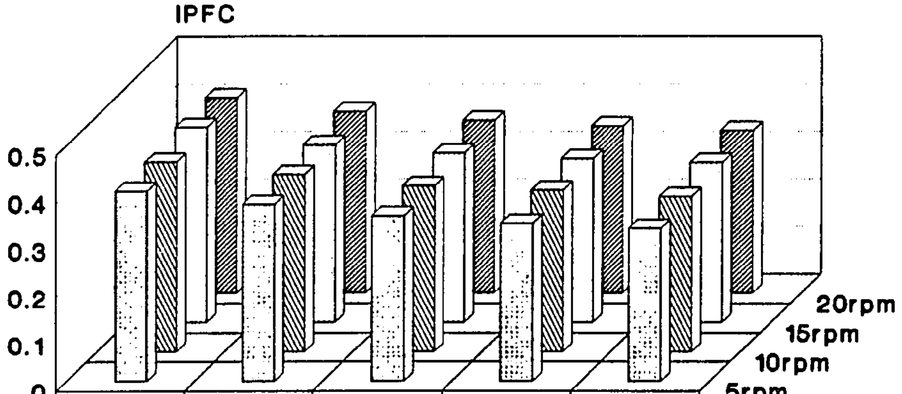
Figure 8.90 IPFC for Pellets Manufactured Using Die A212 as a Function of Normal Pressure for PA 6 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.493 | 0.473 | 0.455 | 0.442 | 0.427 |
| 15rpm | 0.483 | 0.457 | 0.441 | 0.43 | 0.418 |
| 10rpm | 0.461 | 0.449 | 0.435 | 0.425 | 0.413 |
| 5rpm | 0.44 | 0.441 | 0.428 | 0.419 | 0.408 |

Normal Pressure (kPa)

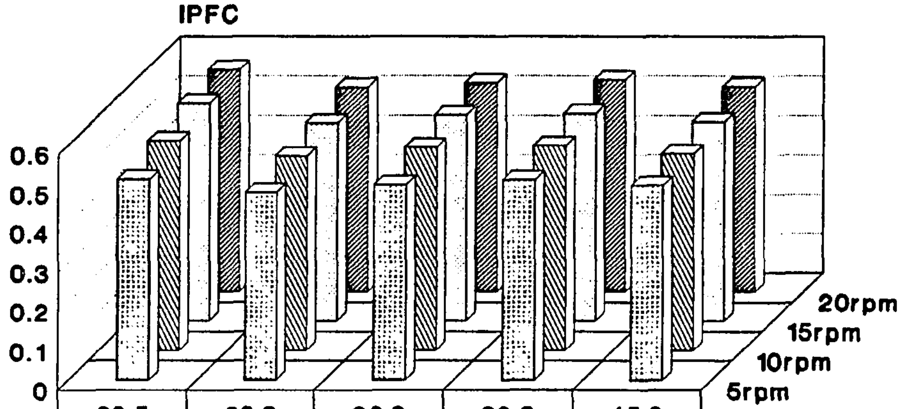
Figure 8.91 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PE with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.412 | 0.383 | 0.364 | 0.352 | 0.343 |
| 15rpm | 0.412 | 0.375 | 0.358 | 0.346 | 0.338 |
| 10rpm | 0.402 | 0.375 | 0.351 | 0.341 | 0.328 |
| 5rpm | 0.402 | 0.375 | 0.351 | 0.335 | 0.324 |

Normal Pressure (kPa)

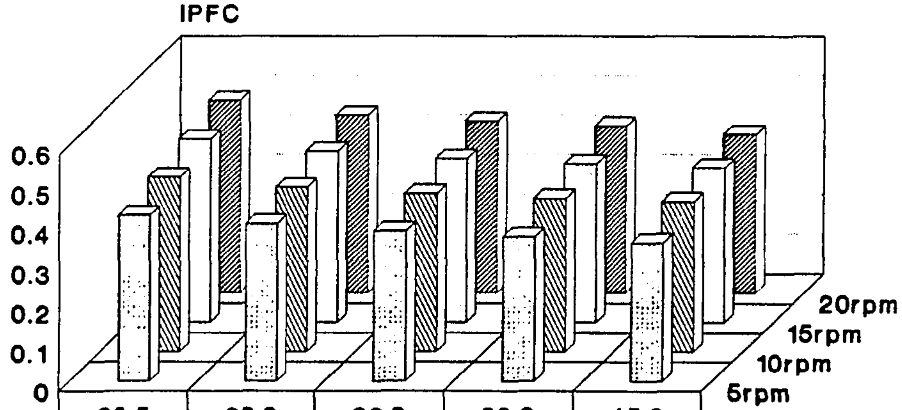
Figure 8.92 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PP with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.566 | 0.52 | 0.532 | 0.54 | 0.522 |
| 15rpm | 0.555 | 0.504 | 0.525 | 0.529 | 0.507 |
| 10rpm | 0.534 | 0.496 | 0.519 | 0.523 | 0.502 |
| 5rpm | 0.512 | 0.479 | 0.499 | 0.512 | 0.498 |

Normal Pressure (kPa)

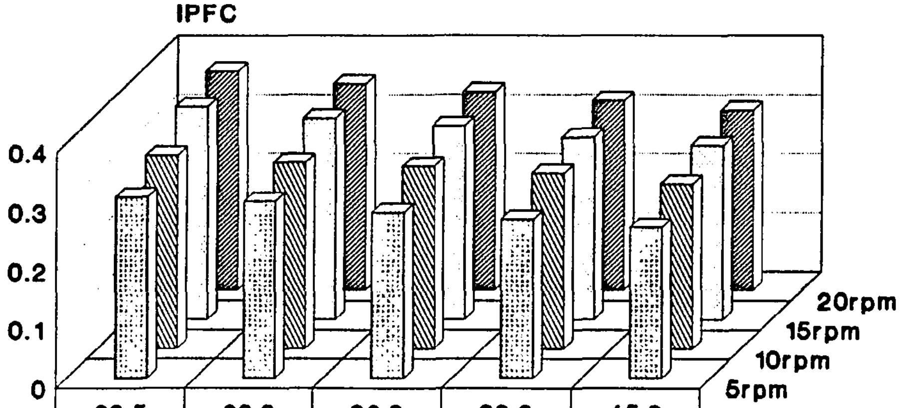
Figure 8.93 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.485 | 0.449 | 0.433 | 0.422 | 0.4 |
| 15rpm | 0.463 | 0.432 | 0.413 | 0.4 | 0.39 |
| 10rpm | 0.442 | 0.416 | 0.4 | 0.388 | 0.38 |
| 5rpm | 0.421 | 0.399 | 0.38 | 0.366 | 0.351 |

Normal Pressure (kPa)

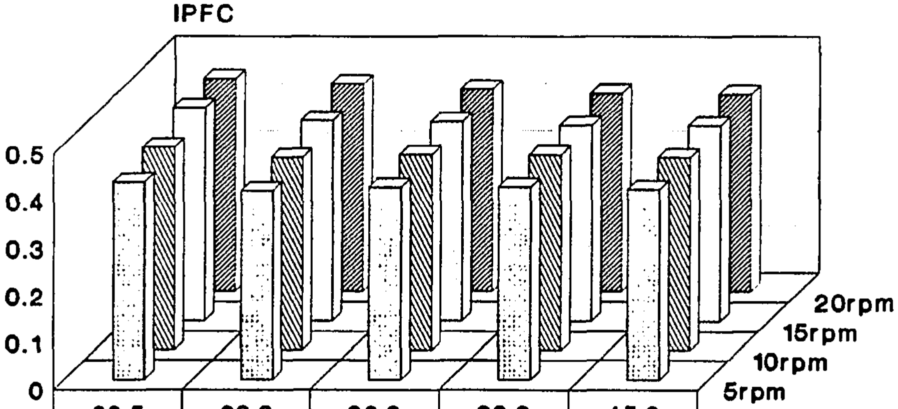
Figure 8.94 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for PA 6 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.372 | 0.35 | 0.336 | 0.321 | 0.305 |
| 15rpm | 0.361 | 0.342 | 0.329 | 0.31 | 0.296 |
| 10rpm | 0.329 | 0.317 | 0.31 | 0.299 | 0.281 |
| 5rpm | 0.308 | 0.301 | 0.283 | 0.271 | 0.257 |

Normal Pressure (kPa)

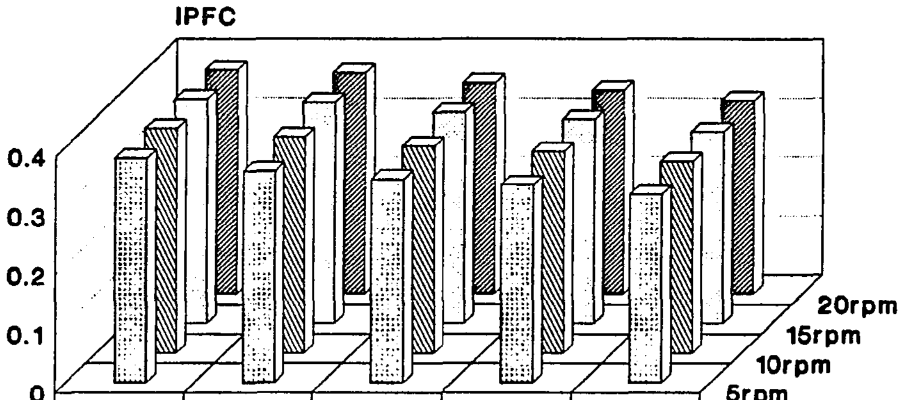
Figure 8.95 IPFC for Pellets Manufactured Using Die A221 as a Function of Normal Pressure for ABS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.451 | 0.441 | 0.428 | 0.419 | 0.418 |
| 15rpm | 0.451 | 0.424 | 0.421 | 0.414 | 0.413 |
| 10rpm | 0.429 | 0.408 | 0.415 | 0.414 | 0.408 |
| 5rpm | 0.419 | 0.4 | 0.408 | 0.408 | 0.403 |

Normal Pressure (kPa)

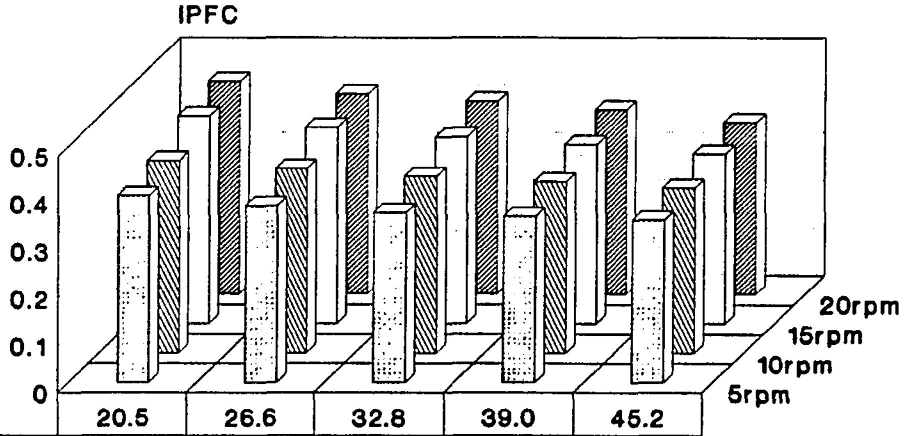
Figure 8.96 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PE with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.38 | 0.375 | 0.358 | 0.346 | 0.328 |
| 15rpm | 0.38 | 0.375 | 0.358 | 0.346 | 0.324 |
| 10rpm | 0.38 | 0.366 | 0.351 | 0.341 | 0.324 |
| 5rpm | 0.38 | 0.358 | 0.345 | 0.335 | 0.319 |

Normal Pressure (kPa)

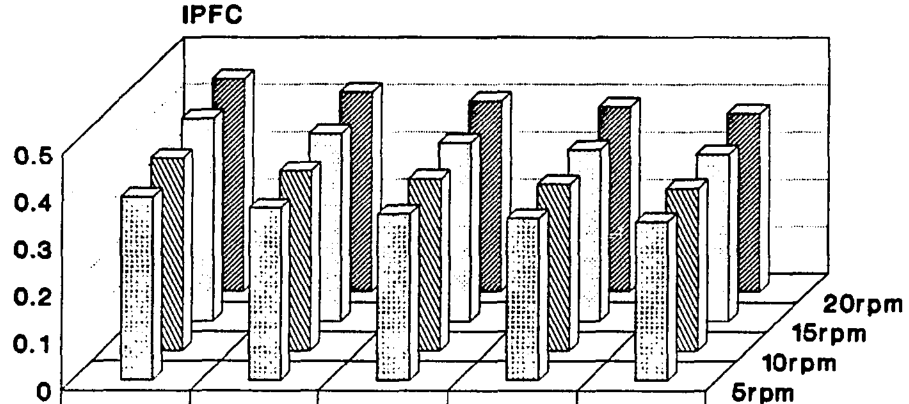
Figure 8.97 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PP with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.448 | 0.422 | 0.406 | 0.389 | 0.362 |
| 15rpm | 0.438 | 0.414 | 0.393 | 0.378 | 0.358 |
| 10rpm | 0.406 | 0.389 | 0.373 | 0.361 | 0.348 |
| 5rpm | 0.395 | 0.373 | 0.359 | 0.35 | 0.343 |

Normal Pressure (kPa)

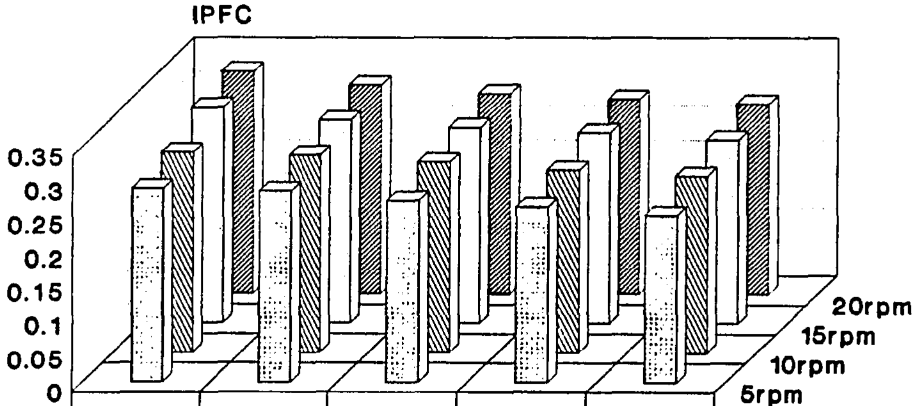
Figure 8.98 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PS with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.453 | 0.424 | 0.406 | 0.394 | 0.38 |
| 15rpm | 0.431 | 0.399 | 0.38 | 0.366 | 0.356 |
| 10rpm | 0.41 | 0.383 | 0.366 | 0.355 | 0.346 |
| 5rpm | 0.389 | 0.367 | 0.353 | 0.344 | 0.337 |

Normal Pressure (kPa)

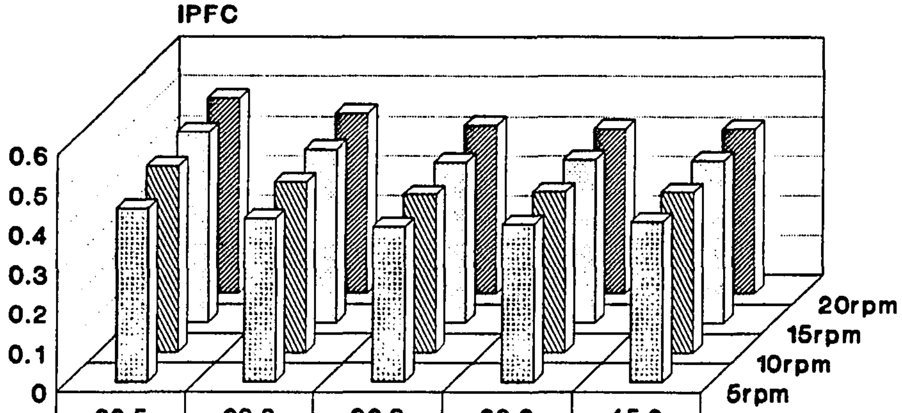
Figure 8.99 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for PA 6 with Agitation.



|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.329 | 0.309 | 0.296 | 0.288 | 0.281 |
| 15rpm | 0.319 | 0.301 | 0.29 | 0.282 | 0.272 |
| 10rpm | 0.297 | 0.293 | 0.283 | 0.271 | 0.262 |
| 5rpm | 0.287 | 0.284 | 0.27 | 0.26 | 0.248 |

Normal Pressure (kPa)

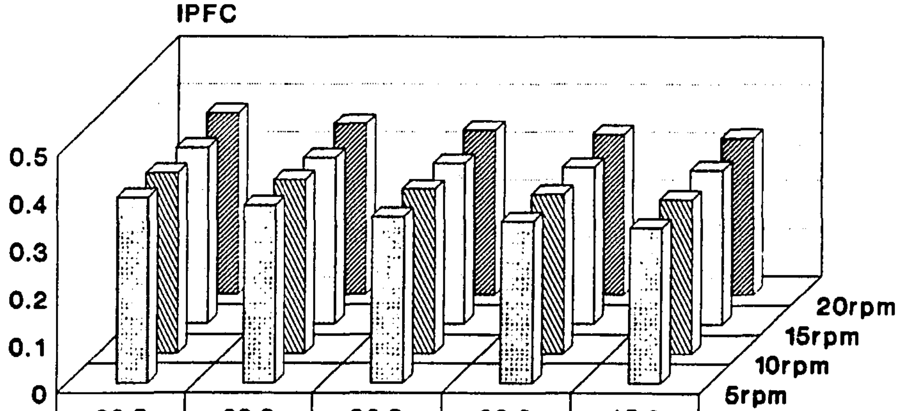
Figure 8.100 IPFC for Pellets Manufactured Using Die A231 as a Function of Normal Pressure for ABS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.493 | 0.457 | 0.428 | 0.419 | 0.418 |
| 15rpm | 0.483 | 0.441 | 0.408 | 0.414 | 0.413 |
| 10rpm | 0.472 | 0.433 | 0.401 | 0.408 | 0.408 |
| 5rpm | 0.44 | 0.416 | 0.395 | 0.402 | 0.408 |

Normal Pressure (kPa)

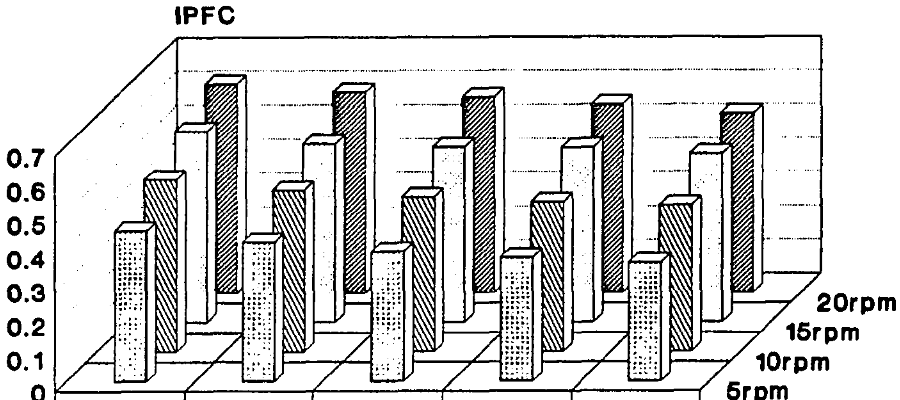
Figure 8.101 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PE with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.38 | 0.358 | 0.345 | 0.335 | 0.328 |
| 15rpm | 0.37 | 0.35 | 0.338 | 0.33 | 0.324 |
| 10rpm | 0.38 | 0.366 | 0.345 | 0.335 | 0.324 |
| 5rpm | 0.391 | 0.375 | 0.351 | 0.341 | 0.328 |

Normal Pressure (kPa)

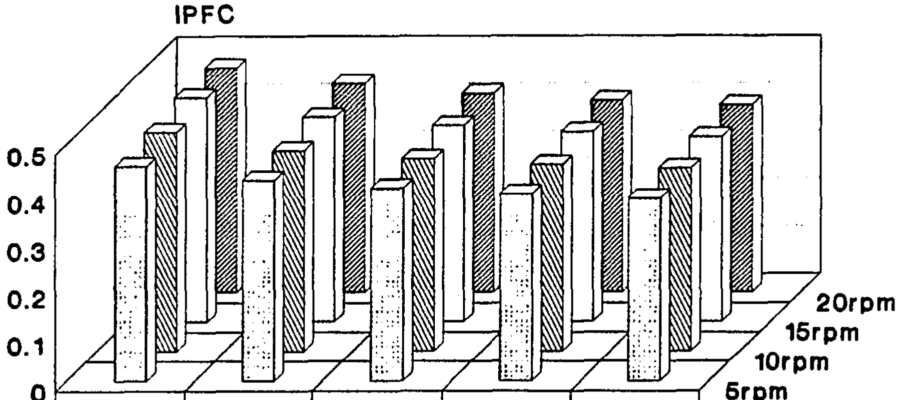
Figure 8.102 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PP with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.619 | 0.594 | 0.579 | 0.567 | 0.531 |
| 15rpm | 0.566 | 0.529 | 0.519 | 0.518 | 0.498 |
| 10rpm | 0.512 | 0.479 | 0.459 | 0.445 | 0.435 |
| 5rpm | 0.448 | 0.414 | 0.386 | 0.367 | 0.353 |

Normal Pressure (kPa)

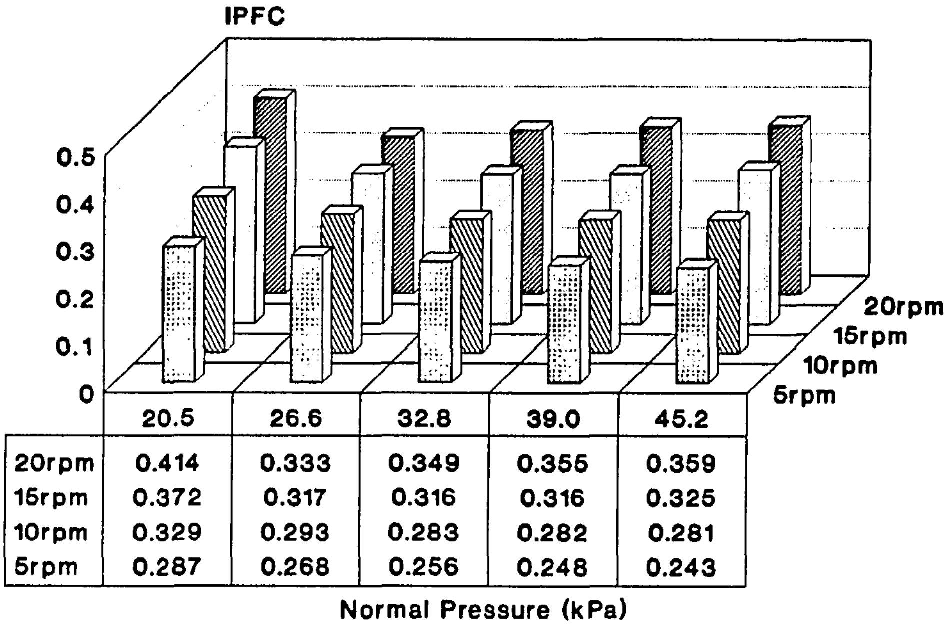
Figure 8.103 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.474 | 0.44 | 0.419 | 0.405 | 0.395 |
| 15rpm | 0.474 | 0.432 | 0.413 | 0.4 | 0.39 |
| 10rpm | 0.463 | 0.424 | 0.406 | 0.394 | 0.385 |
| 5rpm | 0.453 | 0.424 | 0.406 | 0.394 | 0.385 |

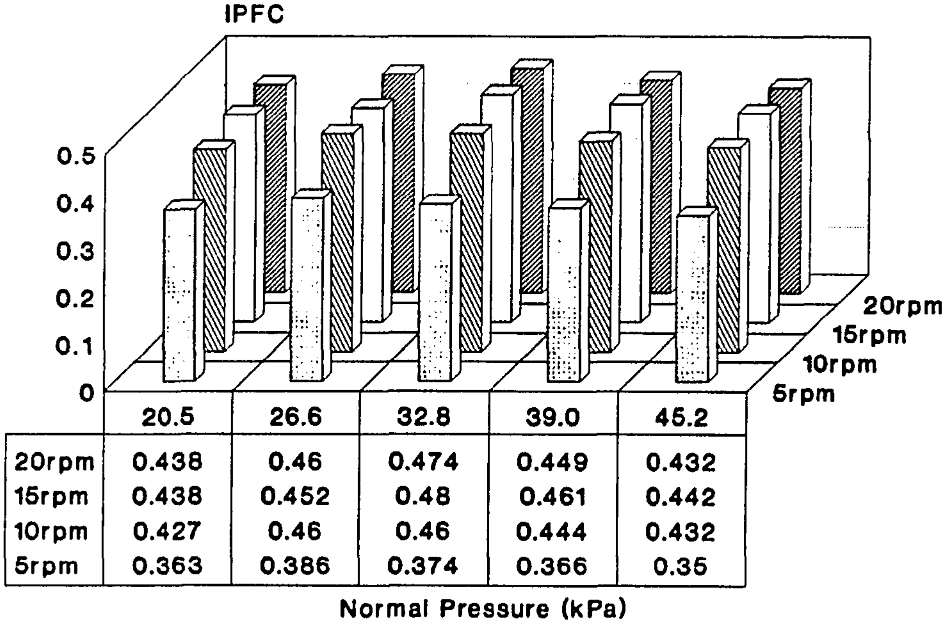
Normal Pressure (kPa)

Figure 8.104 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for PA 6 with Agitation.



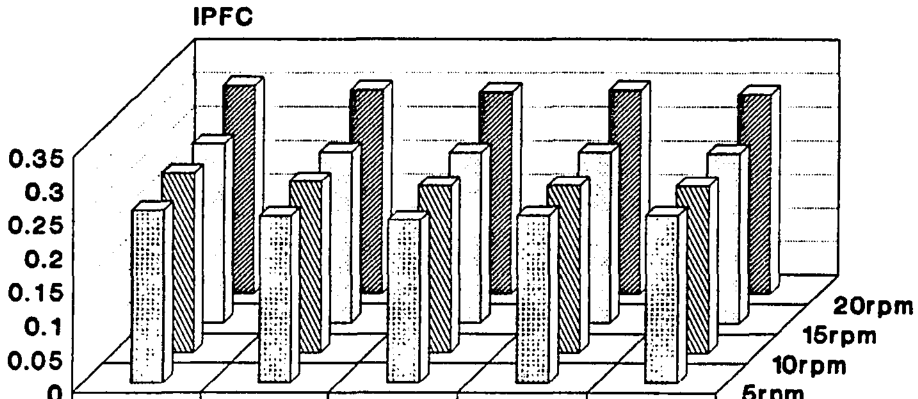
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.414 | 0.333 | 0.349 | 0.355 | 0.359 |
| 15rpm | 0.372 | 0.317 | 0.316 | 0.316 | 0.325 |
| 10rpm | 0.329 | 0.293 | 0.283 | 0.282 | 0.281 |
| 5rpm | 0.287 | 0.268 | 0.256 | 0.248 | 0.243 |

Figure 8.105 IPFC for Pellets Manufactured Using Die A241 as a Function of Normal Pressure for ABS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.438 | 0.46 | 0.474 | 0.449 | 0.432 |
| 15rpm | 0.438 | 0.452 | 0.48 | 0.461 | 0.442 |
| 10rpm | 0.427 | 0.46 | 0.46 | 0.444 | 0.432 |
| 5rpm | 0.363 | 0.386 | 0.374 | 0.366 | 0.35 |

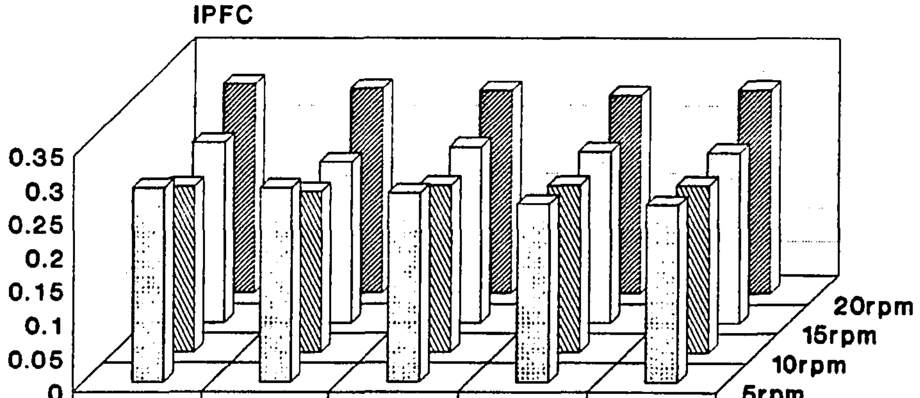
Figure 8.106 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.31 | 0.304 | 0.301 | 0.304 | 0.297 |
| 15rpm | 0.267 | 0.255 | 0.254 | 0.254 | 0.253 |
| 10rpm | 0.267 | 0.255 | 0.248 | 0.248 | 0.248 |
| 5rpm | 0.256 | 0.247 | 0.241 | 0.248 | 0.248 |

Normal Pressure (kPa)

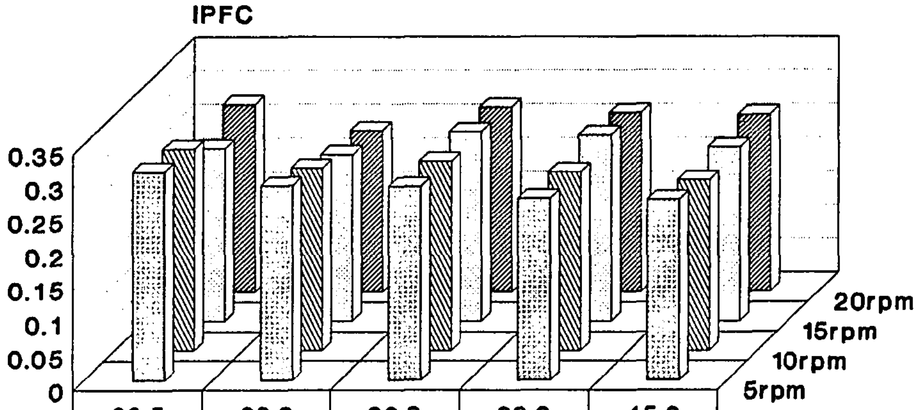
Figure 8.107 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM2 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.31 | 0.304 | 0.301 | 0.293 | 0.302 |
| 15rpm | 0.267 | 0.239 | 0.261 | 0.254 | 0.253 |
| 10rpm | 0.246 | 0.239 | 0.248 | 0.248 | 0.248 |
| 5rpm | 0.288 | 0.288 | 0.281 | 0.265 | 0.263 |

Normal Pressure (kPa)

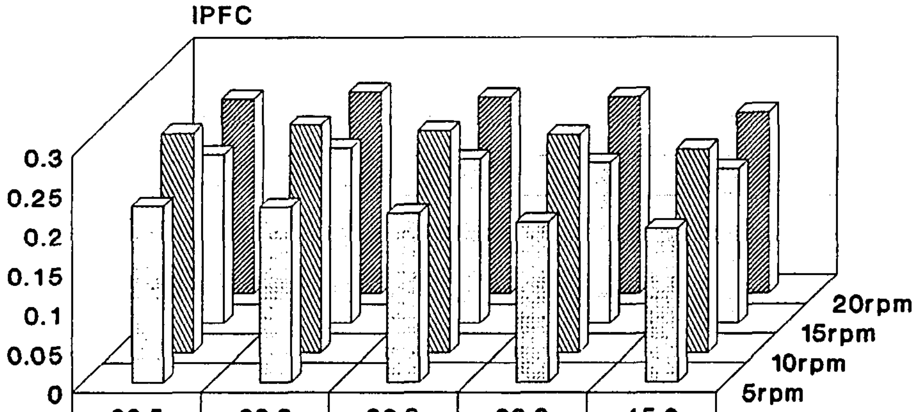
Figure 8.108 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM3 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.278 | 0.239 | 0.274 | 0.265 | 0.263 |
| 15rpm | 0.256 | 0.247 | 0.281 | 0.276 | 0.258 |
| 10rpm | 0.299 | 0.271 | 0.281 | 0.265 | 0.253 |
| 5rpm | 0.31 | 0.288 | 0.287 | 0.27 | 0.268 |

Normal Pressure (kPa)

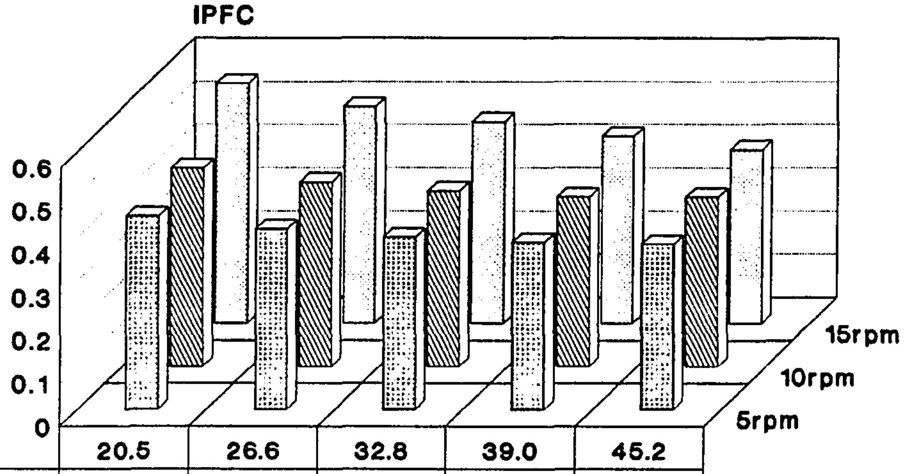
Figure 8.109 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM4 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.246 | 0.255 | 0.248 | 0.248 | 0.229 |
| 15rpm | 0.214 | 0.222 | 0.208 | 0.203 | 0.195 |
| 10rpm | 0.278 | 0.288 | 0.281 | 0.276 | 0.258 |
| 5rpm | 0.224 | 0.222 | 0.214 | 0.203 | 0.195 |

Normal Pressure (kPa)

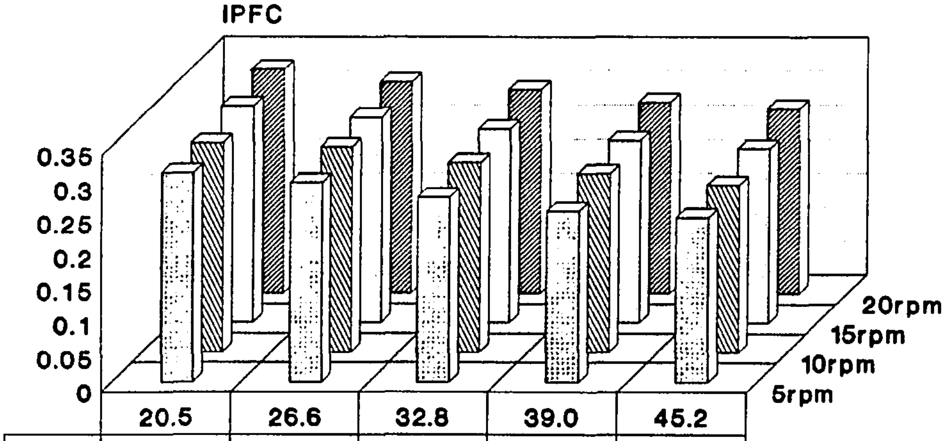
Figure 8.110 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for POM5 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 15rpm | 0.555 | 0.501 | 0.467 | 0.433 | 0.403 |
| 10rpm | 0.459 | 0.427 | 0.407 | 0.393 | 0.393 |
| 5rpm | 0.448 | 0.419 | 0.4 | 0.388 | 0.384 |

Normal Pressure (kPa)

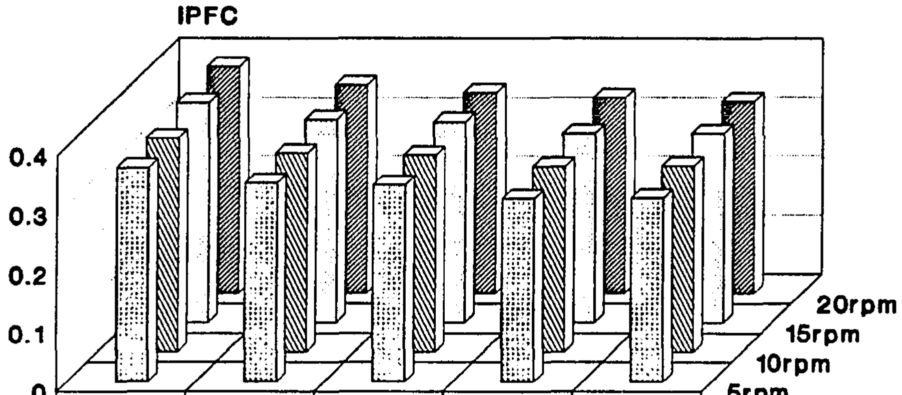
Figure 8.111 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM1 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.331 | 0.312 | 0.301 | 0.282 | 0.273 |
| 15rpm | 0.32 | 0.304 | 0.287 | 0.27 | 0.258 |
| 10rpm | 0.31 | 0.304 | 0.281 | 0.265 | 0.248 |
| 5rpm | 0.31 | 0.296 | 0.274 | 0.254 | 0.244 |

Normal Pressure (kPa)

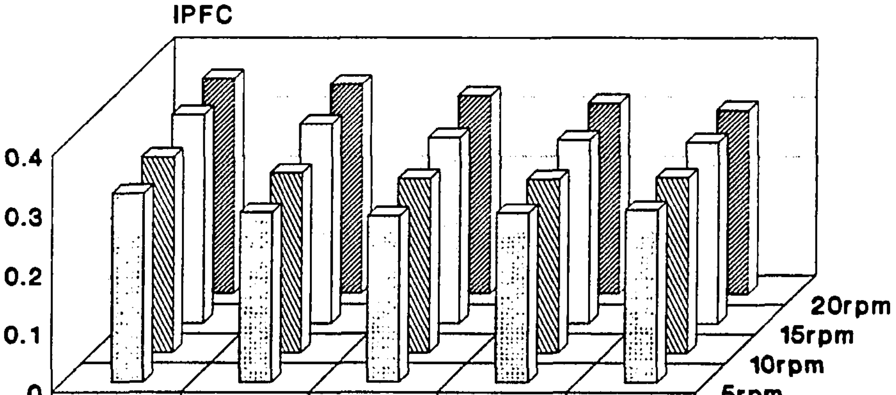
Figure 8.112 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM2 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.384 | 0.353 | 0.341 | 0.332 | 0.326 |
| 15rpm | 0.373 | 0.345 | 0.341 | 0.321 | 0.321 |
| 10rpm | 0.363 | 0.337 | 0.334 | 0.315 | 0.316 |
| 5rpm | 0.363 | 0.337 | 0.334 | 0.31 | 0.311 |

Normal Pressure (kPa)

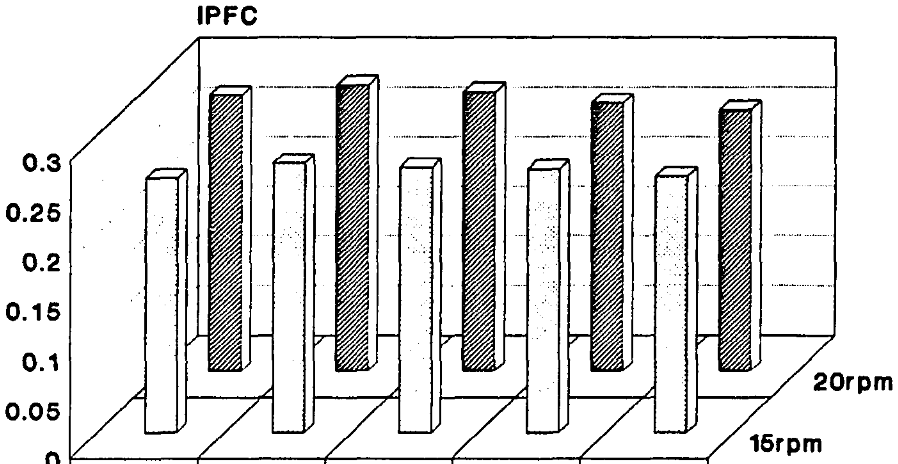
Figure 8.113 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM3 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.363 | 0.353 | 0.334 | 0.321 | 0.311 |
| 15rpm | 0.352 | 0.337 | 0.314 | 0.31 | 0.306 |
| 10rpm | 0.331 | 0.304 | 0.294 | 0.293 | 0.297 |
| 5rpm | 0.32 | 0.288 | 0.281 | 0.287 | 0.292 |

Normal Pressure (kPa)

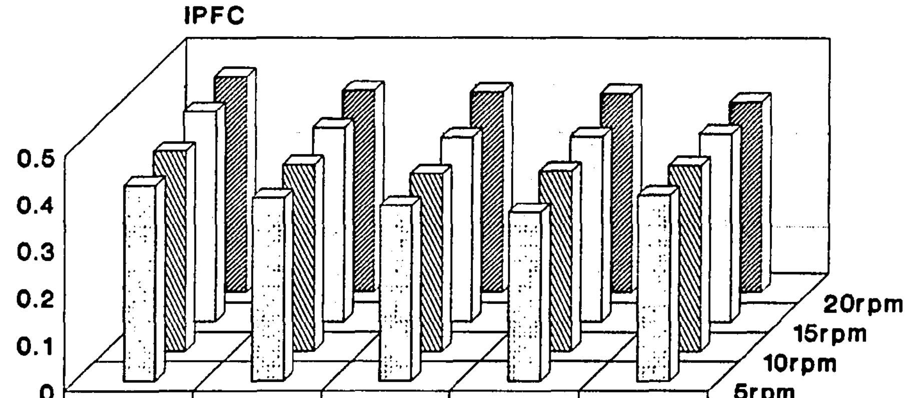
Figure 8.114 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM4 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.278 | 0.288 | 0.281 | 0.27 | 0.263 |
| 15rpm | 0.256 | 0.271 | 0.267 | 0.265 | 0.258 |

Normal Pressure (kPa)

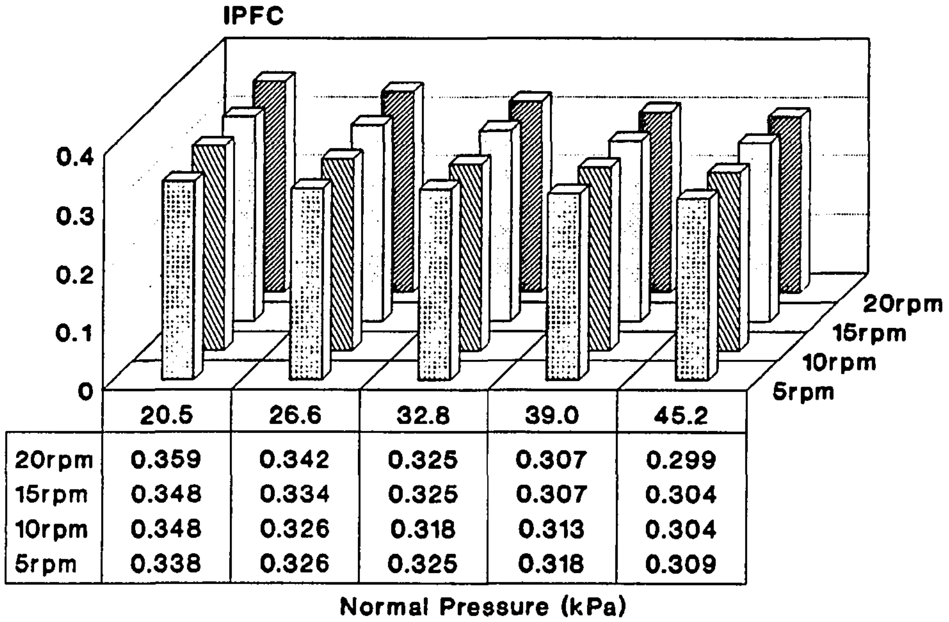
Figure 8.115 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for POM5 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.459 | 0.43 | 0.426 | 0.423 | 0.406 |
| 15rpm | 0.448 | 0.414 | 0.393 | 0.395 | 0.401 |
| 10rpm | 0.427 | 0.398 | 0.379 | 0.384 | 0.396 |
| 5rpm | 0.416 | 0.389 | 0.373 | 0.359 | 0.396 |

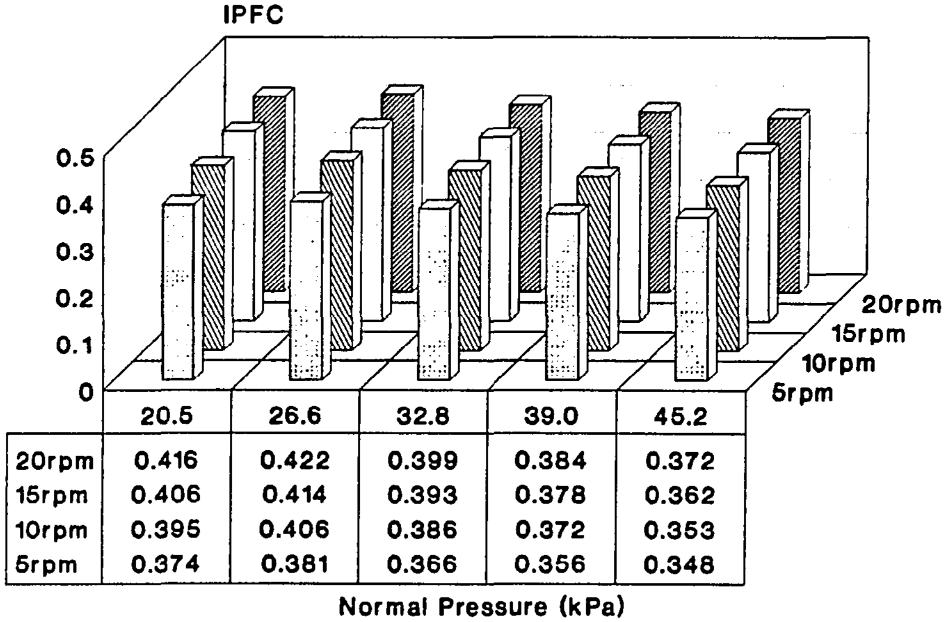
Normal Pressure (kPa)

Figure 8.116 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PE with Agitation.



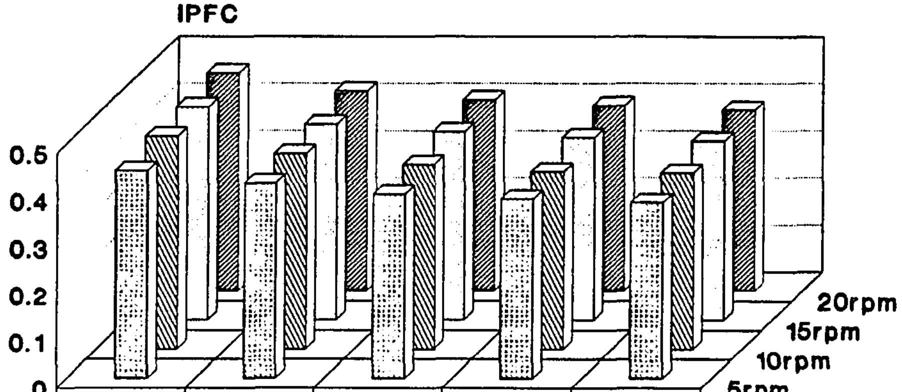
| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.359 | 0.342 | 0.325 | 0.307 | 0.299 |
| 15rpm | 0.348 | 0.334 | 0.325 | 0.307 | 0.304 |
| 10rpm | 0.348 | 0.326 | 0.318 | 0.313 | 0.304 |
| 5rpm | 0.338 | 0.326 | 0.325 | 0.318 | 0.309 |

Figure 8.117 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PP with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.416 | 0.422 | 0.399 | 0.384 | 0.372 |
| 15rpm | 0.406 | 0.414 | 0.393 | 0.378 | 0.362 |
| 10rpm | 0.395 | 0.406 | 0.386 | 0.372 | 0.353 |
| 5rpm | 0.374 | 0.381 | 0.366 | 0.356 | 0.348 |

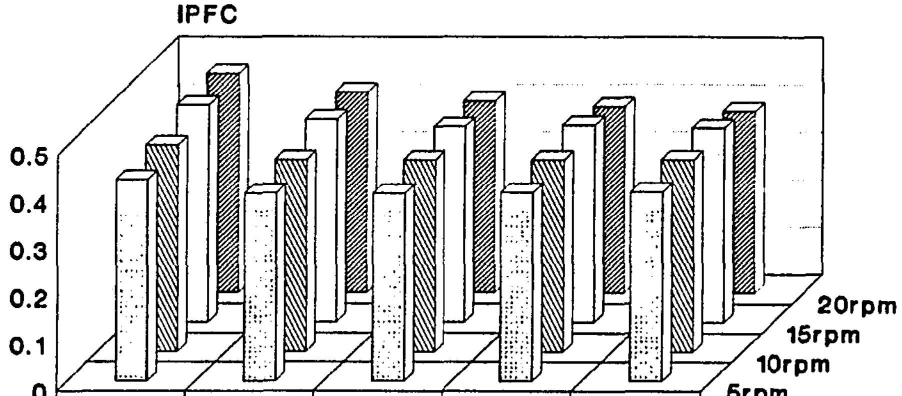
Figure 8.118 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PS with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.463 | 0.424 | 0.406 | 0.394 | 0.385 |
| 15rpm | 0.453 | 0.416 | 0.4 | 0.388 | 0.38 |
| 10rpm | 0.453 | 0.416 | 0.393 | 0.377 | 0.375 |
| 5rpm | 0.442 | 0.416 | 0.393 | 0.383 | 0.375 |

Normal Pressure (kPa)

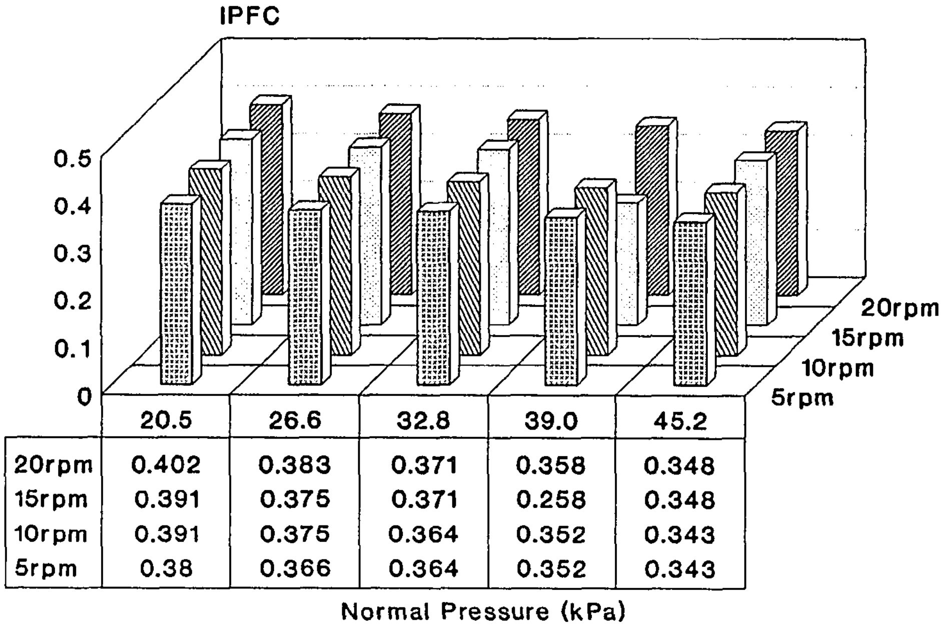
Figure 8.119 IPFC for Pellets Manufactured Using Die A311 as a Function of Normal Pressure for PA 6 with Agitation.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.463 | 0.424 | 0.406 | 0.394 | 0.385 |
| 15rpm | 0.459 | 0.43 | 0.413 | 0.417 | 0.411 |
| 10rpm | 0.438 | 0.406 | 0.406 | 0.406 | 0.406 |
| 5rpm | 0.427 | 0.398 | 0.399 | 0.4 | 0.401 |

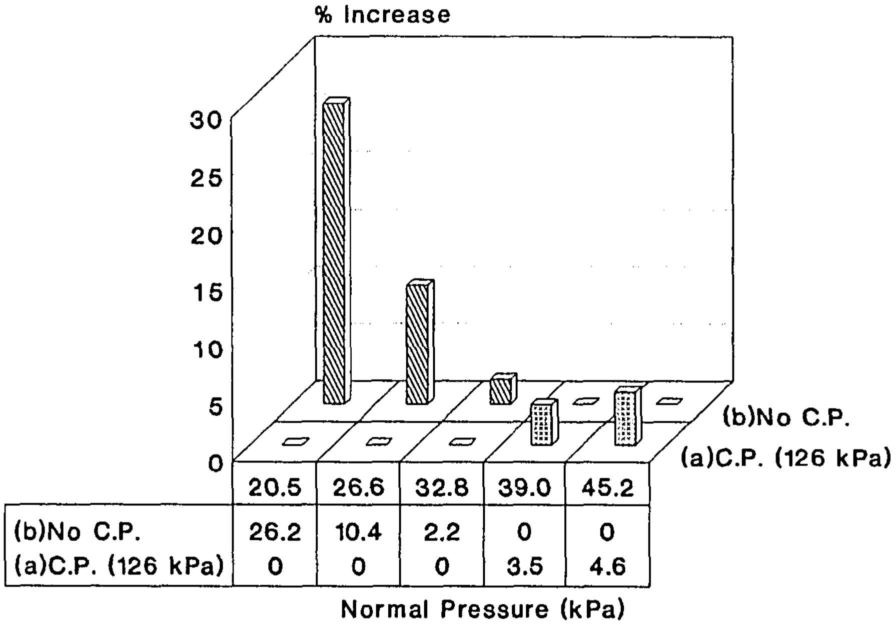
Normal Pressure (kPa)

Figure 8.120 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for PE with Agitation.



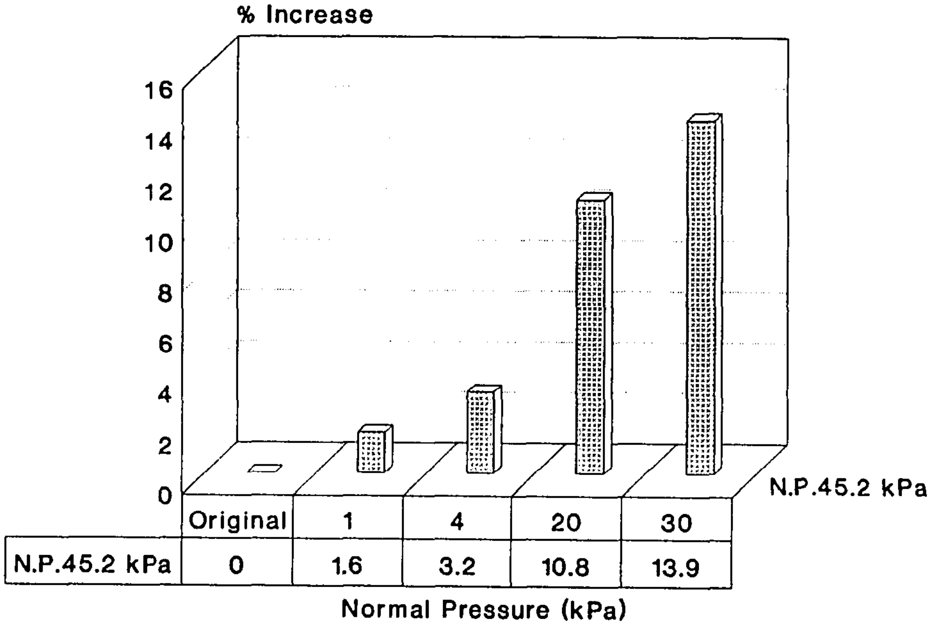
|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 20rpm | 0.402 | 0.383 | 0.371 | 0.358 | 0.348 |
| 15rpm | 0.391 | 0.375 | 0.371 | 0.258 | 0.348 |
| 10rpm | 0.391 | 0.375 | 0.364 | 0.352 | 0.343 |
| 5rpm | 0.38 | 0.366 | 0.364 | 0.352 | 0.343 |

Figure 8.121 IPFC for Pellets Manufactured Using Die A411 as a Function of Normal Pressure for PP with Agitation.



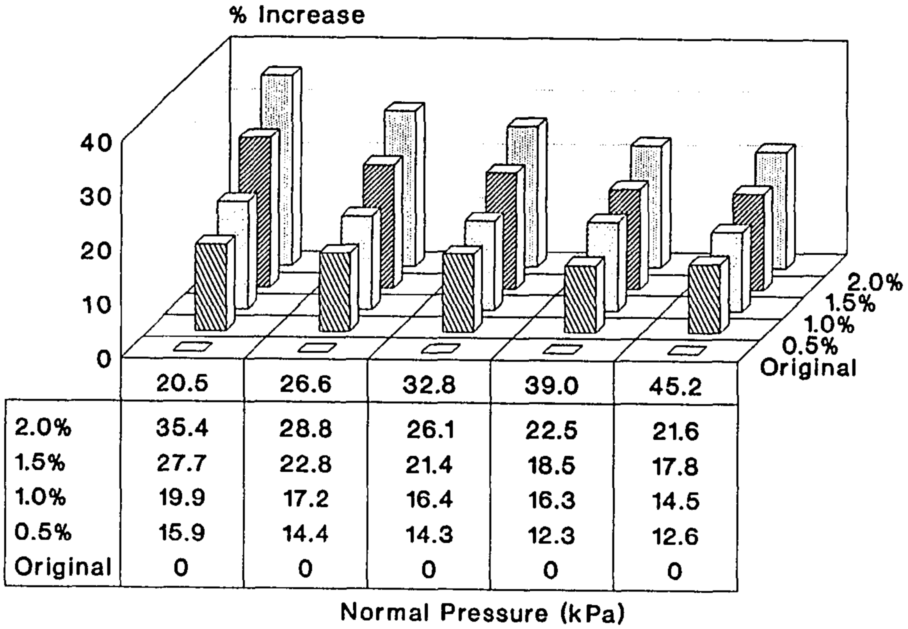
|  | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| (b)No C.P. | 26.2 | 10.4 | 2.2 | 0 | 0 |
| (a)C.P. (126 kPa) | 0 | 0 | 0 | 3.5 | 4.6 |

Figure 8.122 Effect of Consolidation Pressure on IPFC for Pellets Manufactured Using Die A211 of PE.



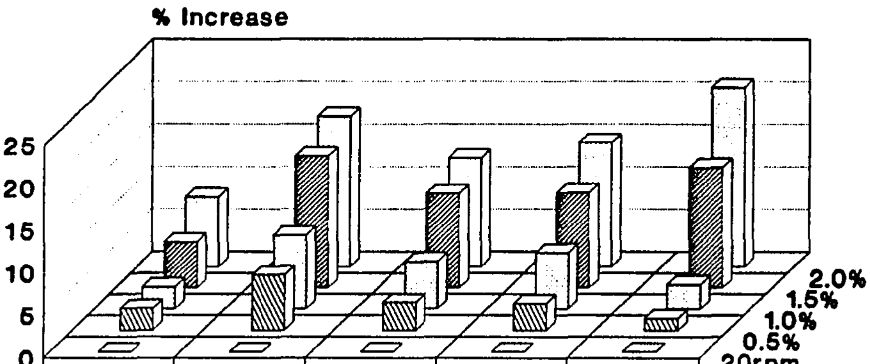
| | Original | 1 | 4 | 20 | 30 |
|---|---|---|---|---|---|
| N.P.45.2 kPa | 0 | 1.6 | 3.2 | 10.8 | 13.9 |

Figure 8.123 Effect of Consolidation Time for Pellets Manufactured Using Die A211 of PE at Consolidation Pressure 126.3kPa.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 35.4 | 28.8 | 26.1 | 22.5 | 21.6 |
| 1.5% | 27.7 | 22.8 | 21.4 | 18.5 | 17.8 |
| 1.0% | 19.9 | 17.2 | 16.4 | 16.3 | 14.5 |
| 0.5% | 15.9 | 14.4 | 14.3 | 12.3 | 12.6 |
| Original | 0 | 0 | 0 | 0 | 0 |

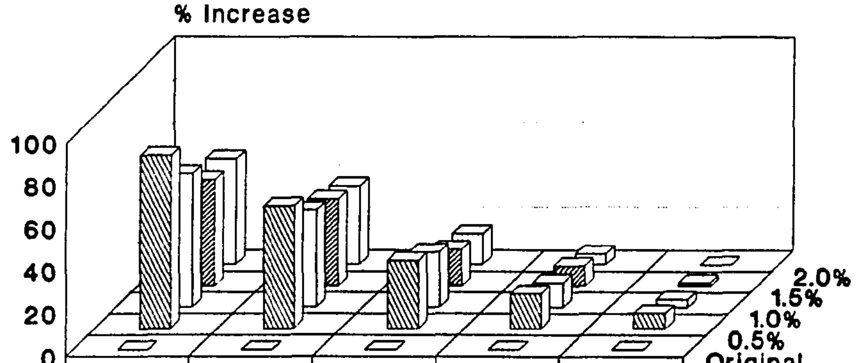
Figure 8.124 % Increase for Pellets with Circular Cross-Sections of PA 6 with Mica Clay.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 8.2 | 17.7 | 12.8 | 14.6 | 21.1 |
| 1.5% | 5.4 | 15.5 | 11.1 | 11.2 | 14.2 |
| 1.0% | 2.6 | 8.7 | 5.6 | 6.6 | 2.9 |
| 0.5% | 2.6 | 6.5 | 3.3 | 3.2 | 1.4 |
| 20rpm | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

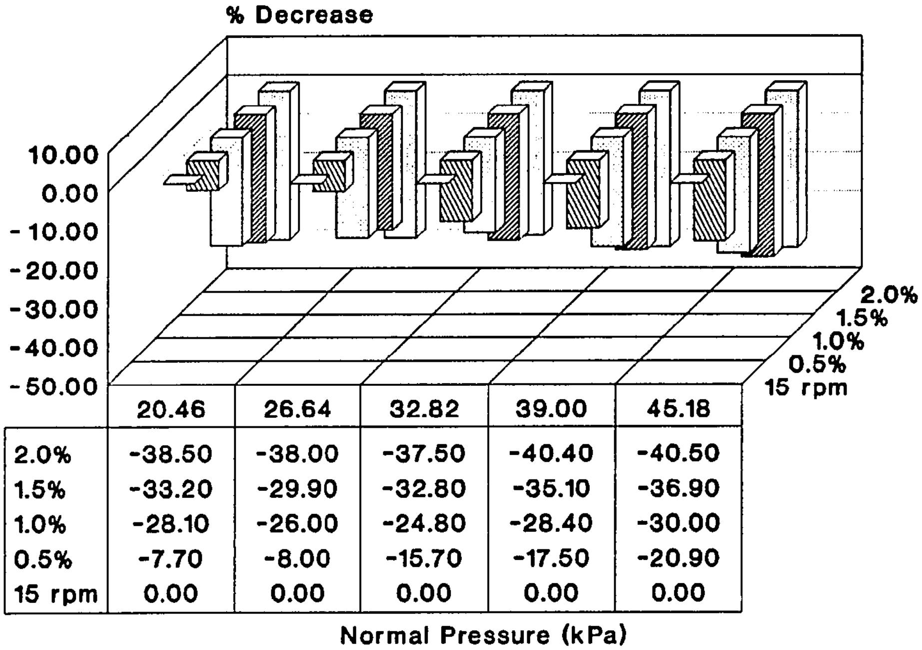
Figure 8.125 % Increase for Pellets Manufactured Using Die A241 of PA 6 with Mica Clay at Extruder Screw Speed 20rpm.



| | 20.5 | 26.6 | 32.8 | 39.0 | 45.2 |
|---|---|---|---|---|---|
| 2.0% | 49.7 | 36.9 | 14.5 | 5 | 0 |
| 1.5% | 49.7 | 40.9 | 17.1 | 9.5 | 1.9 |
| 1.0% | 62.6 | 45.5 | 25.9 | 11.6 | 3.8 |
| 0.5% | 81.3 | 57.6 | 32 | 16.5 | 7.2 |
| Original | 0 | 0 | 0 | 0 | 0 |

Normal Pressure (kPa)

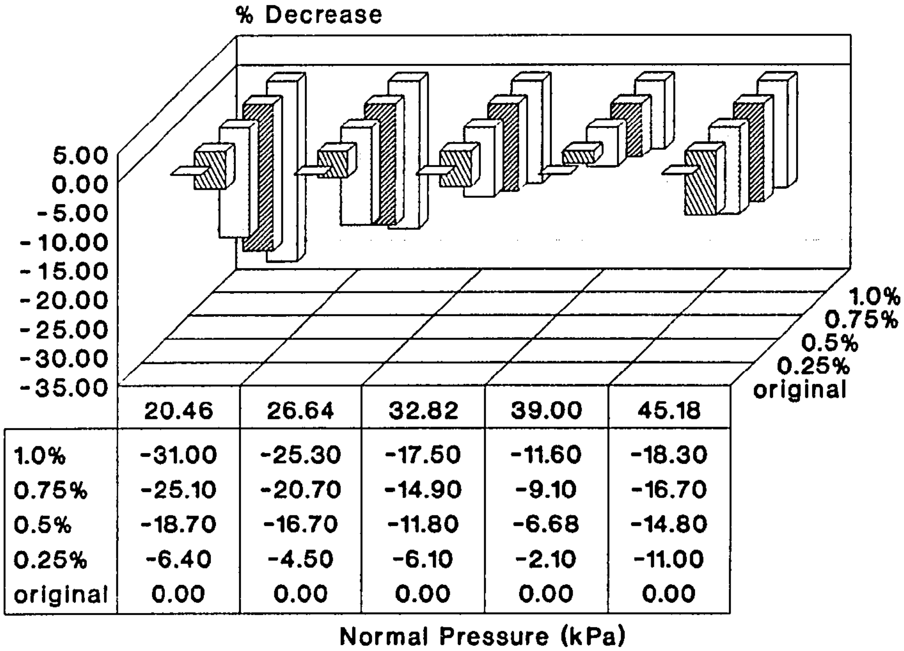
Figure 8.126 % Increase for Pellets with Circular Cross-Sections of POM3 with PBT Powder.



| | 20.46 | 26.64 | 32.82 | 39.00 | 45.18 |
|---|---|---|---|---|---|
| 2.0% | -38.50 | -38.00 | -37.50 | -40.40 | -40.50 |
| 1.5% | -33.20 | -29.90 | -32.80 | -35.10 | -36.90 |
| 1.0% | -28.10 | -26.00 | -24.80 | -28.40 | -30.00 |
| 0.5% | -7.70 | -8.00 | -15.70 | -17.50 | -20.90 |
| 15 rpm | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Normal Pressure (kPa)

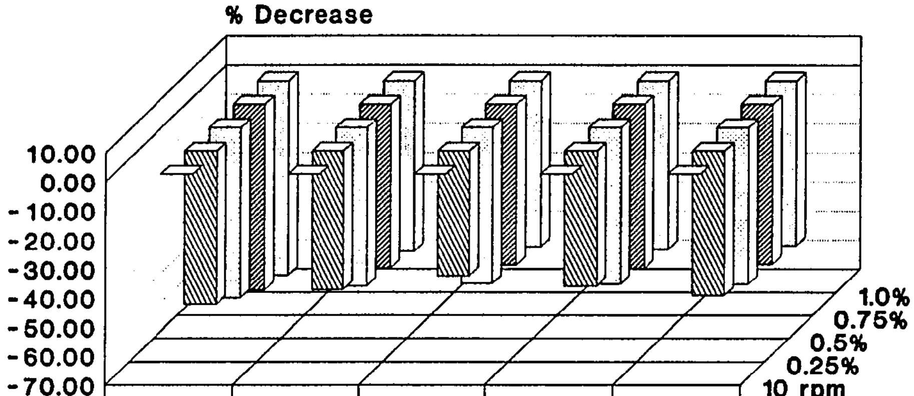
Figure 8.127 % Decrease for Pellets Manufactured Using Die A212 of POM3 with PBT Powder at Extruder Screw Speed 15rpm.



| | 20.46 | 26.64 | 32.82 | 39.00 | 45.18 |
|---|---|---|---|---|---|
| 1.0% | -31.00 | -25.30 | -17.50 | -11.60 | -18.30 |
| 0.75% | -25.10 | -20.70 | -14.90 | -9.10 | -16.70 |
| 0.5% | -18.70 | -16.70 | -11.80 | -6.68 | -14.80 |
| 0.25% | -6.40 | -4.50 | -6.10 | -2.10 | -11.00 |
| original | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Normal Pressure (kPa)

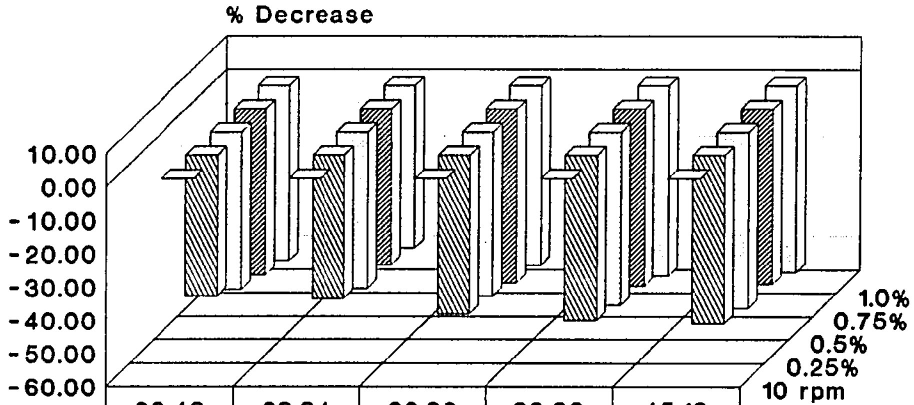
Figure 8.128 % Decrease for Pellets with Circular Cross-Sections of POM3 with Zinc Stearate.



| | 20.46 | 26.64 | 32.82 | 39.00 | 45.18 |
|---|---|---|---|---|---|
| 1.0% | -66.70 | -58.50 | -57.00 | -57.80 | -56.40 |
| 0.75% | -63.80 | -56.30 | -55.10 | -56.50 | -55.00 |
| 0.5% | -58.30 | -54.20 | -53.50 | -53.60 | -53.70 |
| 0.25% | -52.60 | -47.60 | -42.80 | -46.20 | -49.60 |
| 10 rpm | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Normal Pressure (kPa)

Figure 8.129 % Decrease for Pellets Manufactured Using A211 of POM3 with Zinc Stearate.



| | 20.46 | 26.64 | 32.82 | 39.00 | 45.18 |
|---|---|---|---|---|---|
| 1.0% | -52.60 | -48.80 | -53.80 | -57.00 | -55.90 |
| 0.75% | -49.90 | -46.80 | -52.10 | -53.00 | -52.60 |
| 0.5% | -47.20 | -46.80 | -49.00 | -51.80 | -52.60 |
| 0.25% | -42.00 | -42.80 | -47.40 | -49.20 | -50.20 |
| 10 rpm | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Normal Pressure (kPa)

Figure 8.130 % Decrease for Pellets Manufactured Using A212 of POM3 with Zinc Stearate.

# CHAPTER 9

# THE SIMULATION OF THE PLASTICATING EXTRUSION PROCESS WITH EMPHASIS ON THE CONVEYING OF POLYMERIC PARTICULATES

## 9.1 Summary of the Simulation Procedure

The simulation computes the pressure rise in the solids conveying zone of a plasticating extruder from force and torque balances created by the motion of the plasticating screw in the extruder barrel. The integrity of the solid bed is then analyzed by studying the solid bed as a continuum and determining if rupture conditions exist.

The solids conveying zone extends from the hopper to the point where a melt film is formed on the barrel surface. The mathematical model of the solids conveying zone was developed by Darnel and Mol [16] and modified by Duvdevani et al. [47]. The pressure rise across the solid conveying zone is computed from,

$$\Delta P_s = P_o[\exp(\Phi L_f) - 1] \tag{9.1}$$

where,

$$\Phi = \frac{\{ \cos\theta - K\sin\theta - C\frac{f_S}{f_b}(K\sin\phi_S + C\cos\phi_S) - \frac{2D_c}{S_l}\bullet\frac{f_S}{f_b}(KC\tan\phi_S + H^2)\}\, f_b}{D_c H\sin\phi_a\,(H\cos\phi_a + K\sin\phi_a)} \tag{9.2}$$

$$\theta = \arctan\left[\frac{Q}{N_s\pi D_B}\frac{S_l}{}\bullet\frac{1}{\pi S_l D_c(D_B - D_c) - \frac{Q}{N}}\right] \tag{9.3}$$

$$H = \frac{D_B - D_c}{D_B} \tag{9.4}$$

$$C = \frac{D_B - 2D_c}{D_B} \tag{9.5}$$

$$K = \frac{H(\tan\phi_a + f_s)}{1 - f_s\tan\phi_a} \tag{9.6}$$

$$\tan\phi_s = \frac{S_l}{\pi(D_B - 2D_c)} \tag{9.7}$$

and $$\tan\phi_a = \frac{S_l}{\pi(D_B - H)} \tag{9.8}$$

where,

$P_o$ = pressure at feed zone entrance, psi

$L_f$ = feed zone length, in

$D_c$ = channel depth, in

$S_l$ = screw lead, in

$Q$ = volumetric extruder output in feed zone, in$^3$/min

$N_s$ = frequency of screw rotation, rpm

$D_B$ = barrel diameter, in

$\theta$ = angle of movement of the outer surface of the solid plug, radians

$\phi_s$ = helix angle at the screw root, degrees

and $\phi_a$ = helix angle of screw at the screw channel, degrees

Eq. 9.2 contains the coefficients of friction between the barrel and the particulate beds, $f_b$, and the screw and the particulate bed, $f_s$. It is clear that $f_b$ causes motion, whereas, $f_s$, retards motion. Four possible motion situations exist [48] as shown in Figure 9.1. For the force balance on a differential element of the particulate bed.

Case 1

$F_L < F_o$; Stationary Plug; Friction Mobilized,

$$\frac{F_L}{F_o}=\exp[(C_1 f_{w_1} - C_2 f'_w)\frac{KL}{A}] \qquad (9.9)$$

Case 2

$F_L > F_o$; Stationary Plug; Friction Mobilized,

$$\frac{F_L}{F_o}=\exp[(C_1 f_{w_1} + C_2 f'_w)\frac{KL}{A}] \qquad (9.10)$$

Case 3

Plug moves in the direction of the upper plate,

$$\frac{F_L}{F_o}=\exp[(C_1 f_{w_1} - C_2 f_{w_2})\frac{KL}{A}] \qquad (9.11)$$

Case 4

Plug moves in the direction opposite of the upper plate,

$$\frac{F_L}{F_o}=\exp[(C_1 f_{w_1} + C_2 f_{w_2})\frac{KL}{A}] \qquad (9.12)$$

In the foregoing, different kinematic coefficients of frictions on the moving plate $f_{w_1}$ and the stationary walls $f_{w_2}$ exist. The moving plate exerts a force of $C_1 f_{w_1} K(\frac{F}{A})$ in all cases, where $C_1$ is the portion of the "wetted" perimeter of the moving plate and $f_{w_1}$ is the kinematic coefficient of friction. The stationary channel walls in cases 1 and 2 exert a force $C_2 f'_w K(\frac{F}{A})$, where $f'_w$ is the static coefficient of friction and $C_2$ is the portion of the "wetted" perimeter of the lower plate and side walls that is stationary. This force acts in the direction of increasing force. Thus it acts to the left in case 1 and to the right in case 2. Finally in cases 3 and 4 the stationary walls exert a force

$C_2f_{w_2}K(\frac{F}{A})$, where $f_{w_2}$ is the kinematic coefficient of friction. This force acts in the direction opposite to the direction of motion of the plug. Case 3 is similar to the mechanism acting on the particulate bed. Hence, one can assume $f_b$ equals $f_{w_1}$, and $f_s$ equals $f_{w_2}$.

The torque at the barrel surface is calculated from,

$$T_B = \frac{1}{2}\pi D^2{}_B f_b P_o \frac{\cos\theta}{\Phi}[\exp(\Phi L_f) - 1] \qquad (9.13)$$

The power required to pump the solid pellets through the feed zone is computed from,

$$Z_F = (6.6606 \times 10^{-5})\ \pi T_B N_S \qquad (9.14)$$

Figure 9.2 shows typical cross-sections in the melting zone of a plasticating extruder [47] as compared to an idealized cross-section upon which the theoretical model is based, and it demonstrates the features of the melting mechanism. The width of the solid bed usually decreases along the extruder. The rate of decrease is highest when the channel depth does not decrease, but remains constant as is the case in the feed and metering sections of a standard metering type single screw. The reduced solid bed width in the down channel direction, for a parallel-constant depth channel is given by,

$$\frac{X_o}{W} = \frac{X_i}{W}\left(1 - \frac{\varphi\Delta z}{2D_c}\right)^2 \qquad (9.15)$$

where $X_i/W$ is the value at the entrance to the melting zone, W is the channel width, $\Delta z$ an increment in the down channel distance, $D_c$, $D_{cin}$, and $D_{cout}$ are the channel depths of a parallel channel and of a tapered channel at the entrance and exit of the increment, respectively, and $\Psi$ is a dimensionless group which is a measure of the rate of melting defined by,

$$\Psi = \frac{\varphi W^{1/2}}{\left(\frac{X_i}{W}\right)^{1/2} \frac{G}{Dcin}} \qquad (9.16)$$

Eq. 9.16 contains the term $\varphi$ a function of the physical properties and operating conditions. It is defined as,

$$\varphi = \left\{ \frac{V_{bx} U_2 \rho_m [k_m(T_b - T_m) + \frac{U_1}{2}]}{2[C_{ps}(T_m - T_r) + \lambda^*]} \right\}^{1/2} \qquad (9.17)$$

The thickness of the melt film above the solid bed on the barrel surface is calculated from,

$$\delta = \left\{ \frac{2k_m[k_m(T_b - T_m) + U_1]X}{[V_{bx} U_2 \rho_m C_{ps}(T_m - T_r) + \lambda^*]} \right\}^{1/2} \qquad (9.18)$$

$$\lambda^* = \lambda + C_{pm}(T_{av} - T_m) \qquad (9.19)$$

where $U_1$ and $U_2$, are defined as,

$$U_1 = \frac{2K_3}{A_4^2}(A_4 + e^{-A_4} - 1) \qquad (9.20)$$

$$U_2 = 2\left(\frac{1}{1 - e^{-A_4}} - \frac{1}{A_4}\right) \qquad (9.21)$$

$$A_4 = a\frac{T_b - T_m}{n} \qquad (9.22)$$

$C_{ps}$ =specific heat of the solid, BTU/lb °F

$C_{pm}$ =specific heat of the melt, BTU/lb °F

$T_b$ =barrel temperature, °F

$T_m$ =melting temperature of the polymer, °F

$T_{av}$ =average temperature of the polymer in the film, °F

$V_{bx}$ =velocity component in the x direction of the inner surface of the barrel relative to screw, in/sec

X =solid bed width, in

$X_i$ =solid bed width at the entrance of axial increment, in

$X_o$ =solid bed width at the exit of axial increment, in

a =constant

$k_m$ =thermal conductivity of the melt, BTU/hr °F

n =parameter in the "power law" model

$\rho_m$ =density of the melt, $lb/ft^3$

and $\lambda$ =heat of fusion, BTU/lb

The term $U_1$ relates to the heat generated by viscous dissipation in the film, and the term $U_2$ is a measure of decrease in flow rate due to the modified velocity profile. From these, the width of the solid bed , the temperature of plastic melt beside it, and then the melt pressure are computed.

## 9.2 Geometry of the Screw

The objectives of PC EXTRUD® is either to quantitatively evaluate the performance characteristics of an existing screw or to design a new screw to an existing set of quantitative specifications. The Prodex extruder is a 2.5 inch diameter extruder. A photograph is shown in Figure 9.3. The specification of this Prodex extruder may be described as follows. The maximum screw speed is 200 rpm. The mass flow rates range from 50 lb/hr to 300 lb/hr depending on the screw speed. There are six heating zones in the barrel. The entire screw is shown in Figure 9.4. The details of the screw geometry are shown in Figure 9.5. It has eight section zones. The screw may be defined geometrically as follows,

$L$ =total length of the extruder, in

$S_n$ =number of sections with different geometries in the plasticating extruder to be simulated

$L_s$ =length of each geometrical section, in

Dcn =channel depth at the end of each geometrical section, in

$N_t$ =number of channels (threads) in parallel

$S_l$ =screw lead, in

$C_f$ =channel flight width, in

and $C_c$ =channel flight clearance, in

These geometric parameters determine the performance of the screw; and are varied depending upon the material being extruded and the operating requirements. The software can be used effectively to predict the performance of screw pump, in terms of pressure generation, temperature rise or mixing. The EXTRUD® can calculate and plot complete axial plastic melt pressure and temperature profiles, the relative width of the solid bed along the extruder, the power required to run the extruder and the cumulative heat transfer through the whole length of the extruder barrel.

### 9.3 Operating Variables

In addition, PC EXTRUD® also can be used to predict the effects of the following operating variables on the production rate and product quality.

1. changing flow rate,

2. changing screw speed,

3. changing barrel temperature,

It can evaluate these and other changes, quicker, faster and more accurately than with conventional methods. By utilizing the friction factor on both the barrel and the screw surfaces, it can compute the pressure rise across the solids conveying zone of the extruder. From the point where melting commences the extruder is subdivided into short axial increments in each of which constant conditions are assumed. An iterative approach is used to calculate steady-state conditions in each of these increments. In the melting section the thickness and temperature of the melt film above the solid bed on the barrel surface are calculated. In addition, the width of the solid bed, the temperature of the plastic melt beside it, and the plastic melt pressure are computed.

### 9.4 Simulation Input

The input data for PC EXTRUD® can be created by following the format of the input data as described in the Appendix A [57]. The material data bank developed from experimental work from the DATA BANK software [58] of Scientific Process & Research (SPR). It contains the physical processing properties and frictional properties. The input data for the simulation of the performance of plasticating extruders can be classified into three categories. The first is screw geometry, the second is material properties, and the last is the operating conditions. The input data is listed in Appendix B. There are eight geometrical section zones and six heating zones. The screw geometry is input to the computer as follows,

$L$ = 112.14 inches, total length of the extruder

$D_B$ =2.5 inches, barrel inside diameter

$S_n$ =8, section number of screw

$L_{s1}$ =19.8 inches, length for first section of the screw

$S_{l1}$ =2.475 inches, screw lead for first section

$D_{c1}$= 0.437 inch, channel depth at the end of first geometrical section

$L_{s2}$ =27.55 inches, length for second section of the screw

$S_{l2}$ =2.475 inches, screw lead for second section

$D_{c2}$=0.15 inch, channel depth at the end of second geometrical section

$L_{s3}$ =16.6 inches, length for third section of the screw

$S_{l3}$ =3.45 inches, screw lead for third section

$D_{c3}$= 0.450 inch, channel depth at the end of third geometrical section

$L_{s4}$ =2.475 inches, length for fourth section of the screw

$S_{l4}$ =2.475 in, screw lead for fourth section

$D_{c4}$= 0.387 inch, channel depth at the end of fourth geometrical section

$L_{s5}$ =9.9 inches, length for fifth section of the screw

$S_{l5}$ =2.475 in, screw lead for fifth section

$D_{c5}$= 0.437 inch, channel depth at the end of fifth geometrical section

$L_{s6}$ =3.125 inches, length for sixth section of the screw

$S_{l6}$ =3.125 in, screw lead for sixth section

$D_{c6}$= 0.237 inch, channel depth at the end of sixth geometrical section

$L_{s7}$ =16.6 inches, length for seventh section of the screw

$S_{l7}$ =3.45 in, screw lead for seventh section

$D_{c7}$= 0.213 inch, channel depth at the end of seventh geometrical section

$L_{s8}$ =4.95 inches, length for eighth section of the screw

$S_{l8}$ =2.475 in, screw lead for eighth section

$D_{c8}$= 0.213 inch, channel depth at the end of eighth geometrical section

$N_t$ =1, number of channels (threads) in parallel

$C_f$ =0.30 inch, channel flight width for whole screw

and $C_c$ =0.0125 inch, channel flight clearance for whole screw

The operating conditions for the simulations, except as stated, were,

$N_s$ =50rpm, screw speed

G =100lb/hr, flow rate

$T_{b1}$ = 390 °F, barrel temperature for first heating zone

$T_{b2}$ = 400 °F, barrel temperature for second heating zone

$T_{b3}$ = 410 °F, barrel temperature for third heating zone

$T_{b4}$ = 420 °F, barrel temperature for fourth heating zone

$T_{b5}$ = 430 °F, barrel temperature for fifth heating zone

and $T_{b6}$ = 440 °F, barrel temperature for six heating zone

The material properties and frictional coefficients for acetal copolymer grade M90 were taken from the DATA BANK described as above. The input data for each simulation is shown in Appendix B.

### 9.5 Description of the Simulation Printout

After, the prepared data file is run by EXTRUD®. The resulting output of the computer is grouped sequentially as follows [57],

1. Printout of the input data. It includes physical properties, screw and hopper geometry and operating conditions.
2. Hopper, basically computes the pressure under the hopper and the height of the solid column above which there will be no further substantial increase in base pressure.
3. Solid conveying zone. Providing the following tabular information:

| | | |
|---|---|---|
| (a) | LOCATION | axial location along screw, in |
| (b) | PHI | angle of advancement of solid plug, degrees |
| (c) | ROBP | bulk density of solid, lb/ft$^3$ |
| (d) | FRIB | coefficient of friction on barrel surface |
| (e) | FRIS | coefficient of friction on screw surface |
| (f) | TEMPERATURE | inner surface temperature of barrel, °F |

| | | |
|---|---|---|
| | BARREL | |
| (g) | TEMPERATURE SCREW | screw surface temperature, °F |
| (h) | POWER | cumulative power consumption, HP |
| (i) | PRESSURE | pressure at location L, psi |

4. Delay, melting and melt pumping zones. Provides the following tabular information:

| | | |
|---|---|---|
| (a) | L | axial location, in |
| (b) | TOUT | melt pool temperature at location L, °F |
| (c) | X/W | solid bed width |
| (d) | X/W -INJ | solid bed width at the start of screw rotation in injection molding |
| (e) | GRATIO | fraction of output still unmelted |
| (f) | PRESSURE REAL | pressure at axial location L, psi |
| (g) | PRESSURE FULL | pressure assuming solids conveying is not limiting performance, psi |
| (h) | POWER | cumulative power consumed from hopper to axial location L, HP |
| (i) | HOUT | channel depth at location L, in |
| (j) | TBAR | pressure at location L, psi |
| (k) | TVISC | pressure at location L, psi |
| (l) | DHEAT | pressure at location L, psi |
| (m) | FILM TEMP | pressure at location L, psi |
| (n) | TSCREW | pressure at location L, psi |
| (o) | DELTA | pressure at location L, psi |
| (p) | SOBVEF | pressure at location L, psi |
| (q) | VMELTP | melt pool velocity, in/min |

5 Additional printout:

(a) Minimum temperature - due to the presence of unmelted plastic, °F

(b) Temperature fluctuation - due to the presence of unmelted plastic, $^{o}F$

(c) Flow index (N) representing the non-Newtonian character of the melt that is the shear rate dependence of shear stress as $\tau = m_0\gamma^N$

(d) Residence time: melt pool, HRS

(e) Pressure fluctuation - at tip of screw due to flight, psi/cycle

(f) Strength analysis of screw determines the maximum permissible channel depth an cooling hole diameter with the existing channel depth

(g) Break down of power consumption according to its occurrence for solids conveying, melting, mixing, flight clearance, pressurization an mixing devices

(h) Heat conduction through barrel in each header zone, BTU/min

(i) Heat conduction over the whole barrel, BTU/min

(j) Effect of regearing or gear changes on available power

(k) Report on viscosity computation - average and maximum shear rate as well as average and maximum temperature at which viscosity was computed

(l) Pressure rise or drop as well as temperature rise or drop through mixing section

## 9.6 Simulation Results

The purpose of using PC EXTRUD® for the simulation of plasticating extrusion enables the extruder designer and extrusion engineers to simulate the extruder, thereby reducing or eliminating the need for conducting costly experiments. The utilization of the mathematical model [49] involves the simulation of the performance of different size extruders with various screws and operating conditions to determine their relative performance in the desired application. This procedure will yield an optimized design and valuable information on the performance of the extruder under a variety of operating conditions.

In addition to the use of the PC EXTRUD® for the design of extruders, one can simulate the performance of an extruder and study the effect of changing one variable at a time. Thus a great deal of insight may be gained on the process. It has been pointed out before that in the laboratory quite often it is impossible to change one variable without affecting others. The experimental separation of variables is almost impossible. Simulations with the aid of the mathematical model provide a means for separating the variables, allow the derivation of meaningful conclusions on the importance of each individual variable. It is the purpose of this work to discuss the effect of operating conditions and polymer properties on plasticating extrusion by performing simulations using the PC EXTRUD®.

The prepared data files in appendix B are ready for input to PC EXTRUD®. All simulation results are included in appendix B. An example of the printout is as follows,

```
EXPERIMENT NUMBER    1.00       12.00     SCIENTIFIC PROCESS & RESEARCH, INC.

N= 50.0 RPM            OUTPUT=     100.00 LB/HR      SOAK TIME=   0.0 SECONDS
```

After this the screw geometry is typed out:

```
SECTION   LENGTH    CH.DEPTH        WIDTH         LEAD     BAR.    FLT.      NO OF      HOLE

   #       (IN)   SOLID  MELT    SOLID  MELT             DIAM    WIDTH     HOLES      AREA

                   (IN)   (IN)    (IN)   (IN)    (IN)    (IN)    (IN)                 (SQIN)

   1      19.800   0.437  0.000   2.061  0.000   2.475   2.500   0.300

   2      27.550   0.150  0.000   2.061  0.000   2.475   2.500   0.300

   3      16.600   0.150  0.450   1.354  1.354   3.450   2.500   0.300

   4       2.475   0.387  0.000   2.061  0.000   2.475   2.500   0.300

   5       9.900   0.437  0.000   2.061  0.000   2.475   2.500   0.300

   6       3.125   0.237  0.000   2.604  0.000   3.125   2.500   0.300

   7      16.600   0.213  0.000   2.859  0.000   3.450   2.500   0.300     1.000      0.914

   8       4.950   0.213  0.000   2.061  0.000   2.475   2.500   0.300
```

This is followed by portion of the input data related to the hopper and solids conveying. Following this EXTRUD® performs a hopper analysis:

```
ATTENTION   - SOLIDS   HEIGHT   IN   HOPPER   IS   LOW   !

SOLIDS   HEIGHT   =        36.00  IN.  BASE   PRESSURE    =      0.33  PSI

INCREASE   HEIGHT   TO   =      186.01  IN.   MAXIMUM    PRESSURE = 0.75    PSI
```

The hopper analysis reveals that with the hopper geometry used the resin being processed requires a 186.01 inch high column in the hopper. A lower column of solids will effect solids conveying and with it the production rate of the extruder. Under these conditions the variation in column height can cause surging. On the other hand a higher column of solids will not affect the extruder performance. The hopper analysis is followed by the solids conveying zone analysis. It yields the angle of advancement of the solid bed along the solids conveying zone (PHI), the bulk density at points along the solids conveying zone of the extruder as effected by pressure and surface temperature (ROBP), the coefficient of friction on the barrel surface (FRIB) and on the screw surface (FRIS) as affected by the surface temperatures, pressure and resulting bulk density, the barrel and screw surface temperatures, cumulative power consumption from the downstream end of the hopper (POWER) and pressure buildup (PRESSURE). This is shown as follows,

```
                                 SOLIDS  CONVEYING  ZONE  ANALYSIS

OPTIUM  SURFACE  TEMPERATURES  FOR  SOLIDS  CONVEYING:

BARREL  =          67.00  DEG.F          AND       SCREW =          207.00  DEG.F


LOCATION   PHI     ROBP     FRIB    FRIS   TEMPERATURE       DEG F   POWER       PRESSURE

   IN      DEG    LB/CU. FT                   BARREL         SCREW    HP           PSI
  1.00     13.7     21.13   0.059   0.003      67.0          207.0    0.00         0.51
  2.00     13.6     21.22   0.065   0.008      67.0          207.0    0.00         0.79
  3.00     13.5     21.33   0.072   0.014      67.0          207.0    0.00         1.25
  4.00     13.3     21.53   0.084   0.025      67.0          207.0    0.00         2.00
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5.00 | 12.9 | 21.92 | 0.101 | 0.044 | 75.0 | 207.0 | 0.00 | 3.28 |
| 6.00 | 12.7 | 22.12 | 0.072 | 0.054 | 67.0 | 207.0 | 0.01 | 4.03 |
| 7.00 | 12.5 | 22.39 | 0.083 | 0.067 | 67.0 | 207.0 | 0.01 | 4.94 |
| 8.00 | 12.2 | 22.66 | 0.093 | 0.078 | 67.0 | 207.0 | 0.01 | 5.89 |
| 9.00 | 12.0 | 22.96 | 0.105 | 0.091 | 67.0 | 207.0 | 0.01 | 6.98 |
| 10.00 | 11.7 | 23.31 | 0.117 | 0.104 | 67.0 | 207.0 | 0.02 | 8.23 |
| 10.90 | 11.4 | 23.66 | 0.129 | 0.117 | 330.0 | 207.0 | 0.03 | 9.53 |

The solid conveying zone is followed by the delay zone which contains no melt pool only the melt film on the barrel surface which develops to its full thickness along this zone. The delay zone is followed by the melting zone.

The following table yields the melt temperature in the melt pool (TOUT) along the extruder at every location (L), the relative width of the solid bed (X/W) along the extruder, its value in noncontinuous extrusion that is injection molding (X/W INJ), solids content at every point (GRATIO), REALPRESSURE in the case of possible solids conveying problems, FULL PRESSURE when solids conveying problems are eliminated. The cumulative power consumption by the rotating screw (POWER), channel depth (HOUT), barrel temperature (TBAR), viscosity of the melt pool along the extruder (TVISC), the incremental heat transferred through the barrel (D.HEAT) and the maximum melt film temperature at the barrel surface (FILM TEMP). D.HEAT is positive during barrel cooling that is when heat is flowing out through the barrel and negative during barrel heating when heat is flowing into the extruder:

| L | TOUT | X/W | X/W | GRATIO | PRESSURE | | POWER | HOUT | TBAR | TVISC | D.HEAT | FILM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IN | DEG F | SOLID | | | PSI | | HP | IN | DEG F | LB.SEC | BUT/IN | TEMP |
| | | | | | REAL | FULL | | | | /SQ. IN | . MIN | DEG F |
| 13.10 | 342.5 | | | | 471. | 471. | | 0.437 | 349.0 | 0.0811 | | |
| 15.10 | 364.4 | | | | 837. | 837. | | 0.437 | 380.8 | 0.0389 | | |
| 17.10 | 371.3 | | | | 1071. | 1071. | | 0.437 | 390.6 | 0.0903 | | |

```
18.10   359.9   .879  .879  .732  1111.  1111.   0.2   0.437  390.6   0.1863   -32.5    391.

19.80   361.7   .830  .830  .691  1179.  1179.   0.4   0.437  390.6   0.1851    -2.2    391.

24.80   373.3   .763  .763  .655  1379.  1379.   1.1   0.385  394.7   0.1522     2.8    394.

26.10   378.0   .746  .746  .645  1431.  1431.   1.2   0.372  395.5   0.1232     3.5    395.

31.10   391.2   .674  .674  .601  1646.  1646.   1.9   0.320  398.6   0.1098     2.1    398.

36.10   398.9   .596  .596  .546  1899.  1899.   2.5   0.267  401.5   0.1027     1.0    401.

41.10   403.6   .508  .508  .478  2200.  2200.   3.1   0.215  404.4   0.0985    -0.5    404.

46.10   406.3   .402  .402  .390  2527.  2527.   3.7   0.163  407.2   0.0964    -2.6    407.

47.35   406.7   .373  .373  .363  2599.  2599.   3.8   0.150  408.1   0.0960    -4.0    408.

----------------------------------SECONDARY CHANNEL BEGINS--------------------------------

52.35   404.0   .185  .374  .185  2953.  2953.   4.3   0.150  410.6   0.1020    -8.2    410.

57.35   408.0   .077  .188  .077  3282.  3282.   4.6   0.150  413.5   0.1001    -2.7    413.

62.35   413.1   .003  .010  .003  3520.  3520.   506   0.150  416.3   0.0959     3.4    416.

63.95   415.3   .000  .000  .000  3576.  3576.   5.6   0.150  417.4   0.0944     1.8    417.

-------------------------------SECONDARY CHANNEL ENDS-------------------------------------

65.19   417.6   .000  .000  .000  3644.  3644.   5.7   0.269  418.2   0.0876     2.2    417.

66.42   419.1   .000  .000  .000  3687.  3687.   5.8   0.387  418.2   0.0932     1.7    417.

71.37   422.9   .000  .000  .000  3820.  3820.   6.0   0.412  421.6   0.0925     1.6    417.

76.32   426.1   .000  .000  .000  3939.  3939.   6.1   0.437  424.4   0.0915     1.5    417.

77.89   427.2   .000  .000  .000  3981.  3981.   6.2   0.338  425.4   0.0862     1.7    417.

79.45   428.7   .000  .000  .000  4040.  4040.   6.3   0.238  426.3   0.0815     2.1    417.

------------------------------------------------------------------------------------------

               FLUTED SECTION WITH 1. PAIRS OF FLUTES

96.05   428.7   .000  .000  .000  4039.  4039.   6.3   0.213  431.1   0.0815     2.1    417.

------------------------------------------------------------------------------------------

101.00  437.9   .000  .000  .000  4288.  4288.   6.6   0.213  438.3   0.0803     2.1    417.

MINIMUM TEMPERATURE =     437.908  DEG F
```

```
TEMP FLUCTUATION =          0.000  DEG F

FLOW INDEX (N) =            0.763

GRATIO INJ. =               0.000

RESIDENCE TIME:

        MELT POOL   = 0.050008345  HRS

        TORQUE      = 8303.5  INCH. POUNDS
```

The simulation also reveals that due to the presence of unmelted pellets in the extrudate a 0.000 °F temperature fluctuation will be experienced. Without the solids conveying problem the solid totally melt downs. The torque and the break down in power consumption is printed out as follows,

```
POWER BREAK-DOWN:
SOLIDS CONV              =     0.027  HP
MELTING                  =     3.545  HP
MIXING                   =     1.463  HP
FLIGHT CLEAR             =     1.303  HP
COMPRESSION              =     0.195  HP
MIXING DEVICE            =     0.060  HP
PRESSURE FLUCTUATION =         170.41  PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=          -89.1 TO -21.0 BTU/MIN OR
                                              -2.10  TO  -0.49 HP
```

The above gives the heat conduction through the barrel. Positive values for heat represent heat conducted out through the barrel that is cooling while negative values represent heat conducted into the extruder from the barrel that is heating the polymer. It shows that between 0.49 and 2.1 HP were supplied through the barrel in addition to the 5.1 HP used by the motor to rotate the screw.

```
MAXIMUM SCREW SPEED, RPM:                  50.0    75.0   100.0   125.0    150.0    175.0   200.0
POWER CONSUMPTION, % OF AVAILABLE:          6.6     9.9    13.2    16.5     19.8     23.1    36.3
```

The above yields the effect of regearing the extruder. It shows that since the extruder has a 100 rpm maximum screw speed its full power rating can not be obtained except by regearing to have a maximum speed of 50 rpm. The effect of intermediate gear ratios is also given. The above table assumes a DC drive the power of which linearly increases with rotational speed.

```
STRENGTH ANALYSIS OF YOUR SCREW (4140STEE) :

MAXIMUM PERMITTED COOLING HOLES DIAMETER IS 1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.641 INCHES
```

The strength analysis of the screw with the material used to construct the screw (4140 steel) reveals that processing the resin in question with the above barrel temperature profile and operating conditions the screw can be deepened from the present 0.4370 inches to 0.641 inches without endangering the integrity of the screw. It also reveals that without deepening the channel the screw can be cored to a 1.10 inch diameter with the additional strength of the screw into which the 0.4370 inch deep channel has been cut. This however is valid only for the resin grade in question and for the barrel temperatures used. Should the barrel temperature be lowered, power consumption will rise lowering the permitted channel depth accordingly.

Next statistical information is provided on the viscosity data used by the simulation. It yields the shear rate and temperature ranges at which viscosity had to be computed in the simulation.

```
VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
SHEAR RATE              TEMP.            VISCOSITY
   1/SEC                DEG.F           LB.SEC/SQ.IN
  770.55                342.5            0.0588104
    8.18                390.6            0.1541261

VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
SHEAR RATE              TEMP.            VISCOSITY
   1/SEC                DEG.F           LB.SEC/SQ.IN
   14.32                441.3            0.1012381
  230.69                329.0            0.1049526

AT 50.00 RPM & 100.00 LB/HR PRODUCTION RATE
HEAD PRESSURE IS 4288. PSI.
```

### 9.6.1 Varying the Screw Speed

The screw speed is the single most important variable, because it can be controlled best and is also the most often varied.

The screw speed was ranged from 30rpm to 70rpm for acetal copolymer grade M90 at the same barrel temperature, flow rate, material properties, and frictional coefficient. Appendix B represents the operating conditions for acetal copolymer grade M90 with screw speeds from 30 rpm to 70rpm. Appendix B shows the operating conditions for acetal copolymer grade M90 with a screw speed of 30rpm. The solids bed has some fraction unmelt at the end of the extruder. The screw is good enough to endure the strength under this operating conditions. The power consumed 3.4 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with a screw speed of 40rpm. The solids bed melt down occurs at an axial screw position of 67 inches. The screw is good enough to endure the strength under this operating conditions. The power consumed 4.85 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with a screw speed of 50rpm. The solids bed melt down occurs at an axial screw position of 63.95 inches. The head pressure at the exit of the extruder is 4288 psi. The screw is good enough to endure the strength under this operating conditions. The power consumed 8.4 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with a screw speed of 60rpm. The solids bed melt down occurs at an axial screw position of 57.5 inches. The head pressure at the exit of the extruder is 5297 psi. The screw is good enough to endure the strength under this operating conditions. The power consumed 9.0 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with a screw speed of 70rpm. The solids bed melt down occurs at an axial screw position of 52.5 inches. The head pressure at the exit of the extruder is 6158 psi. The screw is good enough to endure the strength under this operating conditions. consumed 7HP for the plasticating extrusion process.

### 9.6.2 Varying the Flow Rate

The flow rates was ranged from 80lb/hr to 120 lb/hr for acetal copolymer grade M90 at the same barrel temperature, screw speed, material properties, and frictional coefficient. Appendix B represents the operating conditions for acetal copolymer grade M90 with flow rates from 80lb/hr to 120 lb/hr. Appendix B shows the operating conditions for acetal copolymer grade M90 with flow rates at 80 lb/hr. The solids bed melt down occurs at an axial screw position of 57.5 inches. The extrudate discharge pressure is 4707 psi. The screw is good enough to endure the strength under this operating conditions. The power consumed 6.3 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with flow rates at 90 lb/hr. The solids bed melt down occurs at an axial screw position of 62.4 inches. The extrudate discharge pressure is 4501 psi. The screw is good enough to endure the strength under this operating conditions. The power consumed 6.4 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with flow rates at 100 lb/hr. The solids bed melt down occurs at an axial screw position of 64 inches. The extrudate discharge pressure is 4288 psi. The screw is good enough to endure the strength under this operating conditions. The power consumed 6.6 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with flow rates at 110 lb/hr. The solids bed melt down occurs at an axial screw position of 76.3 inches. The extrudate discharge pressure is 4024 psi. The screw is good enough to endure the strength under this operating conditions. consumed 7.2 HP for the plasticating extrusion process. Appendix B shows the operating conditions for acetal copolymer grade M90 with flow rates at 120 lb/hr. The solids bed melt down occurs at an axial screw position of 101 inches. The screw is good enough to endure the strength under this operating conditions. The power consumed 8.4 HP for the plasticating extrusion process.

### 9.6.3 Varying the IPFC

By inputting the IPFC instead of the barrel friction in simulation and systematically reducing the barrel diameter from 2.5 inches to 1.75 inches. The effect of the IPFC on the conveying capacity of the solids can be determined.

The IPFC instead of barrel friction was ranged from 0.05 to 0.25 lb/hr for acetal copolymer grade M90 at the same barrel temperature, screw speed, flow rate, and material properties. Appendix B represents the operating conditions for acetal copolymer grade M90 with IPFC from 0.05 to 0.25. Appendix B shows the IPFC is 0.05 for acetal copolymer grade M90 at barrel diameter 2.5 inches. The solid conveying capacity seems to rupture. Appendix B shows the IPFC is 0.10 for acetal copolymer grade M90 at barrel diameter 2.5 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.15 for acetal copolymer grade M90 at barrel diameter 2.5 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.20 for acetal copolymer grade M90 at barrel diameter 2.5 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.25 for acetal copolymer grade M90 at barrel diameter 2.5 inches. The solid conveying capacity is free from rupture.

The IPFC instead of barrel friction was ranged from 0.05 to 0.25 for acetal copolymer grade M90 at the same barrel temperature, screw speed, flow rate, and material properties. Appendix B represents the operating conditions for acetal copolymer grade M90 with IPFC from 0.05 to 0.25. Appendix B shows the IPFC is 0.05 for acetal copolymer grade M90 at barrel diameter 2.25 inches. The solid conveying capacity seems to rupture. Appendix B shows the IPFC is 0.1 for acetal copolymer grade M90 at barrel diameter 2.25 inches. The solid conveying capacity is free from rupture.Appendix B shows the barrel friction is 0.15 for acetal copolymer grade M90 at barrel diameter 2.25 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.20 for acetal copolymer grade M90 at barrel diameter 2.25 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.25 for acetal copolymer grade M90 at barrel diameter 2.25 inches. The solid conveying capacity is free from rupture.

The IPFC instead of barrel friction was ranged from 0.05 to 0.25 for acetal copolymer grade M90 at the same barrel temperature, screw speed, flow rate, and material properties. Appendix B represents the operating conditions for acetal copolymer grade M90 with IPFC from 0.05 to 0.25. Appendix B shows the IPFC is 0.05 for acetal copolymer grade M90 at barrel diameter 2.0 inches. The solid conveying capacity seems to rupture at this moment. Appendix B shows the IPFC is 0.1 for acetal copolymer grade M90 at barrel diameter 2.0 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.15 for acetal copolymer grade M90 at barrel diameter 2.0 inches. The solid conveying capacity is free from rupture. Appendix B shows the IPFC is 0.20 for acetal copolymer grade M90 at barrel diameter 2.0 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.25 for acetal copolymer grade M90 at barrel diameter 2.0 inches. The solid conveying capacity is free from rupture.

The IPFC instead of barrel friction was ranged from 0.05 to 0.25 for acetal copolymer grade M90 at the same barrel temperature, screw speed, flow rate, and material properties. Appendix B represents the operating conditions for acetal copolymer grade M90 with IPFC from 0.05 to 0.25. Appendix B shows the IPFC is 0.05 for acetal copolymer grade M90 at barrel diameter 1.75 inches. The solid conveying capacity seems to rupture. Appendix B shows the IPFC is 0.1 for acetal copolymer grade M90 at barrel diameter 1.75 inches. The solid conveying capacity is also to rupture. Appendix B shows the barrel friction is 0.15 for acetal copolymer grade M90 at barrel diameter 1.75 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.20 for acetal copolymer grade M90 at barrel diameter 1.75 inches. The solid conveying capacity is free from rupture. Appendix B shows the barrel friction is 0.25 for acetal copolymer grade M90 at barrel diameter 1.75 inches. The solid conveying capacity is free from rupture.

## 9.7 Simulation Discussion

### 9.7.1 Effect of Screw Speed

In Figure 9.6 the pressure is presented as a function of axial screw position for different screw speeds for acetal copolymer grade M90. At a high frequency of screw rotation, the axial pressure profiles exhibit a maximum. The relative width of the solid bed (X/W) along the extruder as a function of axial screw position is presented in Figure 9.7 for acetal copolymer grade M90. The relative width of solid bed is decreasing while increasing the screw speed.

### 9.7.2 Effect of Flow Rate

In plasticating extrusion the effect of flow rate on the melting behavior, pressure, temperature, temperature fluctuation of the extrudate, and power consumption is of considerable interest. Running the simulation at various flow rates while keeping all other variables, such like frequency of screw rotation, screw geometry, and flight clearance constant enables information to be obtained on the ratio of width of the solid bed to the width of the screw channel, its thermal and pressure history while traveling through the extruder, as well as on the extrudate discharge pressure, representing the pressure drop requirements from the die.

Figure 9.8 the pressure is presented as a function of axial screw position for different flow rates for Acetal copolymer grade M90 at 415°F barrel temperature with constant screw speed. These pressure profiles increase a monotonically at low flow rates. Figure 9.9 represents the relative width of solid bed as a function of axial screw distance for acetal copolymer grade M90 at various flow rates with constant screw speed. It can be seen that at low flow rates the relative width of solid bed decreases rapidly. At low flow rates a considerable amount of heat is generated, which soon increases the melt temperature in the extruder to above the barrel temperature.

### 9.7.3 Effect of IPFC

By inputting the IPFC instead of the barrel friction in the simulation and systematically reducing the barrel diameter, the effect of the IPFC on the conveying capacity of the solids can be determined.

Figure 9.10 presented the IPFC as a function of axial screw position for acetal copolymer grade M90 at same channel depths. It is clear that solid bed is inhibited rupture by increasing the IPFC value.

From the results presented in Figures 9.10, where full conveying conditions exist the solid bed will convey as a continuum. However, when no conveying conditions exist the solid bed may partially convey, that is, it may rupture. Clearly rupture of the solids bed is most likely to occur near the screw surface. It is also clear that solid bed rupture may be inhibited by increasing the IPFC value, which has been the focus of this dissertation.

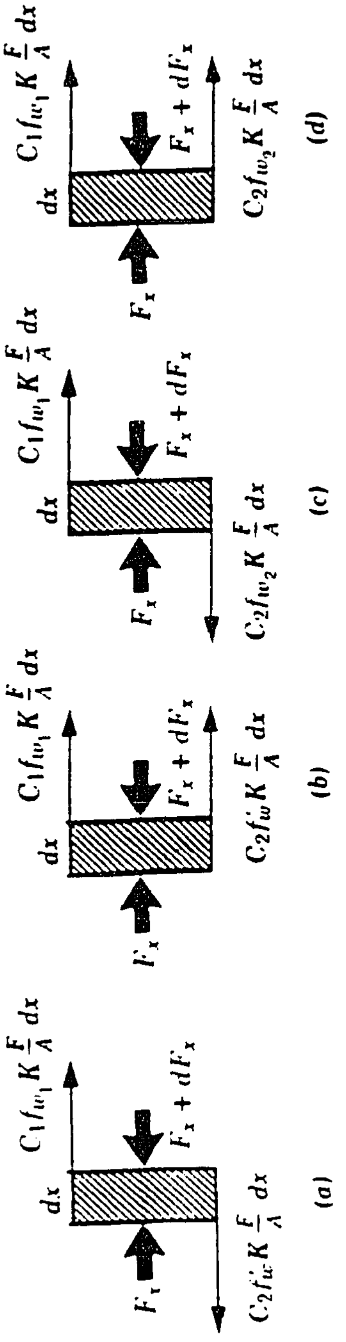


Figure 9.1 Force Balances on a Differential Element of Particulate Bed, (a) Stationary Solids, $F_0 > F_L$, (b) Stationary Solids, $F_0 > F_L$, (c) Solids Move at Constant Velocity in the Position X-Direction, (d) Solids Move at Constant Velocity in the Negative X-Direction.
(From Tadmor, Z., and Gogos, C. G. [48])

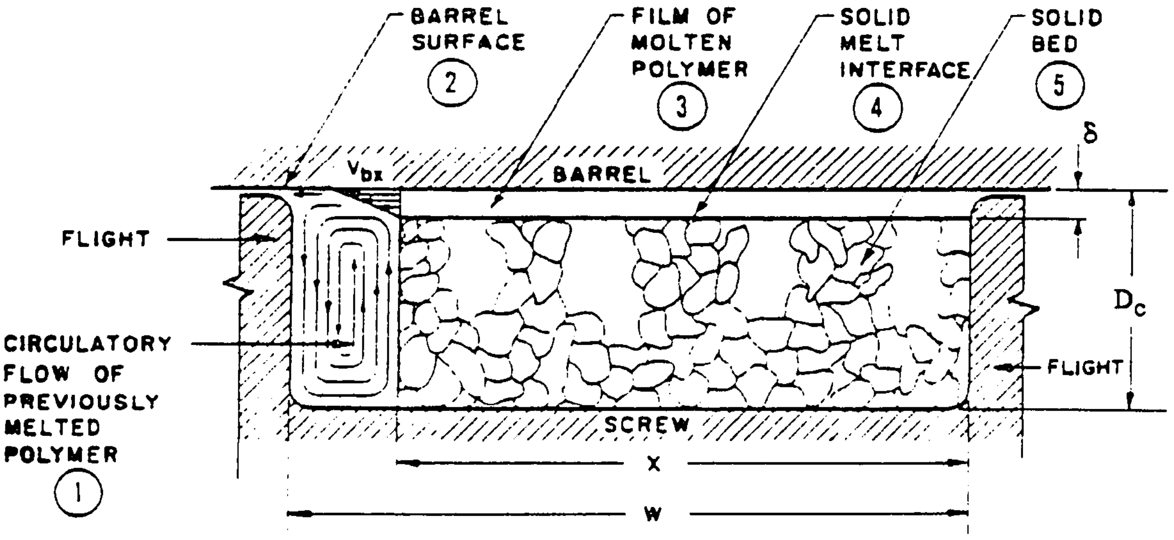


Figure 9.2 Idealized Channel Cross-Section Perpendicular to the Flights Compared to Real Cross-Sections in the Melting Zone.
(From Tadmor, Z., Duvdevani, I. J., and Klein, I, 7, 198 , 1967)

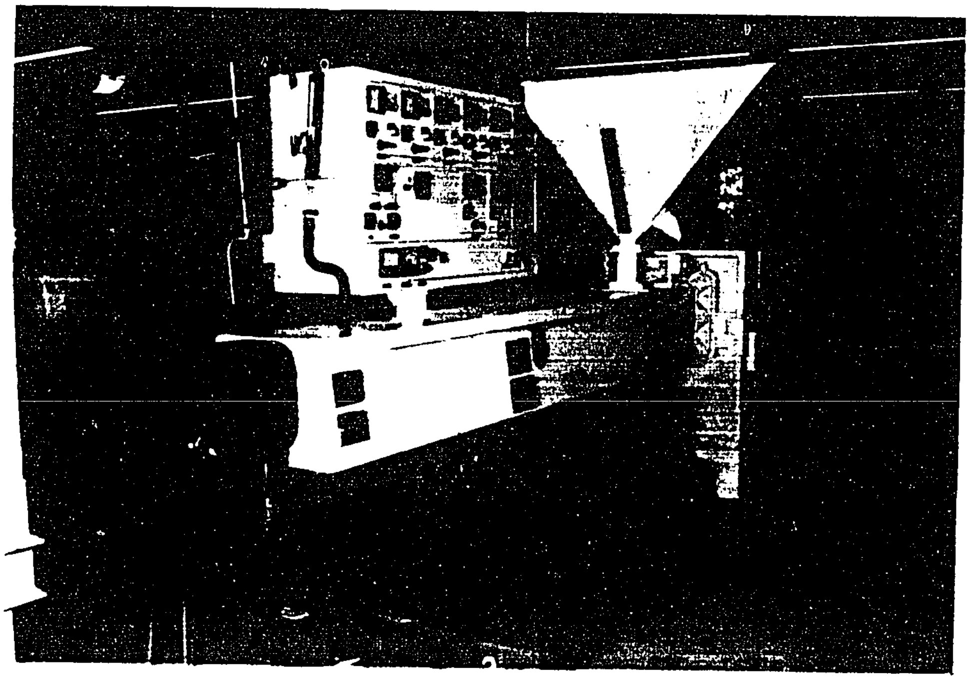


Figure 9.3 Extruder Manufactured by Prodex Co.

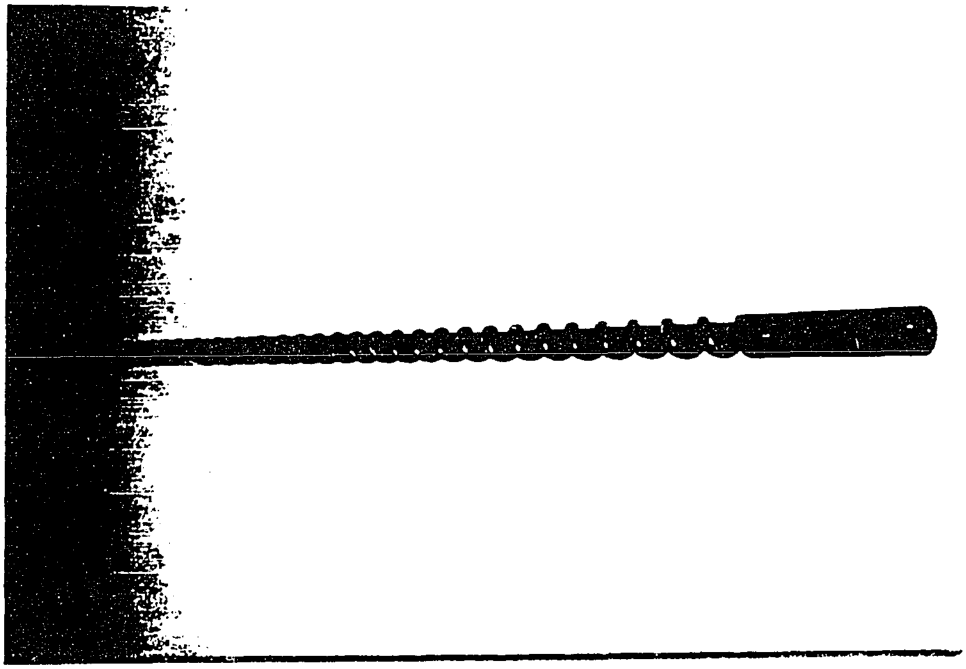
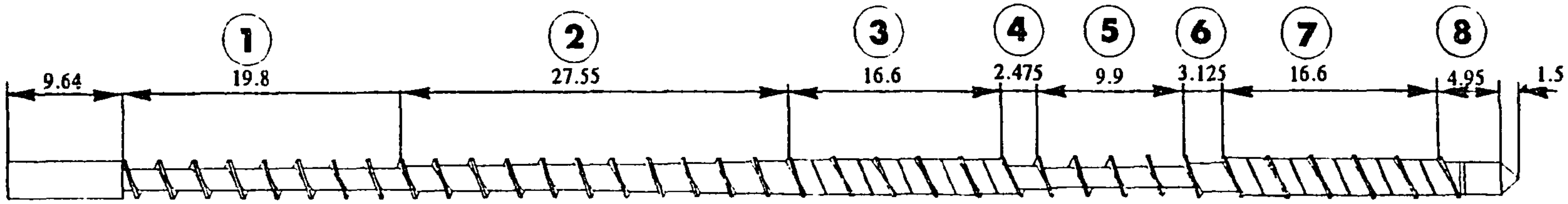


Figure 9.4 Screw Manufactured by Prodex Co.



| No | LEAD | CH.DEPTH SOLID | MELT | FLT. WIDTH | HELIX ANGLE | FLT. CLE. |
|---|---|---|---|---|---|---|
| 1. | 2.475 | 0.437 | 0.0 | 0.300 | 17.6 | 0.0125 |
| 2. | 2.475 | 0.150 | 0.0 | 0.300 | 17.6 | 0.0125 |
| 3. | 3.45 | 0.150 | 0.450 | 0.300 | 23.5 | 0.0125 |
| 4. | 2.475 | 0.387 | 0.0 | 0.300 | 17.6 | 0.0125 |
| 5. | 2.475 | 0.437 | 0.0 | 0.300 | 17.6 | 0.0125 |
| 6. | 3.125 | 0.237 | 0.0 | 0.300 | 19.4 | 0.0125 |
| 7. | 3.45 | 0.213 | 0.0 | 0.300 | 23.5 | 0.0125 |
| 8. | 2.475 | 0.213 | 0.0 | 0.300 | 17.6 | 0.0125 |

Figure 9.5 Details of Prodex Screw

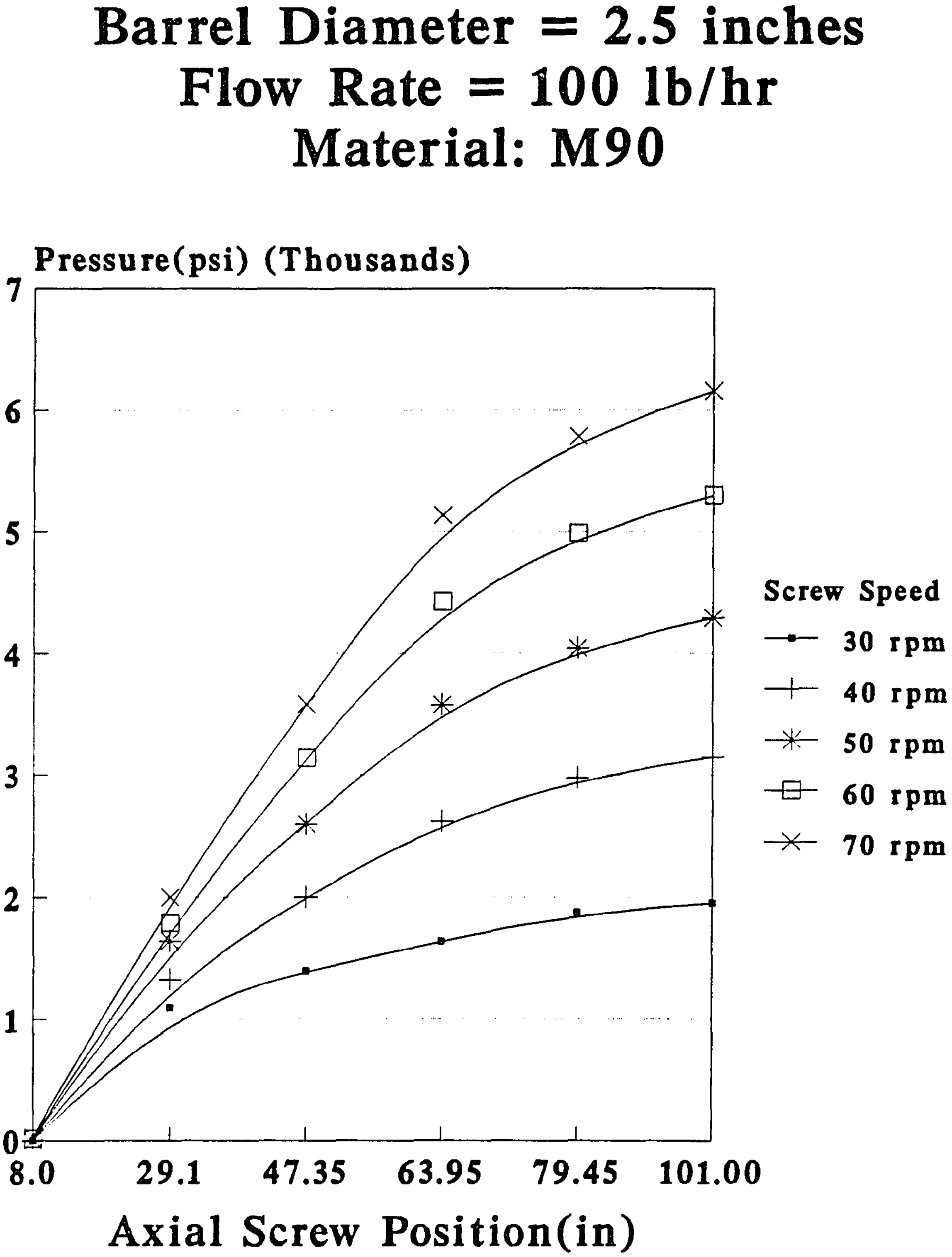


Figure 9.6 The Pressure as a Function of Axial Screw Position for Different Screw Speeds for Acetal Copolymer Grade M90.

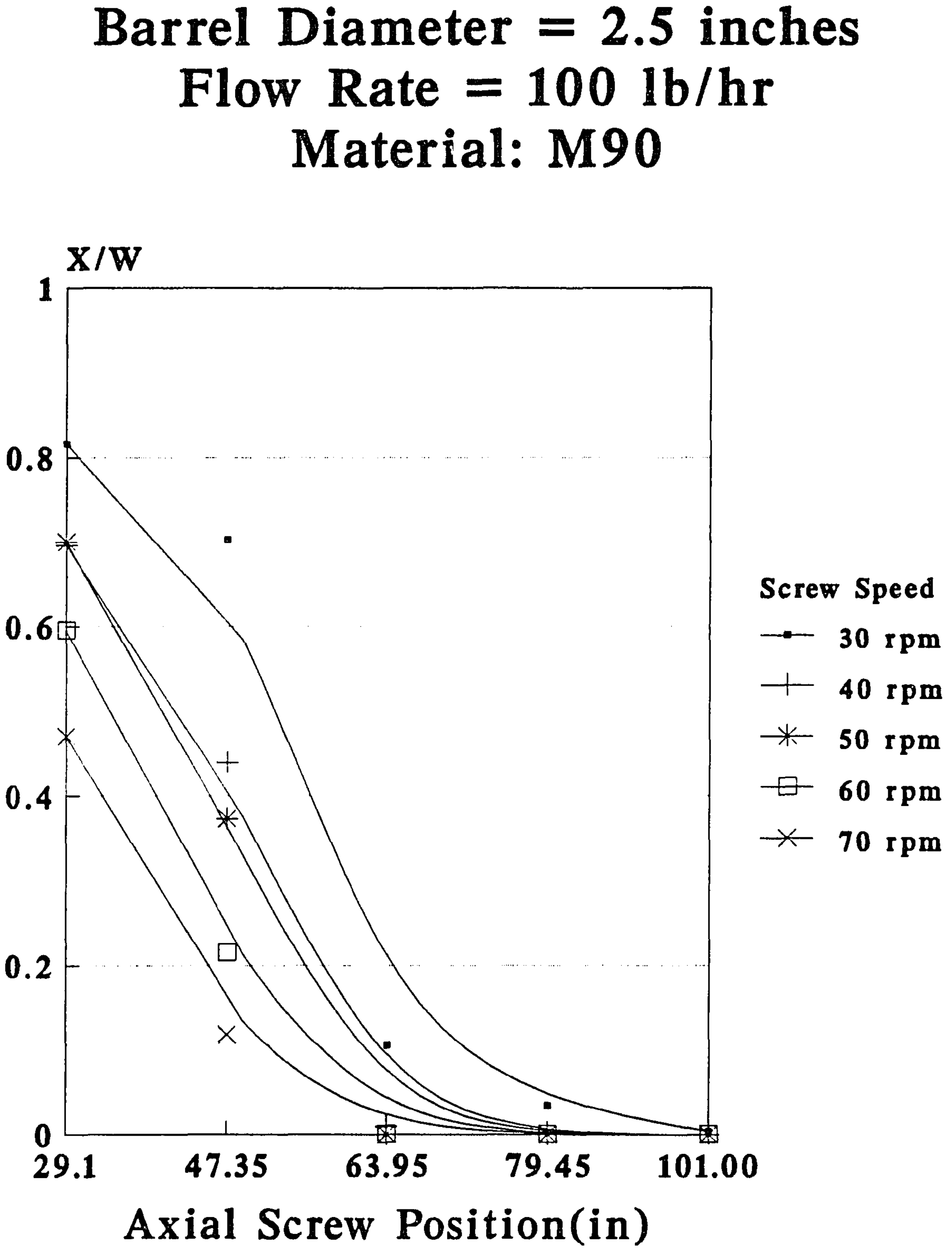


Figure 9.7 The Solid Bed Ratio as a Function of Axial Screw Position for Different Screw Speeds for Acetal Copolymer Grade M90.

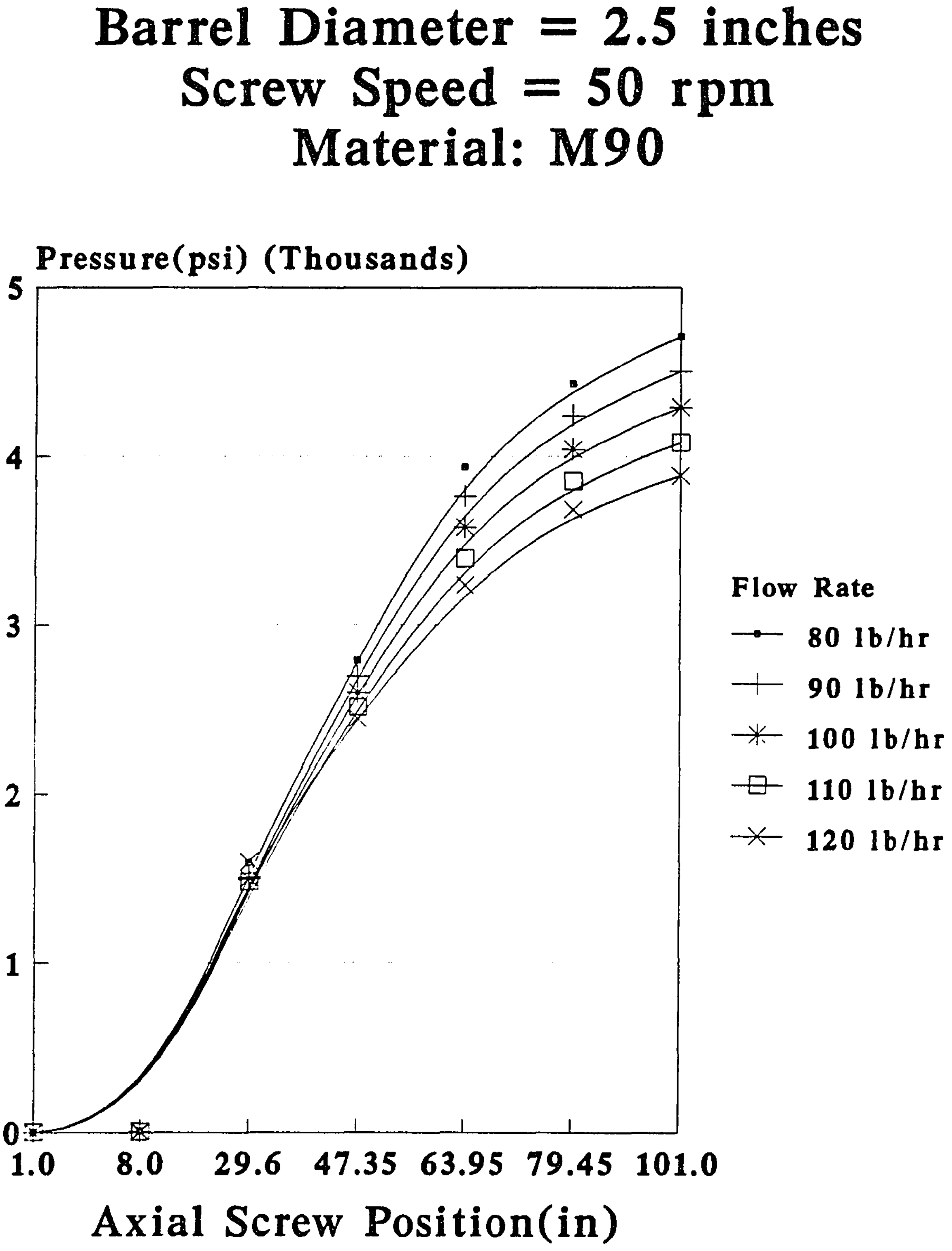


Figure 9.8 The Pressure as a Function of Axial Screw Position for Different Flow Rates for Acetal Copolymer Grade M90.

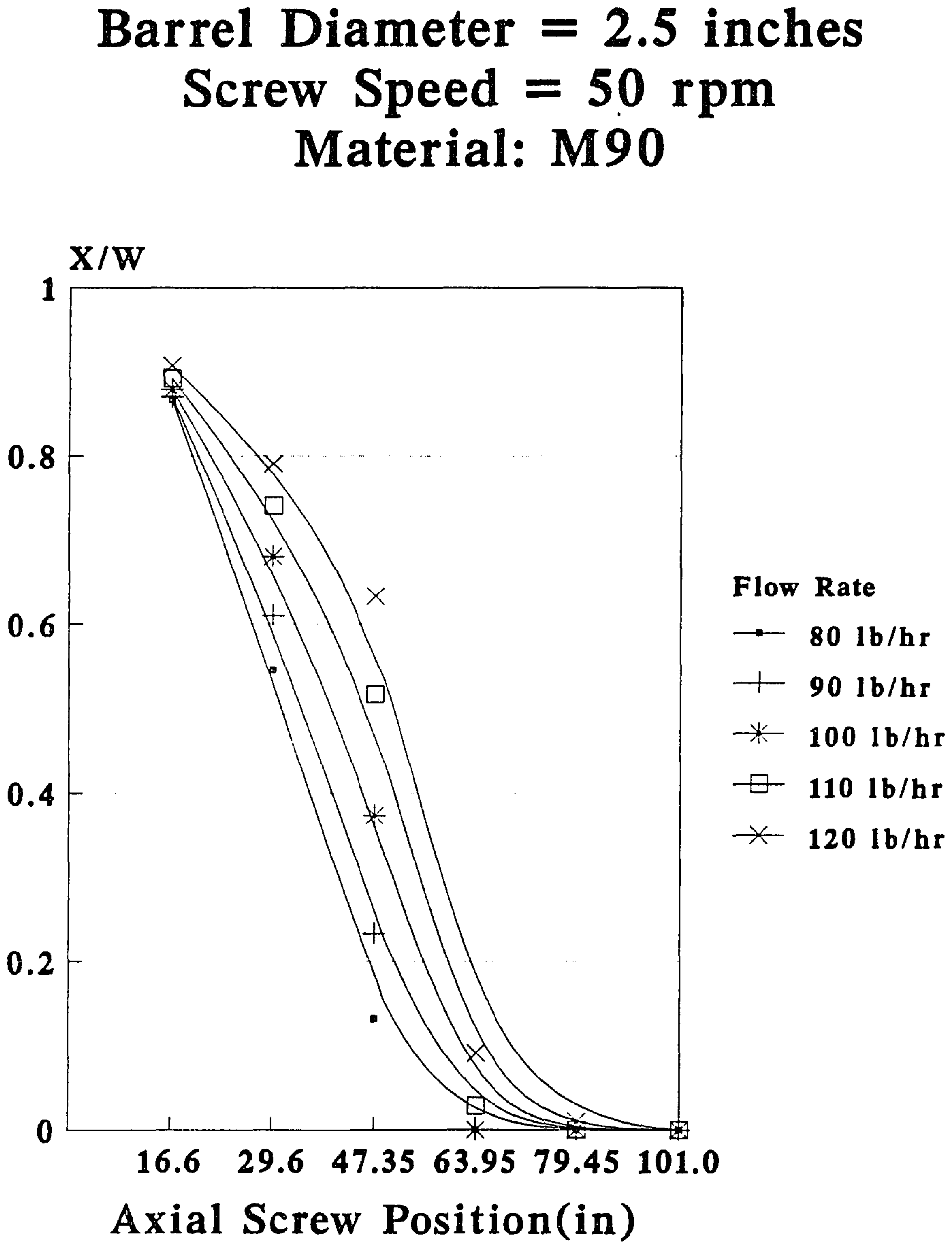


Figure 9.9 The Solid Bed Ratio as a Function of Axial Screw Position for Different Flow Rates for Acetal Copolymer Grade M90.

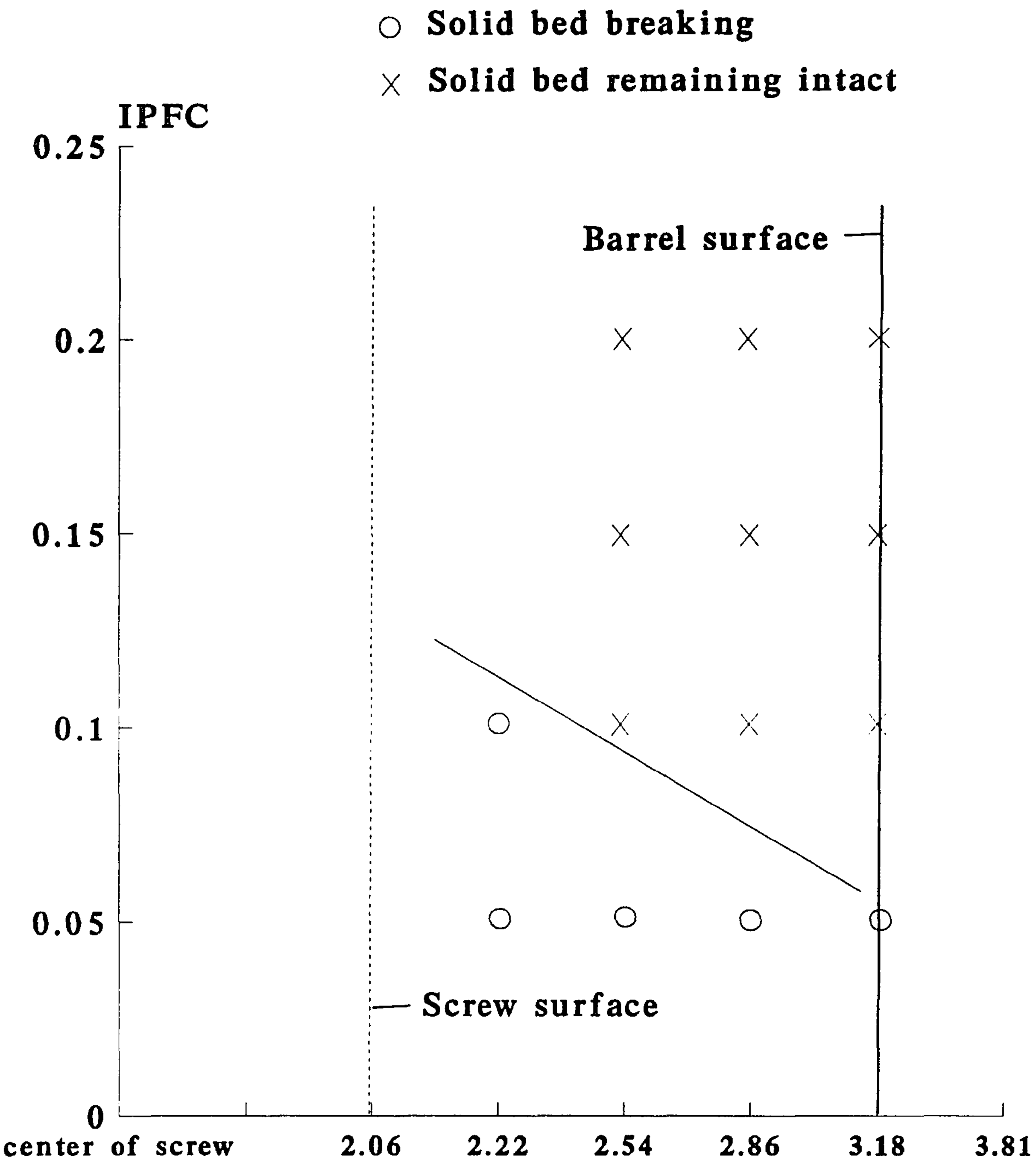


Figure 9.10 The IPFC as a Function of Axial Screw Position at Same Channel Depth for Acetal Copolymer Grade M90

# CHAPTER10

# POSTLUDE

## 10.1 Conclusions

1. Increasing the IPFC ensures that solid bed rupture will be reduced under given operating conditions. This has been shown by numerical simulation and experimental operation of a plasticating extruder. This conclusion was found to be true under all conditions of operation tested. Thus the use of profiled pellets may be expected to reduce the propensity to surge of plasticating extruders.

2. The IPFC has been shown to increase if pellets with profiled cross-sections constitute the feedstock, rather than pellets with circular cross-sections. The highest IPFCs were obtained with pellets of a bilobal cross-sections. The average IPFC of pellets with bilobal cross-sections is 56 % increase than pellets with circular cross-sections. Pellets with trilobal and quadrilobal cross-sections exhibited IPFCs greater than those obtained with pellets of circular cross-sections. The average IPFC of pellets with trilobal and quadrilobal cross-sections is 20% and 34% increase than pellets with circular cross-sections, respectively. Thus pellets with bilobal cross-sections have been isolated as the most likely to obtain surging.

3. Agitation of the particulate continuum prior to measurement of the IPFC ensured closer packing of the particulates and caused an increase in the IPFC. The average IPFC of bilobal pellets with agitation is 89% greater than the pellets with circular cross-sections. The average IPFC of trilobal and quadrilobal pellets with agitation is 51% and 62% increase than the pellets with circular cross-sections. Thus vibration in the feed this at area of the extruder would be expected to improve the conveying capacity and to remove some causes of surging.

4. Consolidation of the particulate continua prior to measurement of the IPFC for specified times at specified pressures did not significantly change the value of the IPFC measured. The consolidation time had a weak influence on the IPFC, increasing only 13% after 30 hours. This implies that profiled pellets will not cause bridging in hoppers and silos to any greater degree than pellets with circular cross-sections.

5. The presence of external lubricants on the surface of the pellets has a significant effect on the IPFC, which is reduced up to 45%. It is clear that the function of external lubricants promote slippage. However, the IPFC of the pellets with bilobal cross-sections is still greater than that of pellets with circular cross-sections. So, greater conveying capacity and a reduction in surging propensity are to be expected.

6. The presence of mineral powder in the form of mica clay intermixed with the pellets cause an increase in IPFC value up to 35%. This implies that during the compounding of mica clay into PBT improved conveying is to be expected. It also implies that the addition of small quantities of mica clay powder could eliminate nonblesome surging.

7. The presence of polymeric powder, PBT powder, intermixed with the pellets cause an increase in the IPFC value up to 20%. This implies that when extruding polymers some feedstock should be in the form of powder if surging occurs. Its addition will minimize surging and improve operation variability.

## 10.2 Future Work

### 10.2.1 Additional Profile Shapes

Although bilobal, trilobal and quadrilobal pellet cross-sections have been developed and tested to date, a host of others are possible. Some additional cross-sections for profiled pellets are presented in Figure 10.1. They could be rectangular, square, triangular, crescent or star. The most important consideration for choosing the shape is the ability to interlock, from any adjacent partition.

### 10.2.2 Additional Resin

To date, the IPFCs of acetal copolymer, high density polyethylene, polypropylene, polystyrene, nylon 6 and acrylonitrile-butadiene-styrene have been measured in the tests. Additional polymers of interest are low density polyethylene, linear low density polyethylene, ethylene-vinyl acetate, ionomer, polymethylpentene, polyvinyl chloride, polyvinylidene chloride, polyvinylacetate, styrene acrylonitrile, polymethylmethacrylene, polyethylene terephthalate, polybutylene terephthalate, polyarylate, polycarbonate, polyethersulfone, polyphenylene oxide, polyvinylidene fluoride, nylon 6/6, polyphenylene sulfide, and polyethorioide. So, their behavior is also of high importance. The benefits in terms of an increase in the interparticulate friction coefficient are expected to be as great, since it is the shape and the material which determines the IPFC. A full range of materials, with varying moduli, both filled and unfilled, need to be evaluated to determine the full advantages of profiled pellets.

### 10.2.3 Additional Resin Grades

To date only one grade of each of the test resins has been evaluated. Many grades exist in use however. Extensive testing of all grades needs to be performed. For example, for nylon 6 over one hundred grades are in common use and require testing. However, since it is the pellet cross section and nor the ingredients which most influence the IPFC increases are to be anticipated.

### 10.2.4 Field Trials

To date most of the work performed has been in the laboratory, and not in production extruders. Although all of the results have validated the initial hypothesis that the interparticulate friction coefficient will increase, it has not been demonstrated comprehensively that there are benefits to the extrusion process. Work must be performed to complete the overall objective, which was to enhance the output of extruders by delaying the onset of surging. Thus field trials must be extensively conducted, for a variety of pellet cross-sections, and a variety of generic resin types with different kinds of extruders. The procedures for field trial can be summarized as the following.

1. The pellets with a circular cross-section for all test samples including acetal copolymer, polyethylene, polypropylene, polystyrene, nylon 6 and ABS must be extruded on the Prodex extruder, which should be operated for specified time period to determine the throughput rate.
2. The pellets with higher IPFC values, such as the pellets with bilobal, trilobal, quadrilobal cross-sections for all test materials must be extruded on the Prodex extruder, which should be operated for the same time period as step 1 to determine the throughput rate, then compared to the equivalent results in step 1.
3. Since the grooved feed sections increase initial compression and increase conveying, outputs are improved greatly. The pellets with circular cross-sections for all materials should be extruded using helical grooved feed throats extruder and the extruder should be operated for a specified time period to determine the throughput rate, then compared to the equivalent results in step 1.

4. The pellets with bilobal, trilobal, quadrilobal cross-sections, and those pellets with new cross-sections for all test materials should be extruded with a helical grooved feed throat extruder and this extruder should be operated for specified time period to determine the throughput rate, then compared to equivalent results in step 2.
5. Since the barrier screws are designed to separate the solid bed from the melt pool, they inhibit solid bed breakup. The pellets with circular cross-section should be extruded for all test materials on barrier screw extruders, including the Hartig MC-3 screw, Maxmelt screw, the Barr-2 screw, the "Efficient" screw, and the VPB screw and the extruders operated for specified time period to determine the throughput rate, Then these results should be compared to the equivalent results in step 1.
6. The pellets with bilobal, trilobal, quadrilobal cross-sections, and those pellets with new shape on the barrier screw extruders, including the Hartig MC-3 screw, Maxmelt screw, the Barr-2 screw, the "Efficient" screw, and the VPB screw, and then operated those extruders for specified time period to determine the throughput rate, then compared to the equivalent results in step 2.
7. The pellets with circular cross-section should be extruded for all test materials in the barrier screws with grooved feed throats extruders and the extruders operated for a specified time period to determine the throughput rate. These results should then be compared to the equivalent results step 1.

The pellets with bilobal, trilobal, quadrilobal cross-sections, and those pellets with new shapes should be extruded on the barrier screws with grooved feed throats extruders and the extruders operated for a specified time period to determine the throughput rate. These results should then be compared to the equivalent results in step 2.

Completing the experiments above, a detailed comparison under various operating condition can be made to determine how the IPFC effects the throughput of different kinds of extruders.

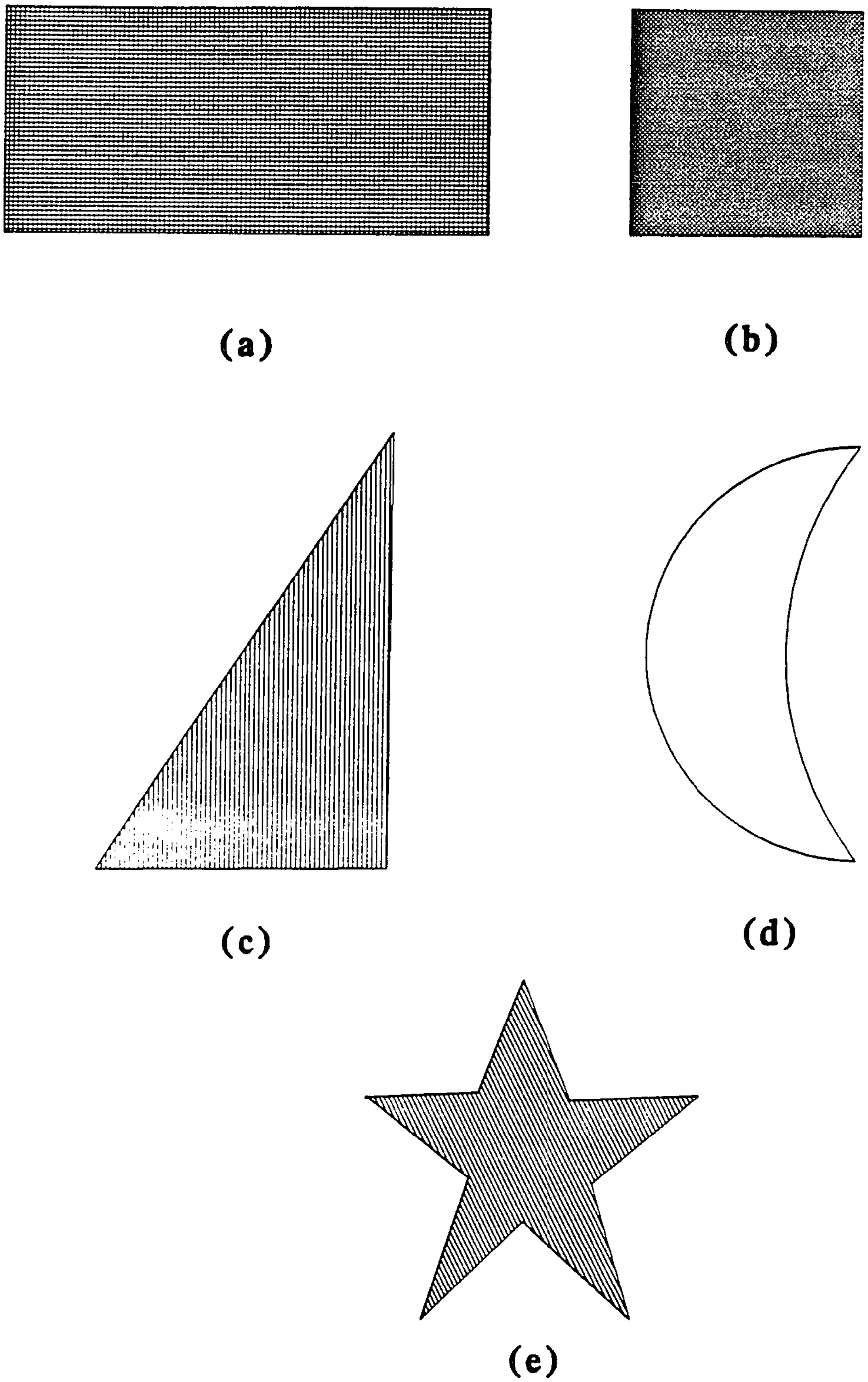


Figure 10.1 Additional Pellet Cross-Sections, (a) Rectangular, (b) Square, (c) Triangular, (d) Crescent, (e) Star.

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# APPENDIX A

The structure of the data file is described as below. It consists of data lines. Each line consists of one or more data fields. Each field can contain one of 3 possible data types:

1. A Fixed Point variable which must not contain a decimal point, (I).
2. A Floating Point variable which does contain a decimal point. If decimal point is absent it is assumed to be at the right hand end of the number, (F).
3. A Character String, (A).

The data file starts with 3-SPEC lines which specify the data file in generalities, and 27 line to describe the screw geometry, barrel temperature, plastic physical properties, frictional coefficient between barrel and screw, and operating condition for running the simulation by using the EXTRUD[1]®.

The 1st spec line describes the mode of running the simulations. This can be either Batch (B) or Conversational (C). The line, therefore, consists of a single field containing at least a single character.

The 2nd spec line includes 11 field. Each field is described as below.

| | | |
|---|---|---|
| 1st field | | Output device number : 6 (for PC) is the user terminal designation. For batch use number: 7 (for PC). OUTDEV |
| 2nd field | | Input device number: 5 (for PC) is the user terminal designation; The device refers only to individual changes to be made at the end of the run in the input option. For batch mode use number: 18 (for PC). The list of variables that can be changed follows this section describing the input data file. INDEV |
| 3rd field | 0 | for viscosity function in English units; viscosity (LB.SEC/IN$^2$) & temperature (°F). |
| | 1 | for viscosity function in poise and temperature in (°C). |
| | 2 | for all input and output in metric units, except resin properties which remain in English units. POISE |

---

[1] Note: EXTRUD® is the Registered Trademark of Scientic Process and Research, Somerset, New Jersey.

| | | |
|---|---|---|
| | 3 | resin properties in metric unit as well. |
| 4th field | 0 | if melting does not continue in plugged channel (usually the case for harder solids). |
| | 1 | if melting to continue in a plugged channel(for soft solids). IPLUG |
| 5th field | 0 | if positive pressures only are to be printed |
| | 1 | if negative pressures to be printed also. IFRES |
| 6th field | 0 | if X/W for plugged channel= .99 otherwise, insert maximum X/W permitted. XTST |
| 7th field | | line number at which reading of data will stop. A diagnostic tool. SCARD |
| 8th field | 0 | for mixing in relief section. |
| | 1 | for no mixing (for hard solids). MIXREL |
| 9th field | 1 | for SDS® Screw[2] . IFRECS |
| 10th field | | Number of sections with dual channel for melt and solids.(Must be used for barrier type screws) MLTCHL |
| 11th field | | Code number for material of which screw is constructed. ITAU |

The 3rd spec line indicated that if user wish to make changes of individual input variables in list form and then put YES, if user do not and then put NO.

The 27th lines of the input data must according to the format described as follows, respectively.

---

[2] Patented U.S. and other countries.

1st LINE
FORMAT(I,6F,10I)
(Mandatory)

| | | |
|---|---|---|
| 1st field | 1 | for complete printout of every increment computed. |
| | 0 | for shortened printout with every 5th increment printed. |
| | -n | for short printout with suppressed heading, every n-th axial increment printed out; n, must be an integer. IPLOT |
| 2nd field | | Run identification number, can be any positive number. ID |
| 3rd field | | Number of parallel flights. NFLT |
| 4th field | | Screw lead at entrance to first geometric section (inches), (mm). SLEAD |
| 5th field | | Barrel diameter (inches), (mm). DBAR |
| 6th field | | Flight width (inches), (mm). FLWD |
| 7th field | | Radial flight clearance (inches), (mm). FLCL |
| 8th field | | Number of geometric sections. |
| 9th field | 1 | for delay in melting start to be computed. |
| | 0 | if calculation suppressed. DLY |
| 10th field | 1 | for injection molding to be computed. |
| | -1 | if Cp vs T has no maximum, e.g. ABS, Polystyrene for injection molding. |
| | 0 | for continuous extrusion. INJ |
| 11th field | 0 | if both barrel heating and efficient cooling available. |
| | 1 | if no efficient barrel cooling available - only heating. |
| | 2 | adiabatic in melt pool, not in melt film. |
| | 3-7 | approaches adiabatic in melt film. COOL |
| 12th field | 0 | if barrel and screw temperature in data file to be used. |
| | 1 | if barrel temperature profile to be optimized with respect to maximum melting rate in the melting zone. |
| | 2 | if screw and barrel temperature to be optimized to maximize solid conveying. OPT |
| 13th field | 0 | for single viscosity function with resin data supplied by user. |
| | 1 | if polymer exhibits melt fracture with discontinuity between 2 viscosity functions. |

| | | |
|---|---|---|
| | 2 | for 2 viscosity ranges to be used for better representation of flow property data without melt fracture, for example to describe the low shear rate Newtonian viscosity range. |
| | -n | for resin data from SPR list of physical properties other than friction. MLFR |
| 14th field | 0 | in case of plasticating extrusion. |
| | 1 | in case of melt extrusion. |
| | -1 | in case of semi-melted feed. MLTX |
| 15th field | | This field used only for the computation of delay in melting start. |
| | 0 | for no target and no die specification (rate mode). |
| | 1 | if series of statistically distributed simulations to be generated from a single set of data. |
| | -1 | for extruder-die combination with production rate to be computed by the computer & die characteristic equation given in 11th line. |
| | -2 | for extruder-die combination with die characteristic given as a single point: output-temperature-pressure drop in 11th line. |
| | -3 | for extruder-die combination using cylindrical die. SERIES |
| 16th field | 0 | in the absence of mixing devices. |
| | 1 | if mixing rings are present. |
| | 2 | if torpedo (unflighted section) is present. |
| | 3 | if fluted section is present-simple computation. Can also be simulated by more accurate method using melt channel. |
| | -n | if more than one type of mixing device is present(n= number of mixing devices in the screw). RGN |
| 17th field | 0 | for low density Polyethylene. |
| | 1 | for high density Polyethylene. |
| | 2 | for Polypropylene and Nylon. |
| | 3 | for rigid PVC, Polystyrene, Polycarbonate, Polymethylmethacrylate, Polyacrylonitrile. |
| | 4 | for 50% longer delay zone than for 3. |
| | 5 | for 100% longer than for 3. |
| | 6 | for 150% longer than for 3. |
| | -1 | for 50% shorter than for 0. |
| | 100 | no melting starts at all. IDL |

2nd LINE
FORMAT(10F)
(Optional)

| | |
|---|---|
| 1st field | Length of 1st geometrical section from downstream or exit end of hopper. SECTION(1) |
| 2nd field | Channel depth at the end of 1st geometrical section from flight tip to screw root. HSEC(1) |
| 3rd field | Length of 2nd geometrical section. SECTION(2) |
| 4th field | Channel depth at the end of 2nd geometrical section. HSEC(2) |
| 5th field | Length of 3rd geometrical section. SECTION(3) |
| 6th field | Channel depth at the end of 3rd geometrical section. HSEC(3) |
| 7th field | Length of 4th geometrical section. SECTION(4) |
| 8th field | Channel depth at the end of 4th geometrical section. HSEC(4) |
| 9th field | Length of 5th geometrical section. SECTION(5) |
| 10th field | Channel depth at the end of 5th geometrical section. HSEC(5) |

1st field on the next line continued as above for 6th through 10th geometrical section.

LINE 2A
FORMAT (15F)
(Optional)

(Replaces 2nd LINE when screw lead is not constant)

(May consist of more than one line if the number of Geometrical Sections is more than 5.)

All dimensions on this line are in inches or millimeters.

| | |
|---|---|
| 1st field | Length of 1st geometrical section from downstream or exit end of hopper. SECLEN (1) |
| 2nd field | Channel depth at the end of 1st geometrical section from flight tip to screw root (flight clearance not included). HSEC (1) |
| 3rd field | Screw lead at end of 1st geometrical section. SLD (1) |
| 4th field | Length of 2nd geometrical section. SECLEN (2) |
| 5th field | Depth at the end of 2nd geometrical section. HSEC (2) |
| 6th field | Screw lead at end of 2nd geometrical section. SLD (2) |
| 7th field | Length of 3rd geometrical section. SECLEN (3) |
| 8th field | Depth at the end of 3rd geometrical section. HSEC (3) |
| 9th field | Screw lead at end of 3rd geometrical section. SLD (3) |
| Etc. | up to 5 geometrical sections per line. |

The only limitation of the data supplied by this line is that the first geometrical section must always be a constant depth section. If compression actually starts at the beginning of the screw. an imaginary constant depth section of zero length has to be introduced.

1st LINE, 4h field (SLEAD) represents screw lead at start of 1st section.

LINE 2B
FORMAT(10F)
(Optional)

Used only together with LINE 2C and only when MLTCHL 2nd spec LINE, 10th field is non-zero.

| | |
|---|---|
| 1st field | Width of melt channel at end of 1st geometric section at which it is present, (Fraction of Total) WM (1) |
| 2nd field | Depth of melt channel at end of 1st geometric section at which it is present, (in.), (mm.) HM (1) |
| 3rd field | Width of melt channel at end of 2nd geometric section at which it is present, (Fraction of Total) WM (2) |
| 4th field | Depth of melt channel at end of 2nd geometric section at which it is present, (in.), (mm.) HM (2) |
| | .<br>.<br>.<br>. |
| 9th field | Width of melt channel at end of 5th geometric section at which it is present, (Fraction of Total) WM (5) |
| 10th field | Depth of melt channel at end of 5th geometric section at which it is present, (in.), (mm.) HM (5) |

up to 5 geometric sections per line.

LINE 2C
FORMAT(2I, 4F)
(Optional)

| | |
|---|---|
| 1st field | Section number where melt channel starts, JJM0 |
| 2nd field | Section number where melt channel ends, JJMEND |
| 3rd field | Width of melt channel at start of JJM0-th geometric section (fraction of total), WM0 |
| 4th field | Depth of melt channel at start of JJM0-th geometric section (in.), (mm.), FWMLT |
| 5th field | Flight Width of auxiliary flight (in), (mm), FWMLT |
| 6th field | Radial clearance of auxiliary flight (in), (mm), FCLMLT |

LINE 2D
FORMAT (15F)
(Optional)

(Replaces 2nd LINE when flight width is not constant)
(May consist of more than one line if the number of geometrical sections is more than 5.)

All dimensions on this line are in inches or millimeters.

| | |
|---|---|
| 1st field | Length of 1st geometrical section from downstream or exit end of hopper. SECTION (1) |
| 2nd field | Channel Depth at the end of 1st geometrical section from flight tip to screw root. (flight clearance not included). HSEC (1) |
| 3rd field | Flight width at end of 1st geometrical section. FLT (1) |
| 4th field | Length of 2nd geometrical section. SECLEN (2) |
| 5th field | Depth at the end of 2nd geometrical section. HSEC (2) |
| 6th field | Flight width at end of 2nd geometrical section. FLT (2) |
| 7th field | Length of 3rd geometrical section. SECLEN (3) |
| 8th field | Depth at the end of 3rd geometrical section. HSEC (3) |
| 9th field | Flight width at end of 3rd geometrical section. FLT(3) |
| Etc. | up to 5 geometrical sections per line. |

The only limitation of the data supplied by this line is that the first geometrical section must always be a constant depth section. If compression actually starts at the beginning of the screw. an imaginary constant depth section of zero length has to be introduced.

1st LINE, 6th field (FLTWID) represents regative of FLT (0), ie. flight width at start of 1st section under the hopper.

## 3rd LINE
## FORMAT
## (Mandatory)

The 3rd line consists of the material properties, it includes thermal conductivity of melt, density of solid bed, heat capacity of melt, heat capacity of solid polymer, heat of fusion, temperature of polymer fed to the extruder and shear rate. This line is mandatory, and the format(7F) of line presented as below,

| | |
|---|---|
| 1st field | Thermal conductivity of melt (Btu/hr. ft°F),(W/m.°C). THCONO |
| 2nd field | Density of solid bed (lb/ft$^3$),(g/cm$^3$). RHOSOL |
| 3rd field | Heat capacity of melt ((Btu/lb°F or cal/g°C),(J/Kg.°K). HETCAM |
| 4th field | Heat capacity of solid polymer ((Btu/lb°F or cal/g°C),(J/Kg.°K). HETCAS |
| 5th field | Heat of fusion ((Btu/lb),(J/Kg). HETFUS |
| 6th field | Temperature of polymer fed to the extruder(°F),(°C). TSOLID |
| 7th field | 0 if shear rate for start of second Newtonian region is 100,000 per sec. Otherwise insert known value for shear rate. GAMAX |

4th LINE
FORMAT(9F)
(Mandatory)

The 4th line describes the melting point for polymer, This line is mandatory, and the format(7F) of line presented as below,

| | |
|---|---|
| 1st field | $R_O$ |
| 2nd field | $T_{MO}$ |
| 3rd field | $R_1$ |
| 4th field | $R_2$ |
| 5th field | $R_{12}$ |
| 6th field | $T_{M1}$ |
| 7th field | $T_{M2}$ |

Defined as:

$$RHO = R_o + R_1 {*} P + R_2 {*} T + R_{12} {*} P {*} T$$

$$T_M = T_{MO} + T_{M1} {*} P + T_{M2} {*} P^2$$

where: P = pressure (lb./sq. in.),(bar)

T = melt temperature ($^oF$),($^oC$)

RHO = melt density (lb./$ft^3$),($g/cm^3$)

$T_M$ = melting point ($^oF$),($^oC$)

5th LINE
FORMAT (9F)
(Mandatory)

The 5th line describes the coefficients of flow equation and shown as below,

| | |
|---|---|
| 1st field | A(i) |
| 2nd field | $A_1$(i) |
| 3rd field | $A_2$(i) |
| 4th field | $A_{11}$(i) |
| 5th field | $A_{22}$(i) |
| 6th field | $A_{12}$(i) |
| 7th field | $A_{14}$(i) |
| 8th field | ATD(i) coefficient of temperature degradation |
| 9th field | ASD -coefficient of shear degradation |

where, coefficients of viscosity equation are defined as:

$$\ln \mathrm{VISC} = A(i) + A(i)^{*}\ln + A_{11}(i)^{*}\ln^{2} + A_{2}(i)^{*}T + A_{22}(i)^{*}T^{2} + A_{12}(i)^{*}T^{*}\ln$$
$$+ A_{14}(i)^{*}T^{*}\ln + A_{14}(i)^{*}\ln{}^{*}P + A_{TD}{}^{*}\mathrm{Theta}^{*} + A_{SD}{}^{*}\mathrm{Theta}^{*}\mathrm{TAU}$$

where,

VISC = Viscosity (lb.sec./in$^2$), (Poise)
$\gamma$ = true (Rabinowitsch corrected) shear rate (sec$^{-1}$)
T = melt temperature ( F), ( C)
P = Pressure (psi), (bar)
Theta = Residence Time in melt pool (hr)
TAU = shear stress (psi), (bar)

LINE 5A
FORMAT(I,5(I,F))
(Optional)

It described mixed feed and shown as below,

| | |
|---|---|
| 1st field | Number of components in resin feed, MATS |
| 2nd field | Resin number of first component in resin feed, INGRID(1) |
| 3rd field | Fraction of first component in feed, FRA(1) |
| 4th field | Resin number of second component in feed, INGRID(2) |
| 5th field | Fraction of second component in feed, FRA(2) |
| 6th field | Resin number of 3rd component in feed, INGRID(3) |
| 7th field | Fraction of 3rd component in feed, FRA(3) |
| 8th field | Resin number of 4th component in feed, INGRID(4) |
| 9th field | Fraction of 4th component in feed, FRA(4) |
| 10th field | Resin number of 5th component in feed, INGRID(5) |
| 11th field | Fraction of 5th component in feed, FRA(5) |

6th LINE
FORMAT (4F, 4I)
Mandatory

For a general case

| | | |
|---|---|---|
| 1st field | C0 | ( F), ( C) |
| 2nd field | C1 | |
| 3rd field | C2 | (1/in), (1/mm)<br>For $T_{bar}$ defined by equation: $T_{bar}$ = C0 [1-C1*exp(-C2*x)]<br>For a special case with constant barrel temperature profile set: C0 = $T_{bar}$; C1 and C2 = 0.<br>If you wish to enter barrel temperatures as point values, C0, C1 and C2 will be disregarded by the program. See 5th field of this 6th LINE. |

where:

$T_{bar}$ = barrel temperature at each axial location ( F), ( C).
x = axial distance from the beginning of first Geometrical Section to the middle of increment (inches).

| | | |
|---|---|---|
| 4th field | P0 | Pressure at entrance to extruder (psi), (bar) or at any arbitrary point where x = 0. This can be used in describing the operation of a partial extruder. Cramer feeder primarily effects bulk density and not entrance pressure. |
| 5th field | 0 | if Tbar equation above is used for barrel temperature. |
| | n | for barrel temperature profile to be supplied as point value with EXTRUD® computing Tbar at each axial location through linear interpolation.(n = number of points at which barrel temperature is supplied, n must be bigger than 2, 20 maximum). Barrel temperatures and locations are supplied on 7th LINE.<br>IPOE |

Note: For temperature given as point values use 7th LINE.
For heater zones use special instructions for 6th and 7th LINES following description of 7th LINE.

| | | |
|---|---|---|
| 6th field | 0 | for normal printout with highest accuracy. |
| | 1 | for solids conveying computed at lower accuracy. |
| | 2 | computed viscosities not printed out either. |
| | 3 | melting also computed at lower accuracy. |
| | 4 | temperature also computed at lower accuracy. ITOL |
| 7th field | 0 | when no friction coefficients for solids are available and solids conveying computations are not desired. |
| | 1 | when any friction coefficients for solids on screw and barrel surfaces are supplied and the temperature of solid plug surface is calculated by the program. ISOL |
| 8th field | n | for frictional property material number of data from SPR friction data file on barrel surface if surfaces are different, below 2 psi if 2 pressure ranges are used. NFRICB |
| 9th field | n | for frictional property material number of data from SPR friction data file on screw surface if surfaces are different, below 2 psi if 2 pressure ranges are used. NFRICS |
| 10th field | n | for frictional property material number of data from SPR friction data file on barrel surface above 2 psi pressure. NFRCBH |
| 11th field | n | for frictional property material number of data from SPR friction data file on screw surface above 2 psi pressure. NFRCSH |

Line 6A
FORMAT (8F)
(Optional)

To maintain constant temperatures over each heater zone, the 1st and 5th field on this line must be set as follows:

| | | |
|---|---|---|
| 1st Field | C0 | Insert -1 for constant temperature zones. |
| 5th field | IPOE | Number of constant temperature zones. |

7th LINE
Barrel Temperature Defined by Points Along Barrel
FORMAT (8F)
(Optional)

(Read-in only if 5th field in 6TH LINE (IPOE) was other than 0)

| | |
|---|---|
| 1st field | Barrel temperature (°F) at zero axial location. Replaced in the hopper area by cooling water temperature as defined by AXDTM in 9th LINE 5th field. TBR(1). |
| 2nd field | Axial location (in.), (mm.) (0.0). AXD(1) |
| 3rd field | Barrel temperature at a point down-channel from 1st point (°F), (°C). TBR (2) |
| 4th field | Axial location of 2nd point (in.), (mm.). AXD(2) |
| 5th field | Barrel temperature at 3rd point (°F), (°C). TBR(3) |
| 6th field | Axial location of 3rd point (in.), (mm.). AXD(3) |
| 7th field | Barrel temperature at 4th point (°F), (°C). TBR(4) |
| 8th field | Axial location of 4th point (in.), (mm.). AXD(4) |

Coolant temperature along AXDTM-9th LINE, 5th field representing length of cooled hopper zone of barrel downstream of hopper will take precedence over high barrel temperatures supplied in this line, i.e., high barrel temperature will be disregarded in Solids Conveying Zone.

LINE 7A
FORMAT (8F)
(Optional)

| | |
|---|---|
| 1st field | Barrel temperature of first zone (°F), (°C). TBR(1) |
| 2nd field | Axial location of downstream end of first zone (in.), (mm.). AXD(1) |
| 3rd field | Barrel temperature of second zone (°F), (°C). TBR(2) |
| 4th field | Axial location of downstream end of second zone (in.), (mm.). AXD(2) |
| etc. | up to 4 temperature zones per line. |

8th LINE
FORMAT (11F)
(Mandatory)

| | | |
|---|---|---|
| 1st field | $F_0$ | -1000 when screw temperature profile not controlled, neutral screw<br>-2000 when controlled in solids conveying zone only<br>-3000 when screw temperature profile is given. F0 |
| 2nd field | $F_1$ | represents screw surface temperature if F0=-2000<br>represents no. of screw temperatures if F0=-3000 must be at least 3 and in this case must be followed by LINE 8A identical in format to LINE 7A. F1 |
| 3rd field | $F_2$ | F2 |

Note: For the general case: F0, F1 and F2 are coefficients of equation expressing screw surface temperature as a function of axial location, x:

$T_{screw} = F_0 + F_1 * x + F_2 * x^2$ (°F), (°C)
x = axial location (in.), (mm.)

| | |
|---|---|
| 4th field | Number of parallel holes or flute pairs in mixing device. PARHOL |
| 5th field | Area of each hole (in.$^2$), (mm$^2$.)<br>Radial flight clearance for torpedo (in.), (mm.). HLAREA |
| 6th field | Axial location of Solid Bed Break-up if EXPNO is negative (in.), (mm.). BREAK |
| 7th field* | Desired Head Pressure for starve-fed screws (psi), (bar). HEADPR |
| 8th field* | Axial Location of Vent (in.), (mm.). ACDISV |
| 9th field | Axial Location (in.), (mm.) where simulation is to be interrupted for changes. STOP |
| 10th field | Maximum Screw Speed with present gear ratio (rpm), RPMMAX |
| 11th field | Maximum HP rating of extruder (HP), (KW), HPMAX |

* Not to be used in Extruder-Die combination.

9th LINE
FORMAT (10F)
(Mandatory)

| | | |
|---|---|---|
| 1st field | | Screw Speed (rpm). RPM |
| 2nd field | | Output (Production Rate) (lb./hr.), (Kg/hr.)<br>(disregarded if run in extruder-die combination mode).<br>OUTPUT |
| 3rd field | 0 | for most materials; |
| | 1 | for rigid materials in pellet form. |
| 4th field | | Soak Time per cycle for injection molding (sec.). SOKTIM |
| 5th field | | Axial length of cooled barrel from start of first geometrical section (in.), (mm.).<br>AXDTM.<br>Overrides Barrel Temperature given in LINE 6 or 7. |
| 6th field | | Reciprocating Length for injection molding (in.), (mm.).<br>RECLEN |
| 7th field | | Injection Pressure (psi), (bar). PRESIN |
| 8th field | | Flight Width at barrel surface (in.), (mm.). FLTWB |
| 9th field | | Radial Length of tapered flight width (in.), (mm.). HFTPR |
| 10th field | | Flight Wear, radial (in.), (mm.) WEAR |

10th LINE
FORMAT (30A2)
(Mandatory)

Columns 2 through 60: Any text identifying run, the material or the extruder such as:
MARLEX 6002 FOR LINE 3.

Pressure Mode
11th LINE
FORMAT (7F)
(Optional)

Need only if the output of the extruder is to be computed as an extruder-die combination, and if the 15th field on the 1st LINE is -1, the coefficients of the die characteristics are described by the following equation:

$$\text{PDROP} = (a_1 + a_2{*}T + a_3{*}T^2) * (\text{OUTPUT})^{(b_1 + b_2{*}T + b_3{*}T_2)} * \exp(c/T_{abs})$$

where: PDROP = pressure drop across die (psi), (bar)
T = extrudate temperature (°F), (°C)
OUTPUT = output lb./hr.), (Kg/hr)
$T_{abs}$ = absolute temperature (°R), (°K)

| | | | |
|---|---|---|---|
| 1st field | $a_1$ | (psi), (bar) | DIECOE (1) |
| 2nd field | $a_2$ | (psi/°F), (bar/°C) | DIECOE (2) |
| 3rd field | $a_3$ | (psi/°$F^2$), (bar/°$C^2$) | DIECOE (3) |
| 4th field | $b_1$ | --- | DIECOE (4) |
| 5th field | $b_2$ | (°$F^{-1}$), (°$C^{-1}$) | DIECOE (5) |
| 6th field | $b_3$ | (°$F^{-2}$), (°$C^{-2}$) | DIECOE (6) |
| 7th field | c | (°F), (°C) | DIECOE (7) |

### For Single Point Die Performance
(15th field of 1st LINE =-2)
(Optional)

When the performance of the extruder with a die at one set of operating conditions is known, EXTRUD® must be supplied with the Production Rate (OUTPUT), Melt Temperature (TOUT), and Pressure Drop along the die.

| | | |
|---|---|---|
| 1st field | Output (lb./hr.), (Kg/hr.). | DIECOE (1) |
| 2nd field | Melt Temperature (°F), (°C). | DIECOE (2) |
| 3rd field | Pressure drop along die (psi), (bar). | DIECOE (3) |

### For Die with One or More Cylindrical Holes
(15th field of 1st LINE =-3)
(Optional)

| | | |
|---|---|---|
| 1st field | Discharge Pressure of Die (psi), (bar). | DIECOE (1) |
| 2nd field | Die Radius (in.), (mm). | DIECOE (2) |
| 3rd field | Die Length (in.), (mm). | DIECOE (3) |
| 4th field | Melt Temperature in Die (°F), (°C). | DIECOE (4) |
| 5th field | Number of cylindrical holes. | DIECOE (5) |

MIxing Devices
12th LINE
FORMAT (10I)
(Optional)

Need only if Mixing Devices are present and if 16th
field on LINE 1 (IRING) is 1, 2, 3 or -N.

The location of each mixing device has to be listed by its section number in increasing order.

| | |
|---|---|
| 1st field | Section number of 1st mixing device. KRING (1) |
| 2nd field | Section number of 2nd mixing device. KRING (2) |
| 3rd field | Section number of 3rd mixing device. KRING (3) |
| Etc. | up to 10 per line. |

Each mixing device counts as a Geometrical Section and its length has to be given on the 2nd LINE. The channel depth at the end of the mixing section must be equal to the depth at the beginning of the next Geometrical Section. For the simulation of the performance of a screw with mixing devices, information on the number of parallel holes and on the size of each hole must also be given on the 8th LINE if 16th field on LINE 1 is 1, 2 or 3.

13th LINE
FORMAT (5 [2F,I])
(Optional)

Needed only if the 16th field on LINE 1 (IRING) is -N. The 12th LINE must be followed by one or more lines describing: number of parallel holes PH (i), hole area HA (i), and type (1, 2 or 3) KR (i) for each mixing device sequentially, up to five mixing devices per line.

PH (1) HA (1) KR (1) -------------------------------- PH (5) HA (5) KR (5)

Fluted Mixing Sections
Line 13A
FORMAT (I,2F,I,7F)
(Optional)

Needed only for FLUTED MIXING SECTIONS

| | |
|---|---|
| 1st field | KROS1 - Indicator of inlet channel (flute) geometry. |
| 2nd field | WMAD1 - Width of inlet channel at barrel surface (in), (mm)<br>Use maximum value if changing. |
| 3rd field | HMAD1 - Depth of inlet channel (in), (mm)<br>Use maximum value if changing. |
| 4th field | KROS2 - Indicator of outlet channel geometry. |
| 5th field | WMAD2 - Width of outlet channel at barrel surface (in), (mm)<br>Use maximum value if changing. |
| 6th field | HMAD2 - Depth of outlet channel (in), (mm)<br>Use maximum value if changing. |
| 7th field | FCLE1 - Radial clearance of barrier from inlet to outlet channel (in), (mm). |
| 8th field | FCLE2 - Radial clearance of flight separating pairs of flutes (in), (mm). usually: FCLE2 < FCLE1 |
| 9th field | FWI1 - Width of barrier from inlet to outlet channel (in), (mm). |
| 10th field | FWI2 - Flight separting flute pairs (in), (mm). |
| 11th field | ANGMAD - Angle between screw axis and flute (degrees) |

All the above variables are also included in the INPUT list and can be changed when EXTRUD® says: TYPE IN INPUT.

On the PC in graphical/conversational mode detailed explanation can be obtained on the meaning of the above variables.

| Values for KROS1 & KROS2 | |
|---|---|
| Cross Section is ellipse | 1 |
| Cross Section is rectangle with circular bottom | |
| HMADx < WMADx | 2 |
| HMADx > WMADx | 3 |
| Cross Section is rectangle | 4 |

Note: The number of parallel inlet flutes must be given as PARHOL on 8th LINE, 4th field if IRING = 3 (RNG =3) (1st LINE, 16th field) or as PH(1) on 13 th LINE if more than one type of mixing device is present in the screw (IRING = negative), where I refers to 1st, 2nd etc. mixing device from the hopper to he end of Screw.

Entrance pressure to the fluted section must always be positive. If this is not the case, operating conditions must be changed until entrance pressure becomes positive, e.g. RPM increased, OUTPUT decreased etc.

14th LINE
FORMAT (3F)
(Optional)

Needed only for the case of partially melted feed, this line must be inserted giving X/W, GRATIO, and melt input temperature (°F), (°C) for the feed.

| | |
|---|---|
| 1st field | X/W at inlet. |
| 2nd field | GRATIO fraction of solids at inlet. |
| 3rd field | TIN melt inlet temperatures (°F), (°C). |

Target
15th LINE
FORMAT (1)
(Optional)

Needed only if the Target option is used that is a series of simulations is to be generated automatically and only if the 15th field on the 1st LINE is 1.

| | |
|---|---|
| 1st field | Number of variables to be varied simultaneously in the series. |

16th LINE
FORMAT (11I)
(Optional)

Needed only with 15th LINE.
(1 line for each variable)

| | |
|---|---|
| 1st field | Code number defining variable. |
| 2nd field | n - the subscript number* defining the location of variable. |
| 3rd to 11th | Section no. of up to 9 additional sections whose <u>depth</u> (HSEC), <u>length</u> (SECLEN) or <u>lead</u> (SLD) varies together with that of the reference section in 2nd field or mixing ring no. whose number of <u>holes</u> vary (PH), or heater number whose <u>barrel temperature</u> varies (TBR) together with that of the reference section in 2nd field. |

* 0 if not applicable.

17th LINE
FORMAT (6F)
(Optional)

May consist of several lines.

Needed only with 15th &16th LINEs.

| | |
|---|---|
| 1st field | The center point around which the first variable will be varied. |
| 2nd field | Step size for the first variable. |
| 3rd field | Center point for second variable. |
| 4th field | Step size for second variable. |
| Etc. | Up to 3 variable per LINE. |

LINE 17A
FORMAT (1)
(Optional)

| | |
|---|---|
| 1st field | Number of Responses to be collected simultaneously in the series. |

LINE 17B
FORMAT (20I)
(Optional)

Needed only with 15th line and
when the value in LINE 17A is not 0.

| | |
|---|---|
| 1st field | Code number defining 1st response to be collected in a summary table. See next page for definition of codes. |
| 2nd field | Axial Location*, (in), (mm) at which 1st response is to be collected |
| 3rd field | Code number defining 2nd response. |
| 4th field | Axial location*, (in), (mm) at which 2nd response is to be collected |

Etc. Up to 10 responses per line.

Solids Conveying Data
18th LINE
FORMAT (8F)
(Mandatory)

| | |
|---|---|
| 1st field | Maximum diameter of hopper (in.), (mm).<br>If hopper is not circular, take hydraulic diameter (4 x cross-sectional area of the hopper, divided by its perimeter). DHOP |
| 2nd field | Bulk density (lb./ft.$^3$), (g/cm$^3$). ROB |
| 3rd field | Constant term in coefficient of friction function on barrel surface, FRIB0. Must be 0 if friction data to be used from SPR list. If FRIB0 is other than 0 in this field, this value will replace the value given in the SPR list. All other coefficients in the friction equation will remain as given in the data base. |
| 4th field | Constant term in coefficient of friction function on screw surface, FRIS0. Equation defining the Coefficient of Friction on the Barrel also defines the Coefficient of Friction on the screw. If friction data to be taken from SPR list, FRIS0 must be 0. If other than 0 this value will replace that given in the data base. All other coefficients will be taken from the SPR data base. |
| 5th field | Static coefficient of friction of solid feed on the hopper surface.<br>(0 if not available). |
| 6th field | Thickness of barrel wall in cooled hopper section (in), (mm.). WBAR |
| 7th field | Average temperature of cooling medium for hopper(°F), (°C)<br>Important for Solid Conveying computation. TBW |
| 8th field | Pellet diameter (in), (mm.). DPEL |

19th LINE
FORMAT (8F)
(Mandatory)

| | |
|---|---|
| 1st field | Thermal conductivity of barrel metal (Btu/hr.ft.°F), (W/m.°C). (Typical for steel 25 BTU/hr.ft.°For 14.457W/m.°C). TCONB |
| 2nd field | Thermal conductivity of solid plastic at feed temperature (Btu/hr.ft.°F), (W/m.°C). TCONS. |
| 3rd field | Angle of repose of the feed (degrees). ANGREP (0 if not available). |
| 4th field | Height of the solids in the hopper* (in.), (mm.). HSH |
| 5th field | Height of the tapered portion hopper (in.), (mm.). (0 if not available). HOPT |
| 6th field | Hopper Diameter adjacent to barrel (in.), (mm.). DHOPX |
| 7th field | Barrel wall thickness from controller sensor to inner surface of barrel following the cooled hopper section (in.), (mm). If set to 0, program assumes that inner barrel surface temperature equals the barrel temperature given. WBAR1 |
| 8th field | Height of lower portion of hopper with constant small diameter (in.), (mm.). HOPST |

* If height of solids in hopper is set to zero (left blank), the critical solids level is computed and the corresponding maximum hopper base pressure is used. If height is supplied for the solids in the hopper, the corresponding pressure at the base of the hopper is computed.

20th LINE
FORMAT (7F)
(Mandatory)

| | |
|---|---|
| 1st field | Coefficient Rb1 in the bulk density expression:<br>(use 0 if Rb1 not available) |

$$RHO_{bp} = RHO_{sol} - (RHO_{sol} - RHO_{b0})*\exp(-R_{b1}*P)$$

Where: $RHO_{bp}$ =Bulk density at pressure P (lb./ft$^3$), (g/cm$^3$)
$RHO_{sol}$ =Density of sol plastic at room temperature (lb./ft$^3$), (g/cm$^3$)
$RHO_{b0}$ =Bulk density when P = 0 (lb./ft$^3$), (g/cm$^3$)
P =Pressure (psi), (bar)

Followed by 6 fields defining the first 6 terms of the coefficient of friction equation on the barrel surface (optional, remains zero if properties from SPR data file).

(Optional)

| | |
|---|---|
| 2nd field | FRIB1 |
| 3rd field | FRIB11 |
| 4th field | FRIB12 |
| 5th field | FRIB13 |
| 6th field | FRIB2 |
| 7th field | FRIB22 |

where the coefficients of friction are defined 18-th LINE.

### 21st LINE
### FORMAT (6F)
### (Optional)

Defining the 7th through 12th term of the coefficient Friction equation on the Barrel surface.

| | |
|---|---|
| 1st field | FRIB23 |
| 2nd field | FRIB3 |
| 3rd field | FRIB33 |
| 4th field | FRB111 |
| 5th field | FRB333 |
| 6th field | FRB112 |

### 22nd LINE
### FORMAT (6F)
### (Optional)

Defining the 13th through 18th term of the coefficient of Friction equation on the Barrel surface.

| | |
|---|---|
| 1st field | FRB113 |
| 2nd field | FRB123 |
| 3rd field | FRB223 |
| 4th field | FRB221 |
| 5th field | FRB331 |
| 6th field | FRB332 |

### 23rd LINE
FORMAT (6F)
(Optional)

Defining the 1st through 6th term of the coefficient of Friction equation on the Screw surface.

| | |
|---|---|
| 1st field | FRIS1 |
| 2nd field | FRIS11 |
| 3rd field | FRIS12 |
| 4th field | FRIS13 |
| 5th field | FRIS2 |
| 6th field | FRIS22 |

### 24th LINE
FORMAT (6F)
(Optional)

Defining the 7th through 12th term of the coefficient of Friction equation on the Screw surface.

| | |
|---|---|
| 1st field | FRIS23 |
| 2nd field | FRIS3 |
| 3rd field | FRIS33 |
| 4th field | FRS111 |
| 5th field | FRS333 |
| 6th field | FRS112 |

25th LINE
FORMAT (6F)
(Optional)

Defining the 13th through 18th term of the coefficient of Friction equation on the Screw surface.

| | |
|---|---|
| 1st field | FRS113 |
| 2nd field | FRS123 |
| 3rd field | FRS223 |
| 4th field | FRS221 |
| 5th field | FRS331 |
| 6th field | FRS332 |

Injection Molding
26th LINE
FORMAT (8F)
(Optional)

Needed only for injection molding and only if SHOT size, CYCLE time, and Screw Rotation Time (EXTIM) are to be supplied.

| | | |
|---|---|---|
| 1st field | Shot size (oz.), (g). | SHOT |
| 2nd field | Total Cycle time (sec/cycle). | CYCLE |
| 3rd field | Screw Rotation Time (sec/cycle). | EXTIM |

When this 26th line is non-zero, the values given for OUTPUT (9th LINE, 2nd field) and for Soak Time (9th LINE, 4th field) are disregarded. Both variables are now internally computed by EXTRUD from the molding data given in this line. If this 26th line is zero, then the OUTPUTand SOAK TIME values are taken from the 9th line.

Namelist
27th LINE

Needed only if 3rd SPEC LINE was YES.

This LINE starts in column 2 with $ followed by the word "INPUT", a space, and the list of variables to be varied separated by a comma. The list can contain as many sublines as needed but should end with a space followed by$ (DOLLAR SIGN< not ESC mode). Every subline must start in column 2. Each line except the last must end with a comma.

```
Column: 123456789...........................................etc..........................................80
                   $INPUT RPM =60., OUTPUT =189 (space) $
```

If no more changes are requested, instead of a list of Input Variables, BEND =-1 should be entered.

## APPENDIX B

## INPUT DATA

### (I) Varying Screw Speed

```
*******************************************************************************
*                       Barrel Diameter :       2.5 inches                    *
*                       Material :              Acetal copolymer grade M90    *
*                       Screw Speed :           30 rpm                        *
*                       Flow Rate :             100 lb/hr                     *
*******************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 30.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
***********             Screw Speed :           40 rpm          ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 40.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Screw Speed :          50 rpm          **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Screw Speed :          60 rpm          **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 60.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Screw Speed :          70 rpm          **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 70.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

# INPUT DATA

## (II) Varying Flow Rate

```
*****************************************************************************
*                    Barrel Diameter :      2.5 inches                      *
*                    Material :             Acetal copolymer grade M90      *
*                    Screw Speed :          50 rpm                          *
*                    Flow Rate :            80 lb/hr                        *
*****************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 80.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0

**********              Flow Rate :              90 lb/hr            **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 90.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Flow Rate :          100 lb/hr        **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Flow Rate :          110 lb/hr        **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 110.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********          Flow Rate :          120 lb/hr          **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 120.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.0 0.0 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

## INPUT DATA

### (III) Varying IPFC

```
****************************************************************************
*               Barrel Diameter :        2.5 inches                        *
*               Material :               Acetal copolymer grade M90        *
*               Screw Speed :            50 rpm                            *
*               Flow Rate :              100 lb/hr                         *
*               IPFC :                   0.05                              *
****************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.05 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
**********     IPFC :                  0.10                   **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.10 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :               0.15               ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.15 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :               0.20               **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.20 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********    IPFC :                    0.25                    **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.475 2.50 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.475 27.55 0.150 2.475 16.6 0.15 3.45 2.475 0.3875 2.475 9.9 0.4375 2.475
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.475
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 100.0 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.5 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.25 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
****************************************************************************
*                 Barrel Diameter :     2.25 inches                        *
*                 Material :            Acetal copolymer grade M90         *
*                 Screw Speed :         50 rpm                             *
*                 Flow Rate :           87.8 lb/hr                         *
*                 IPFC :                0.05                               *
****************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.225 2.250 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.225 27.55 0.15 2.225 16.6 0.15 3.45 2.225 0.3875 2.225 9.9 0.4375 2.225
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.225
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 87.8 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.25 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.05 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                    0.10                    **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.225 2.250 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.225 27.55 0.15 2.225 16.6 0.15 3.45 2.225 0.3875 2.225 9.9 0.4375 2.225
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.225
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 87.8 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.25 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.10 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                    0.15                    **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.225 2.250 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.225 27.55 0.15 2.225 16.6 0.15 3.45 2.225 0.3875 2.225 9.9 0.4375 2.225
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.225
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 87.8 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.25 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.15 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
***********     IPFC :                  0.20                    ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.225 2.250 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.225 27.55 0.15 2.225 16.6 0.15 3.45 2.225 0.3875 2.225 9.9 0.4375 2.225
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.225
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 87.8 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.25 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.20 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
***********     IPFC :                  0.25                    ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 2.225 2.250 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 2.225 27.55 0.15 2.225 16.6 0.15 3.45 2.225 0.3875 2.225 9.9 0.4375 2.225
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 2.225
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 87.8 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.25 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.25 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
********************************************************************************
*               Barrel Diameter :        2.0 inches                            *
*               Material :               Acetal copolymer grade M90            *
*               Screw Speed :            50 rpm                                *
*               Flow Rate :              75.6 lb/hr                            *
*               IPFC :                   0.05                                  *
********************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.975 2.0 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.975 27.55 0.15 1.975 16.6 0.15 3.45 1.975 0.3875 1.975 9.9 0.4375 1.975
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.975
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 75.6 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.0 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.05 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********      IPFC :                   0.10                      **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.975 2.0 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.975 27.55 0.15 1.975 16.6 0.15 3.45 1.975 0.3875 1.975 9.9 0.4375 1.975
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.975
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 75.6 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.0 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.10 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                    0.15                     **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.975 2.0 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.975 27.55 0.15 1.975 16.6 0.15 3.45 1.975 0.3875 1.975 9.9 0.4375 1.975
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.975
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 75.6 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.0 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.15 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
***********    IPFC :                    0.20                     ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.975 2.0 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.975 27.55 0.15 1.975 16.6 0.15 3.45 1.975 0.3875 1.975 9.9 0.4375 1.975
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.975
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 75.6 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.0 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.20 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********      IPFC :                  0.25                    ***********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.975 2.0 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.975 27.55 0.15 1.975 16.6 0.15 3.45 1.975 0.3875 1.975 9.9 0.4375 1.975
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.975
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 75.6 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 2.0 INCHES OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.25 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
****************************************************************************
*                  Barrel Diameter :      1.75 inches                      *
*                  Material :             Acetal copolymer grade M90       *
*                  Screw Speed :          50 rpm                           *
*                  Flow Rate :            63.5 lb/hr                       *
*                  IPFC :                 0.05                             *
****************************************************************************
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.725 1.75 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.75 27.55 0.15 1.75 16.6 0.15 3.45 1.75 0.3875 1.75 9.9 0.4375 1.75
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.75
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 63.5 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 1.75 INCH OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.05 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                    0.10                    **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.725 1.75 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.75 27.55 0.15 1.75 16.6 0.15 3.45 1.75 0.3875 1.75 9.9 0.4375 1.75
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.75
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 63.5 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 1.75 INCH OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.10 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                    0.15                    **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.725 1.75 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.75 27.55 0.15 1.75 16.6 0.15 3.45 1.75 0.3875 1.75 9.9 0.4375 1.75
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.75
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 63.5 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 1.75 INCH OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.15 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                  0.20                  **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.725 1.75 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.75 27.55 0.15 1.75 16.6 0.15 3.45 1.75 0.3875 1.75 9.9 0.4375 1.75
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.75
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 63.5 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 1.75 INCH OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.20 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

```
**********     IPFC :                  0.25                  **********
C
 6 5 0 1 1 0.999 0 0 0 1 1
Y
 -5 1.0 1.0 1.725 1.75 0.30 0.0125 -8 1 0 0 2 -70 0 0 3
 19.8 0.4375 1.75 27.55 0.15 1.75 16.6 0.15 3.45 1.75 0.3875 1.75 9.9 0.4375 1.75
 3.125 0.2375 3.125 16.6 0.2125 3.45 4.95 0.2125 1.75
  0.5 0.45 0.5 0.30
  3 3 0.5 0.15 0.15 0.1625
0.0 0.0 0.0 0.0 0.0 70.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 415.0 0.0 0.0 0.0 6 0 1 368 368 368 368
 390.0 15.2 400.0 32.855 410.0 50.51 420.0 68.165
430.0 85.82 440.0 103.475
-2000.0 120.0 0.0 1 0.914 0.0 0.0 0.0 0.0 200 100
 50.0 63.5 1 0.0 4.60 0.0 0.0 0.30
 M90 SIMULATE IN 1.75 INCH OF TWO-STAGE SCREW EXTRUDER
  7
 21.15284 0 0.25 0.10 0 0.45 75
 25.0 0.20 0.0 36.0 24.0 3.6833 0.05 8.0
 0.0
```

# OUTPUT OF SIMULATION

## (I) Varying Screw Speed

```
1MS30
    EXPERIMENT NUMBER    1.01        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 30.0 RPM      OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.    NO OF    HOLE
       #      (IN)   SOLID  MELT  SOLID MELT             DIAM    WIDTH   HOLES    AREA
                     (IN)   (IN)   (IN)  (IN)    (IN)    (IN)    (IN)             (SQIN)
       1     19.800  0.437  0.000 2.061 0.000   2.475   2.500   0.300
       2     27.550  0.150  0.000 2.061 0.000   2.475   2.500   0.300
       3     16.600  0.150  0.450 1.354 1.354   3.450   2.500   0.300
       4      2.475  0.387  0.000 2.061 0.000   2.475   2.500   0.300
       5      9.900  0.437  0.000 2.061 0.000   2.475   2.500   0.300
       6      3.125  0.237  0.000 2.604 0.000   3.125   2.500   0.300
       7     16.600  0.213  0.000 2.859 0.000   3.450   2.500   0.300   1.000    0.914
       8      4.950  0.213  0.000 2.061 0.000   2.475   2.500   0.300

                                HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
       INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                          SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =     120.00 DEG.F      AND      SCREW =    207.00 DEG.F


     LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN    DEG LB/CU.FT                BARREL    SCREW     HP        PSI
        1.00  40.3   21.10   0.025 0.001    131.2    207.0    0.00      0.38
        2.00  40.3   21.10   0.024 0.001    134.9    207.0    0.00      0.42
        3.00  40.2   21.12   0.024 0.003    136.3    207.0    0.00      0.47
        4.00  40.2   21.12   0.024 0.003    137.3    207.0    0.00      0.52
        5.00  40.0   21.15   0.036 0.004    108.1    207.0    0.00      0.57
    FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
    FRIS=    0.422595E-02 FRIB=    0.217960E-02
        6.00  40.0   21.15   0.002 0.004     70.0    207.0    0.00      0.58
        7.00  40.0   21.15   0.001 0.004     70.0    207.0    0.00      0.57
        7.82  40.0   21.15   0.001 0.004     70.0    207.0    0.00      0.56
        8.01  40.0   21.15   0.001 0.004     70.0    207.0    0.00      0.56
        8.21  40.0   21.15   0.001 0.004     70.0    207.0    0.00      0.55
        8.24  40.0   21.15   0.001 0.004    329.8    207.0    0.00      0.55


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI      HP     IN   DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                     /SQ.IN  .MIN  DEG F
    10.90 342.5                   0.   360.       0.437 349.0 0.0916
    12.60 342.5                   0.   654.       0.437 349.0 0.1008
    14.60 355.5                   0.   936.       0.437 368.1 0.1004
    16.10 349.0 .943 .943 .833    0.   995. 0.06 0.437 380.8 0.1981 -24.8    381.
    19.80 353.8 .866 .866 .763    0. 1023. 0.27 0.437 391.8 0.2323  -3.4    391.
    24.10 365.8 .843 .843 .754    0. 1056. 0.50 0.393 394.3 0.1692   1.2    394.
    29.10 378.7 .816 .816 .736    0. 1094. 0.77 0.340 397.3 0.1507   1.1    397.
    34.10 388.0 .788 .788 .718    0. 1206.  1.0 0.288 400.2 0.1390   1.0    400.
    39.10 395.0 .759 .759 .700    0. 1318.  1.3 0.236 403.1 0.1309   0.9    403.
    44.10 400.5 .726 .726 .683    0. 1397.  1.5 0.184 406.0 0.1251   0.8    405.
    47.35 403.5 .702 .702 .669    0. 1396.  1.7 0.150 408.1 0.1220  -2.7    408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 389.6 .458 .925 .458    0. 1408.  1.9 0.150 410.4 0.1404 -15.8    410.
    57.35 390.9 .259 .632 .259    0. 1504.  2.1 0.150 413.2 0.1406  -9.8    413.
    62.35 396.7 .135 .411 .135    0. 1610.  2.2 0.150 416.1 0.1337  -6.0    416.
    63.95 398.5 .105 .350 .105    0. 1638.  2.2 0.150 417.1 0.1315  -5.4    417.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
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```
 65.19 400.9 .096 .096 .095    0. 1662.  2.3 0.269 418.0 0.1227   0.4   418.
 66.42 403.3 .102 .102 .092    0. 1685.  2.3 0.387 418.7 0.1273   0.3   419.
 71.37 408.9 .063 .063 .056    0. 1758.  2.4 0.412 421.3 0.1242  -0.1   421.
 76.32 413.9 .034 .034 .030    0. 1823.  2.8 0.437 424.2 0.1208   1.0   424.
        FILM THICKNESS IS 0 - TBAR=  0.4247E+03
        FILM THICKNESS IS 0 - TBAR=  0.4247E+03
 77.89 415.8 .028 .028 .028    0. 1846.  2.9 0.338 425.3 0.1145   2.3   425.
 79.45 417.7 .025 .025 .025    0. 1875.  3.0 0.238 426.2 0.1091   2.4   426.
 ---------------------------------------------------------------------------
            FLUTED SECTION WITH  1. PAIRS OF FLUTES
 96.05 438.8 .025 .025 .018    0. 1874.  3.0 0.213 431.0 0.1091   2.4   426.
 --------------------------------------------------------------------------
101.00 438.5 .004 .004 .004    0. 1953.  3.4 0.213 438.3 0.0983   1.7   438.


MINIMUM TEMPERATURE=   437.120 DEG F
TEMP FLUCTUATION=        1.376 DEG F
FLOW INDEX (N)=          0.826
GRATIO INJ.=             0.004
RESIDENCE TIME:
     MELT POOL=   0.052195735 HRS


TORQUE  =        7106.8 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.000 HP
MELTING      =   2.286 HP
MIXING       =   0.452 HP
FLIGHT CLEAR =   0.589 HP
COMPRESSION  =   0.052 HP
MIXING DEVICE=   0.024 HP
PRESSURE FLUCTUATION=        63.72 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=   -224.2 TO    -163.8 BTU/MIN  OR
                                        -5.28 TO     -3.86 HP

MAXIMUM SCREW SPEED,RPM:             30.0  58.3  86.7 115.0 143.3 171.7 200.0
POWER CONSUMPTION, % OF AVAILABLE:   3.4   6.6   9.8  13.0  16.2  19.4  22.6

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.672 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F      LB.SEC/SQ.IN
     403.44        376.9        0.0611026
       1.27        380.8        0.1945229


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F      LB.SEC/SQ.IN
      22.82        439.0        0.0947747
     125.59        329.0        0.1295692
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
```

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1MS40
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 40.0 RPM       OUTPUT=  100.00 LB/HR       SOAK TIME=  0.00 SECONDS



   SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
      #      (IN)   SOLID  MELT  SOLID MELT              DIAM    WIDTH  HOLES    AREA
                     (IN)   (IN)   (IN)  (IN)    (IN)    (IN)    (IN)           (SQIN)
      1     19.800  0.437  0.000 2.061 0.000   2.475   2.500   0.300
      2     27.550  0.150  0.000 2.061 0.000   2.475   2.500   0.300
      3     16.600  0.150  0.450 1.354 1.354   3.450   2.500   0.300
      4      2.475  0.387  0.000 2.061 0.000   2.475   2.500   0.300
      5      9.900  0.437  0.000 2.061 0.000   2.475   2.500   0.300
      6      3.125  0.237  0.000 2.604 0.000   3.125   2.500   0.300
      7     16.600  0.213  0.000 2.859 0.000   3.450   2.500   0.300  1.000   0.914
      8      4.950  0.213  0.000 2.061 0.000   2.475   2.500   0.300


                              HOPPER ANALYSIS

     ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

     SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
     INCREASE HEIGHT TO =    186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                         SOLIDS CONVEYING ZONE ANALYSIS


  OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
  BARREL =      96.00 DEG.F     AND      SCREW =    207.00 DEG.F


   LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
      IN    DEG LB/CU.FT               BARREL    SCREW    HP        PSI
     1.00   20.8   21.12  0.045 0.003   101.9    207.0    0.00      0.45
     2.00   20.7   21.15  0.046 0.004   103.6    207.0    0.00      0.61
     3.00   20.6   21.21  0.050 0.008   104.5    207.0    0.00      0.83
     4.00   20.4   21.32  0.056 0.013   104.9    207.0    0.00      1.12
     5.00   20.2   21.42  0.062 0.019    92.2    207.0    0.00      1.53
     6.00   20.1   21.48  0.030 0.022    70.0    207.0    0.00      1.69
     6.55   20.1   21.48  0.029 0.022    70.0    207.0    0.00      1.74
     7.05   20.1   21.48  0.028 0.022    70.0    207.0    0.00      1.78
     7.55   20.0   21.51  0.028 0.024    70.0    207.0    0.00      1.82
     8.05   20.0   21.51  0.027 0.024    70.0    207.0    0.00      1.86
     8.55   20.0   21.51  0.026 0.024    70.0    207.0    0.00      1.89
     9.05   20.0   21.54  0.027 0.025    70.0    207.0    0.00      1.91
  FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
  FRIS=     0.251617E-01 FRIB=     0.251022E-01
     9.55   20.0   21.54  0.026 0.025    70.0    207.0    0.00      1.93
    10.05   20.0   21.54  0.026 0.025    70.0    207.0    0.00      1.94
    10.10   20.0   21.54  0.026 0.025   329.8    207.0    0.00      1.95


  L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
  IN    DEG F     SOLID          PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                            REAL  FULL                     /SQ.IN  .MIN  DEG F
  12.60 342.5                 0.   479.       0.437 349.0 0.0853
  14.60 355.5                 0.   840.       0.437 368.0 0.0904
  16.10 354.1 .878 .878 .727  0.   934. 0.10 0.437 380.8 0.2088 -35.8   381.
  19.80 359.3 .790 .790 .652  0.  1042. 0.45 0.437 391.8 0.1956  -2.4   391.
  24.10 371.1 .747 .747 .633  0.  1168. 0.83 0.393 394.3 0.1447   2.6   394.
  29.10 384.3 .696 .696 .608  0.  1325.  1.3 0.340 397.3 0.1289   1.7   397.
  34.10 393.0 .640 .640 .575  0.  1503.  1.7 0.288 400.3 0.1193   1.0   400.
  39.10 398.4 .576 .576 .533  0.  1705.  2.1 0.236 403.2 0.1136   0.0   403.
  44.10 401.4 .500 .500 .474  0.  1909.  2.5 0.184 406.0 0.1106  -1.5   405.
  47.35 402.6 .439 .439 .425  0.  2004.  2.6 0.150 408.0 0.1095  -3.4   408.
  -------------------------SECONDARY CHANNEL BEGINS--------------------------
  52.35 397.8 .240 .485 .240  0.  2183.  3.1 0.150 410.5 0.1179 -10.8   410.
  57.35 400.4 .096 .235 .096  0.  2398.  3.4 0.150 413.3 0.1168  -3.0   413.
  62.35 407.2 .021 .064 .021  0.  2575.  3.8 0.150 416.2 0.1104   0.4   416.
  63.95 405.4 .009 .030 .009  0.  2619.  4.0 0.150 417.3 0.1085   1.7   417.
  --------------------------SECONDARY CHANNEL ENDS--------------------------
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         FILM THICKNESS IS 0 - TBAR=  0.4175E+03
         FILM THICKNESS IS 0 - TBAR=  0.4175E+03
  65.19 411.4 .004 .004 .004     0. 2666.  4.2 0.269 418.1 0.1014   3.7   418.
  66.42 413.0 .002 .002 .002     0. 2700.  4.3 0.387 418.8 0.1069   0.7   419.
         FILM THICKNESS IS 0 - TBAR=  0.4192E+03
         FILM THICKNESS IS 0 - TBAR=  0.4192E+03
  71.37 418.3 .000 .000 .000     0. 2805.  4.4 0.412 421.5 0.1049   1.1   419.
  76.32 422.4 .000 .000 .000     0. 2897.  4.5 0.437 424.3 0.1028   1.0   419.
  77.89 423.6 .000 .000 .000     0. 2930.  4.6 0.338 425.4 0.0973   1.2   419.
  79.45 425.2 .000 .000 .000     0. 2975.  4.6 0.238 426.3 0.0924   1.4   419.
 ---------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 425.2 .000 .000 .000     0. 2974.  4.7 0.213 431.1 0.0924   1.4   419.
 --------------------------------------------------------------------------
101.00 433.7 .000 .000 .000     0. 3145.  4.8 0.213 438.2 0.0910   1.4   419.


MINIMUM TEMPERATURE=   433.725 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.789
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.052126914 HRS


TORQUE  =        7634.1 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.002 HP
MELTING      =   2.803 HP
MIXING       =   0.932 HP
FLIGHT CLEAR =   0.946 HP
COMPRESSION  =   0.131 HP
MIXING DEVICE=   0.041 HP

PRESSURE FLUCTUATION=        119.39 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=   -159.2 TO     -86.5 BTU/MIN  OR
                                        -3.75 TO     -2.04 HP


MAXIMUM SCREW SPEED,RPM:             40.0  66.7  93.3 120.0 146.7 173.3 200.0
POWER CONSUMPTION, % OF AVAILABLE:    4.8   8.1  11.3  14.5  17.8  21.0  24.2

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.658 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     686.10        374.1        0.0502803
       4.95        380.8        0.1767041


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
      33.41        438.2        0.0882818
     343.05        329.0        0.0903600
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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1MS50
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM       OUTPUT=  100.00 LB/HR       SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD   BAR.    FLT.   NO OF   HOLE
      #      (IN)   SOLID  MELT  SOLID MELT            DIAM    WIDTH  HOLES   AREA
                    (IN)   (IN)   (IN)  (IN)   (IN)    (IN)    (IN)          (SQIN)
      1     19.800  0.437  0.000 2.061 0.000  2.475   2.500   0.300
      2     27.550  0.150  0.000 2.061 0.000  2.475   2.500   0.300
      3     16.600  0.150  0.450 1.354 1.354  3.450   2.500   0.300
      4      2.475  0.387  0.000 2.061 0.000  2.475   2.500   0.300
      5      9.900  0.437  0.000 2.061 0.000  2.475   2.500   0.300
      6      3.125  0.237  0.000 2.604 0.000  3.125   2.500   0.300
      7     16.600  0.213  0.000 2.859 0.000  3.450   2.500   0.300  1.000   0.914
      8      4.950  0.213  0.000 2.061 0.000  2.475   2.500   0.300

                           HOPPER ANALYSIS

     ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

     SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
     INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                     SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      67.00 DEG.F      AND      SCREW =     207.00 DEG.F


    LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT               BARREL   SCREW     HP        PSI
      1.00   13.7  21.13  0.059 0.003    67.0    207.0    0.00       0.51
      2.00   13.6  21.22  0.065 0.008    67.0    207.0    0.00       0.79
      3.00   13.5  21.33  0.072 0.014    67.0    207.0    0.00       1.25
      4.00   13.3  21.53  0.084 0.025    67.0    207.0    0.00       2.00
      5.00   12.9  21.92  0.101 0.044    75.0    207.0    0.00       3.28
      6.00   12.7  22.12  0.072 0.054    67.0    207.0    0.01       4.03
      7.00   12.5  22.39  0.083 0.067    67.0    207.0    0.01       4.94
      8.00   12.2  22.66  0.093 0.078    67.0    207.0    0.01       5.89
      9.00   12.0  22.96  0.105 0.091    67.0    207.0    0.01       6.98
     10.00   11.7  23.31  0.117 0.104    67.0    207.0    0.02       8.23
     10.90   11.4  23.66  0.129 0.117   330.0    207.0    0.03       9.53


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F      SOLID          PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                  /SQ.IN  .MIN  DEG F
    13.10 342.5                  471.  471.       0.437 349.0 0.0811
    15.10 364.4                  837.  837.       0.437 380.8 0.0839
    17.10 371.3                 1071. 1071.       0.437 390.6 0.0903
    18.10 359.9 .879 .879 .732 1111. 1111.   0.2 0.437 390.6 0.1863 -32.5   391.
    19.80 361.7 .830 .830 .691 1179. 1179.   0.4 0.437 390.6 0.1851  -2.2   391.
    24.80 373.3 .763 .763 .655 1379. 1379.   1.1 0.385 394.7 0.1522   2.8   394.
    26.10 378.0 .746 .746 .645 1431. 1431.   1.2 0.372 395.5 0.1232   3.5   395.
    31.10 391.2 .674 .674 .601 1646. 1646.   1.9 0.320 398.6 0.1098   2.1   398.
    36.10 398.9 .596 .596 .546 1899. 1899.   2.5 0.267 401.5 0.1027   1.0   401.
    41.10 403.6 .508 .508 .478 2200. 2200.   3.1 0.215 404.4 0.0985  -0.5   404.
    46.10 406.3 .402 .402 .390 2527. 2527.   3.7 0.163 407.2 0.0964  -2.6   407.
    47.35 406.7 .373 .373 .363 2599. 2599.   3.8 0.150 408.1 0.0960  -4.0   408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 404.0 .185 .374 .185 2953. 2953.   4.3 0.150 410.6 0.1020  -8.2   410.
    57.35 408.0 .077 .188 .077 3282. 3282.   4.6 0.150 413.5 0.1001  -2.7   413.
    62.35 413.1 .003 .010 .003 3520. 3520.   5.6 0.150 416.3 0.0959   3.4   416.
    63.95 415.3 .000 .000 .000 3576. 3576.   5.6 0.150 417.4 0.0944   1.8   417.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
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  65.19 417.6 .000 .000 .000 3644. 3644.  5.7 0.269 418.2 0.0876   2.2    417.
  66.42 419.1 .000 .000 .000 3687. 3687.  5.8 0.387 418.9 0.0932   1.7    417.
  71.37 422.9 .000 .000 .000 3820. 3820.  6.0 0.412 421.6 0.0925   1.6    417.
  76.32 426.1 .000 .000 .000 3939. 3939.  6.1 0.437 424.4 0.0915   1.5    417.
  77.89 427.2 .000 .000 .000 3981. 3981.  6.2 0.338 425.4 0.0862   1.7    417.
  79.45 428.7 .000 .000 .000 4040. 4040.  6.3 0.238 426.3 0.0815   2.1    417.
  ----------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 428.7 .000 .000 .000 4039. 4039.  6.3 0.213 431.1 0.0815   2.1    417.
  ---------------------------------------------------------------------------
 101.00 437.9 .000 .000 .000 4288. 4288.  6.6 0.213 438.3 0.0803   2.1    417.


MINIMUM TEMPERATURE=   437.908 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.763
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=    0.050008345 HRS


TORQUE  =        8303.5 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.027 HP
MELTING      =   3.545 HP
MIXING       =   1.463 HP
FLIGHT CLEAR =   1.313 HP
COMPRESSION  =   0.195 HP
MIXING DEVICE=   0.060 HP
PRESSURE FLUCTUATION=        170.41 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=     -89.1 TO     -21.0 BTU/MIN  OR
                                         -2.10 TO     -0.49 HP


MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:    6.6   9.9  13.2  16.5  19.8  23.1  26.3


STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.641 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F      LB.SEC/SQ.IN
     770.55        342.5       0.0588104
       8.18        390.6       0.1541261


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F      LB.SEC/SQ.IN
      14.32        441.3       0.1012381
     230.69        329.0       0.1049526
AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  4288. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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1MS60
   EXPERIMENT NUMBER     1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 60.0 RPM      OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS



   SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
      #      (IN)   SOLID  MELT  SOLID MELT              DIAM    WIDTH  HOLES    AREA
                    (IN)   (IN)   (IN)  (IN)     (IN)    (IN)    (IN)           (SQIN)
      1     19.800  0.437  0.000 2.061 0.000    2.475   2.500   0.300
      2     27.550  0.150  0.000 2.061 0.000    2.475   2.500   0.300
      3     16.600  0.150  0.450 1.354 1.354    3.450   2.500   0.300
      4      2.475  0.387  0.000 2.061 0.000    2.475   2.500   0.300
      5      9.900  0.437  0.000 2.061 0.000    2.475   2.500   0.300
      6      3.125  0.237  0.000 2.604 0.000    3.125   2.500   0.300
      7     16.600  0.213  0.000 2.859 0.000    3.450   2.500   0.300  1.000   0.914
      8      4.950  0.213  0.000 2.061 0.000    2.475   2.500   0.300

                           HOPPER ANALYSIS

     ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

     SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
     INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                     SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      63.50 DEG.F      AND     SCREW =    207.00 DEG.F


    LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                BARREL   SCREW    HP        PSI
      1.00  10.2  21.15  0.068 0.004      63.5   207.0    0.00      0.55
      2.00  10.1  21.26  0.075 0.010      63.5   207.0    0.00      0.93
      3.00  10.0  21.45  0.087 0.020      63.5   207.0    0.00      1.61
      4.00   9.7  21.80  0.109 0.038      63.5   207.0    0.00      2.88
      5.00   9.3  22.50  0.142 0.071      73.0   207.0    0.01      5.44
      6.00   9.0  23.06  0.121 0.095      63.5   207.0    0.01      7.38
      7.00   8.6  23.76  0.146 0.120      63.5   207.0    0.02      9.95
      8.00   8.1  24.71  0.173 0.147      63.5   207.0    0.04     13.48
      9.00   7.5  26.00  0.197 0.170      63.5   207.0    0.06     18.36
      9.30   7.3  26.53  0.229 0.175     330.0   207.0    0.07     20.59


    L    TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F      SOLID         PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                   /SQ.IN  .MIN  DEG F
    11.68 342.5                 546.  546.       0.437 349.0 0.0826
    13.60 342.5                 920.  920.       0.437 349.0 0.0960
    16.10 356.2 .871 .871 .723 1183. 1183.   0.3 0.437 380.8 0.1806 -29.7    381.
    19.80 362.8 .757 .757 .627 1351. 1351.   1.0 0.437 391.8 0.1583  -0.6    391.
    24.10 377.4 .684 .684 .581 1546. 1546.   1.7 0.393 394.4 0.1138   4.4    394.
    29.10 391.9 .595 .595 .522 1789. 1789.   2.6 0.340 397.5 0.1004   2.6    397.
    34.10 400.1 .501 .501 .453 2075. 2075.   3.4 0.288 400.4 0.0934   1.3    400.
    39.10 405.3 .400 .400 .372 2422. 2422.   4.2 0.236 403.3 0.0893  -0.1    403.
    44.10 409.2 .290 .290 .277 2845. 2845.   4.9 0.184 406.1 0.0865  -1.6    406.
    47.35 411.4 .215 .215 .209 3140. 3140.   5.3 0.150 408.2 0.0851  -3.1    408.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 412.8 .087 .175 .087 3645. 3645.   5.8 0.150 410.8 0.0878  -2.9    410.
   TBAR WAS CHANGED AT AXIAL LOC=   54.35 IN. TO TBAR= 434.0 F
   IN ORDER TO CONVERGE.
    57.35 417.7 .000 .000 .000 4073. 4073.   7.3 0.150 413.7 0.0857   3.1    434.
    62.35 422.9 .000 .000 .000 4358. 4358.   7.6 0.150 416.5 0.0823   2.5    434.
    63.95 424.0 .000 .000 .000 4423. 4423.   7.7 0.150 417.6 0.0817   2.3    434.
    -------------------------SECONDARY CHANNEL ENDS-------------------------
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  65.19 425.8 .000 .000 .000 4507. 4507.  7.8 0.269 418.4 0.0758   2.9   434.
  66.42 426.4 .000 .000 .000 4559. 4559.  7.8 0.387 419.1 0.0815   2.3   434.
  71.37 428.1 .000 .000 .000 4717. 4717.  8.1 0.412 421.7 0.0821   2.2   434.
  76.32 429.9 .000 .000 .000 4860. 4860.  8.4 0.437 424.4 0.0820   2.1   434.
  77.89 430.8 .000 .000 .000 4910. 4910.  8.4 0.338 425.5 0.0771   2.3   434.
  79.45 432.3 .000 .000 .000 4983. 4983.  8.5 0.238 426.4 0.0725   2.9   434.
  ---------------------------------------------------------------------------
            FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 432.3 .000 .000 .000 4982. 4982.  8.6 0.213 431.2 0.0725   2.9   434.
  --------------------------------------------------------------------------
 101.00 442.1 .000 .000 .000 5297. 5297.  9.0 0.213 438.4 0.0717   3.0   434.


 MINIMUM TEMPERATURE=   442.133 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.742
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.052399963 HRS


 TORQUE  =        9414.4 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.070 HP
 MELTING      =   4.513 HP
 MIXING       =   2.214 HP
 FLIGHT CLEAR =   1.822 HP
 COMPRESSION  =   0.283 HP
 MIXING DEVICE=   0.081 HP
 PRESSURE FLUCTUATION=        210.67 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=      7.8 TO       85.2 BTU/MIN  OR
                                          0.18 TO       2.01 HP


 MAXIMUM SCREW SPEED,RPM:             60.0  83.3 106.7 130.0 153.3 176.7 200.0
 POWER CONSUMPTION, % OF AVAILABLE:   9.0  12.4  15.9  19.4  22.9  26.4  29.9

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.616 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
    1160.66         331.1         0.0529186
      12.82         380.8         0.1544832


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
      17.19         447.5        0.0948087
    1160.66         319.0        0.0576891
 AT  60.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  5297. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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1MS70
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 70.0 RPM       OUTPUT=  100.00 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH        WIDTH       LEAD    BAR.    FLT.    NO OF    HOLE
       #      (IN)   SOLID  MELT   SOLID MELT              DIAM    WIDTH   HOLES    AREA
                     (IN)   (IN)    (IN)  (IN)     (IN)    (IN)    (IN)            (SQIN)
       1     19.800  0.437  0.000 2.061 0.000    2.475   2.500   0.300
       2     27.550  0.150  0.000 2.061 0.000    2.475   2.500   0.300
       3     16.600  0.150  0.450 1.354 1.354    3.450   2.500   0.300
       4      2.475  0.387  0.000 2.061 0.000    2.475   2.500   0.300
       5      9.900  0.437  0.000 2.061 0.000    2.475   2.500   0.300
       6      3.125  0.237  0.000 2.604 0.000    3.125   2.500   0.300
       7     16.600  0.213  0.000 2.859 0.000    3.450   2.500   0.300  1.000   0.914
       8      4.950  0.213  0.000 2.061 0.000    2.475   2.500   0.300

                               HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
      INCREASE HEIGHT TO =    186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                        SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      60.50 DEG.F      AND      SCREW =     207.00 DEG.F

    LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                BARREL    SCREW     HP        PSI
       1.00   8.1  21.16  0.076 0.004      60.5    207.0    0.00       0.59
       2.00   8.0  21.28  0.084 0.011      60.5    207.0    0.00       1.08
       3.00   7.9  21.56  0.102 0.026      60.5    207.0    0.00       2.02
       4.00   7.6  22.10  0.136 0.053      60.5    207.0    0.01       4.00
       5.00   7.1  23.39  0.193 0.107      71.5    207.0    0.01       8.76
       6.00   6.6  24.66  0.183 0.146      60.5    207.0    0.03      13.36
       7.00   6.0  26.48  0.213 0.175      60.5    207.0    0.06      20.32
       7.70   5.4  28.38  0.210 0.172      60.5    207.0    0.10      27.49
       7.85   5.3  28.85  0.210 0.172     329.5    207.0    0.10      29.35


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F     SOLID           PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                  /SQ.IN  .MIN  DEG F
    10.18 342.5                  575.  575.      0.437 349.0 0.0826
    12.18 342.5                  959.  959.      0.437 349.0 0.0971
    14.10 342.1 .872 .872 .727 1158. 1158.  0.4 0.437 349.0 0.1963 -22.6   355.
    19.10 358.6 .714 .714 .591 1412. 1412.  1.8 0.437 391.2 0.1482   0.5   391.
    19.80 361.6 .690 .690 .572 1447. 1447.  1.9 0.437 391.7 0.1409   0.1   391.
    22.10 373.1 .644 .644 .541 1564. 1564.  2.4 0.413 393.1 0.1094   5.7   393.
    27.10 391.1 .542 .542 .470 1831. 1831.  3.5 0.361 396.3 0.0936   3.4   396.
    32.10 400.7 .437 .437 .391 2139. 2139.  4.5 0.309 399.3 0.0861   1.9   399.
    37.10 406.9 .330 .330 .304 2513. 2513.  5.4 0.257 402.2 0.0816   0.7   402.
    42.10 412.0 .223 .223 .211 2981. 2981.  6.2 0.205 405.1 0.0784  -0.1   405.
    47.10 417.0 .123 .123 .119 3552. 3552.  7.0 0.153 408.0 0.0758  -0.1   407.
    47.35 417.3 .118 .118 .115 3582. 3582.  7.0 0.150 408.3 0.0755  -0.4   408.
    ---------------------------SECONDARY CHANNEL BEGINS---------------------------
   TBAR WAS CHANGED AT AXIAL LOC=    50.35 IN. TO TBAR= 434.0 F
   IN ORDER TO CONVERGE.
    52.35 420.9 .000 .000 .000 4229. 4229.  8.8 0.150 410.9 0.0769   4.7   434.
    57.35 426.6 .000 .000 .000 4732. 4732.  9.3 0.150 413.8 0.0746   3.9   434.
    62.35 429.0 .000 .000 .000 5058. 5058.  9.7 0.150 416.7 0.0730   3.2   434.
    63.95 429.5 .000 .000 .000 5133. 5133.  9.9 0.150 417.7 0.0728   3.0   434.
    ----------------------------SECONDARY CHANNEL ENDS----------------------------
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  65.19 431.1 .000 .000 .000 5232. 5232. 10.0 0.269 418.5 0.0674   3.7   434.
  66.42 431.5 .000 .000 .000 5291. 5291. 10.1 0.387 419.2 0.0730   3.0   434.
  71.37 431.8 .000 .000 .000 5475. 5475. 10.4 0.412 421.7 0.0742   2.8   434.
  76.32 433.0 .000 .000 .000 5639. 5639. 10.7 0.437 424.5 0.0745   2.6   434.
  77.89 433.8 .000 .000 .000 5698. 5698. 10.8 0.338 425.6 0.0698   3.0   434.
  79.45 435.4 .000 .000 .000 5783. 5783. 11.0 0.238 426.5 0.0654   3.7   434.
  ----------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 435.4 .000 .000 .000 5782. 5782. 11.1 0.213 431.3 0.0654   3.7   434.
  ---------------------------------------------------------------------------
 101.00 446.1 .000 .000 .000 6158. 6158. 11.5 0.213 438.5 0.0646   3.9   434.


 MINIMUM TEMPERATURE=   446.076 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.724
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.054696292 HRS


 TORQUE  =        10365.2 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.104 HP
 MELTING      =   5.474 HP
 MIXING       =   3.061 HP
 FLIGHT CLEAR =   2.427 HP
 COMPRESSION  =   0.369 HP
 MIXING DEVICE=   0.104 HP
 PRESSURE FLUCTUATION=        247.25 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=     112.4 TO      194.5 BTU/MIN  OR
                                           2.65 TO       4.58 HP


 MAXIMUM SCREW SPEED,RPM:             70.0  91.7 113.3 135.0 156.7 178.3 200.0
 POWER CONSUMPTION, % OF AVAILABLE:   11.5  15.1  18.6  22.2  25.8  29.3  32.9


 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.596 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
     1369.03        323.7       0.0516086
       17.62        349.0       0.1859733


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
       20.05        453.9       0.0890560
     1369.03        319.0       0.0533599
 AT  70.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  6158. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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## OUTPUT OF SIMULATION

### (II) Varying Flow Rate

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1MF80
   EXPERIMENT NUMBER     1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM       OUTPUT=   80.00 LB/HR       SOAK TIME=  0.00 SECONDS



   SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD    BAR.    FLT.   NO OF   HOLE
      #      (IN)    SOLID  MELT  SOLID MELT            DIAM   WIDTH   HOLES   AREA
                     (IN)   (IN)   (IN)  (IN)    (IN)   (IN)    (IN)          (SQIN)
      1    19.800  0.437   0.000 2.061 0.000   2.475  2.500  0.300
      2    27.550  0.150   0.000 2.061 0.000   2.475  2.500  0.300
      3    16.600  0.150   0.450 1.354 1.354   3.450  2.500  0.300
      4     2.475  0.387   0.000 2.061 0.000   2.475  2.500  0.300
      5     9.900  0.437   0.000 2.061 0.000   2.475  2.500  0.300
      6     3.125  0.237   0.000 2.604 0.000   3.125  2.500  0.300
      7    16.600  0.213   0.000 2.859 0.000   3.450  2.500  0.300  1.000  0.914
      8     4.950  0.213   0.000 2.061 0.000   2.475  2.500  0.300

                             HOPPER ANALYSIS

     ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

     SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
     INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                        SOLIDS CONVEYING ZONE ANALYSIS


  OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
  BARREL =      65.50 DEG.F      AND      SCREW =     197.00 DEG.F


   LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
      IN    DEG LB/CU.FT                 BARREL   SCREW     HP        PSI
     1.00    9.6  21.12  0.062 0.003      65.5   197.0     0.00       0.53
     2.00    9.5  21.22  0.068 0.008      65.5   197.0     0.00       0.87
     3.00    9.4  21.40  0.080 0.018      65.5   197.0     0.00       1.44
     4.00    9.2  21.69  0.097 0.033      65.5   197.0     0.00       2.47
     5.00    8.9  22.22  0.122 0.059      75.0   197.0     0.00       4.40
     6.00    8.7  22.60  0.097 0.076      65.5   197.0     0.01       5.72
     7.00    8.5  23.04  0.114 0.094      65.5   197.0     0.01       7.30
     8.00    8.2  23.60  0.134 0.115      65.5   197.0     0.02       9.32
     9.00    7.8  24.31  0.155 0.137      65.5   197.0     0.03      11.95
     9.90    7.5  25.13  0.175 0.157     329.1   197.0     0.04      14.97


   L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
   IN    DEG F     SOLID          PSI       HP    IN   DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                    /SQ.IN  .MIN  DEG F
   12.25 342.5                 506.  506.       0.437 349.0 0.0867
   14.10 346.7                 838.  838.       0.437 355.2 0.0969
   16.60 360.4 .867 .867 .717 1063. 1063.   0.2 0.437 389.8 0.1760 -24.5   390.
   19.80 365.9 .753 .753 .623 1189. 1189.   0.6 0.437 392.0 0.1565  -3.1   392.
   24.60 380.8 .653 .653 .557 1379. 1379.   1.3 0.387 394.7 0.1147   1.8   394.
   29.60 392.2 .545 .545 .479 1594. 1594.   1.9 0.335 397.7 0.1037   0.3   397.
   34.60 398.5 .431 .431 .390 1850. 1850.   2.4 0.283 400.7 0.0979  -0.8   400.
   39.60 403.0 .313 .313 .291 2167. 2167.   3.0 0.231 403.5 0.0941  -1.7   403.
   44.60 407.0 .193 .193 .185 2556. 2556.   3.4 0.179 406.4 0.0913  -2.3   406.
   47.35 409.3 .131 .131 .128 2787. 2787.   3.7 0.150 408.0 0.0899  -2.2   408.
   -----------------------SECONDARY CHANNEL BEGINS-------------------------
   52.35 412.5 .002 .005 .002 3252. 3252.   4.7 0.150 410.8 0.0912   3.8   410.
  TBAR WAS CHANGED AT AXIAL LOC=   52.35 IN.  TO TBAR= 434.0 F
  IN ORDER TO CONVERGE.
   57.35 419.1 .000 .000 .000 3630. 3630.   5.0 0.150 413.7 0.0878   2.3   434.
   62.35 422.6 .000 .000 .000 3879. 3879.   5.2 0.150 416.5 0.0854   1.9   434.
   63.95 423.3 .000 .000 .000 3936. 3936.   5.3 0.150 417.5 0.0849   1.7   434.
   ------------------------SECONDARY CHANNEL ENDS-------------------------
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 65.19 424.8 .000 .000 .000 4010. 4010.  5.4 0.269 418.4 0.0791   2.1    434.
 66.42 425.3 .000 .000 .000 4056. 4056.  5.4 0.387 419.1 0.0849   1.7    434.
 71.37 426.6 .000 .000 .000 4195. 4195.  5.6 0.412 421.6 0.0857   1.6    434.
 76.32 428.5 .000 .000 .000 4319. 4319.  5.8 0.437 424.4 0.0856   1.5    434.
 77.89 429.3 .000 .000 .000 4363. 4363.  5.9 0.338 425.5 0.0806   1.7    434.
 79.45 430.8 .000 .000 .000 4427. 4427.  5.9 0.238 426.4 0.0760   2.1    434.
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                FLUTED SECTION WITH  1. PAIRS OF FLUTES
 96.05 430.8 .000 .000 .000 4426. 4426.  6.0 0.213 431.2 0.0760   2.1    434.
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101.00 440.8 .000 .000 .000 4707. 4707.  6.2 0.213 438.4 0.0748   2.2    434.


MINIMUM TEMPERATURE=   440.794 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.750
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.065096207 HRS


TORQUE  =         7877.5 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.043 HP
MELTING      =   2.935 HP
MIXING       =   1.671 HP
FLIGHT CLEAR =   1.345 HP
COMPRESSION  =   0.213 HP
MIXING DEVICE=   0.059 HP
PRESSURE FLUCTUATION=        187.10 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=     -31.8 TO      28.1 BTU/MIN  OR
                                         -0.75 TO      0.66 HP


MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:   6.2   9.4  12.5  15.6  18.7  21.9  25.0

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.652 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE       TEMP.        VISCOSITY
    1/SEC         DEG.F       LB.SEC/SQ.IN
     969.99       337.7        0.0548940
      11.73       389.8        0.1468164


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE       TEMP.        VISCOSITY
    1/SEC         DEG.F       LB.SEC/SQ.IN
      14.32       442.2        0.1006939
     969.99       319.0        0.0626749
AT  50.00 RPM &   80.00 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  4707. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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1MF90
    EXPERIMENT NUMBER    1.00      SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM      OUTPUT=   90.00 LB/HR      SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH      WIDTH     LEAD   BAR.   FLT.   NO OF   HOLE
      #       (IN)   SOLID MELT   SOLID MELT         DIAM   WIDTH  HOLES   AREA
                     (IN)  (IN)   (IN) (IN)  (IN)   (IN)    (IN)          (SQIN)
      1     19.800  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      2     27.550  0.150  0.000 2.061 0.000  2.475  2.500  0.300
      3     16.600  0.150  0.450 1.354 1.354  3.450  2.500  0.300
      4      2.475  0.387  0.000 2.061 0.000  2.475  2.500  0.300
      5      9.900  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      6      3.125  0.237  0.000 2.604 0.000  3.125  2.500  0.300
      7     16.600  0.213  0.000 2.859 0.000  3.450  2.500  0.300  1.000  0.914
      8      4.950  0.213  0.000 2.061 0.000  2.475  2.500  0.300

                            HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =    36.00 IN. BASE PRESSURE =     0.33 PSI
      INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                     SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =     66.00 DEG.F     AND     SCREW =    202.00 DEG.F

    LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER   PRESSURE
        IN   DEG LB/CU.FT              BARREL   SCREW     HP        PSI
       1.00 11.5  21.12  0.060 0.002    66.0    202.0    0.00      0.52
       2.00 11.5  21.22  0.066 0.008    66.0    202.0    0.00      0.83
       3.00 11.3  21.36  0.075 0.015    66.0    202.0    0.00      1.35
       4.00 11.1  21.62  0.092 0.029    66.0    202.0    0.00      2.23
       5.00 10.8  22.06  0.112 0.051    75.0    202.0    0.00      3.82
       6.00 10.6  22.34  0.084 0.064    66.0    202.0    0.01      4.85
       7.00 10.3  22.68  0.097 0.079    66.0    202.0    0.01      6.00
       8.00 10.0  23.08  0.112 0.096    66.0    202.0    0.01      7.42
       9.00  9.7  23.55  0.129 0.113    66.0    202.0    0.02      9.13
      10.00  9.4  24.12  0.147 0.131    66.0    202.0    0.03     11.24
      10.30  9.3  24.32  0.152 0.137   330.0    202.0    0.03     11.96


    L    TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F      SOLID         PSI       HP   IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                  /SQ.IN  .MIN  DEG F
    12.60 342.5                496.  496.        0.437 349.0 0.0844
    14.60 355.5                861.  861.        0.437 368.0 0.0901
    17.10 360.1 .870 .870 .721 1081. 1081.  0.2 0.437 390.0 0.1809 -29.1   390.
    19.80 363.9 .784 .784 .649 1188. 1188.  0.5 0.437 391.9 0.1696  -2.1   390.
    24.10 375.3 .712 .712 .605 1357. 1357.  1.1 0.393 394.6 0.1220   2.2   394.
    25.10 378.9 .695 .695 .594 1397. 1397.  1.2 0.382 395.0 0.1197   2.6   395.
    30.10 391.2 .606 .606 .534 1610. 1610.  1.9 0.330 398.0 0.1074   1.1   397.
    35.10 398.2 .510 .510 .463 1863. 1863.  2.5 0.278 400.9 0.1008   0.0   400.
    40.10 402.7 .405 .405 .378 2171. 2171.  3.0 0.226 403.8 0.0968  -1.4   403.
    45.10 406.0 .289 .289 .277 2534. 2534.  3.6 0.173 406.6 0.0943  -2.8   406.
    47.35 407.3 .233 .233 .226 2694. 2694.  3.8 0.150 408.1 0.0934  -4.0   408.
    ------------------------SECONDARY CHANNEL BEGINS---------------------------
    52.35 408.5 .094 .190 .094 3102. 3102.  4.2 0.150 410.7 0.0963  -3.8   410.
    57.35 412.9 .002 .004 .002 3462. 3462.  5.1 0.150 413.6 0.0942   0.4   413.
    62.35 419.2 .000 .000 .000 3706. 3706.  5.3 0.150 416.5 0.0899   1.9   414.
    63.95 420.5 .000 .000 .000 3761. 3761.  5.4 0.150 417.5 0.0890   1.7   414.
    -------------------------SECONDARY CHANNEL ENDS--------------------------
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 65.19 422.3 .000 .000 .000 3832. 3832.  5.5 0.269 418.3 0.0828   2.2   414.
 66.42 423.1 .000 .000 .000 3876. 3876.  5.5 0.387 419.0 0.0886   1.7   414.
 71.37 425.4 .000 .000 .000 4012. 4012.  5.7 0.412 421.6 0.0889   1.6   414.
 76.32 427.6 .000 .000 .000 4133. 4133.  5.9 0.437 424.4 0.0885   1.5   414.
 77.89 428.6 .000 .000 .000 4175. 4175.  5.9 0.338 425.5 0.0834   1.7   414.
 79.45 430.0 .000 .000 .000 4237. 4237.  6.0 0.238 426.4 0.0788   2.1   414.
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             FLUTED SECTION WITH  1. PAIRS OF FLUTES
 96.05 430.0 .000 .000 .000 4236. 4236.  6.1 0.213 431.2 0.0788   2.1   414.
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101.00 439.5 .000 .000 .000 4501. 4501.  6.3 0.213 438.3 0.0776   2.2   414.


MINIMUM TEMPERATURE=   439.452 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.757
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.056948207 HRS


TORQUE  =        7984.1 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.034 HP
MELTING      =   3.137 HP
MIXING       =   1.577 HP
FLIGHT CLEAR =   1.334 HP
COMPRESSION  =   0.209 HP
MIXING DEVICE=   0.060 HP
PRESSURE FLUCTUATION=       179.06 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=    -64.3 TO       1.4 BTU/MIN  OR
                                        -1.51 TO      0.03 HP


MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:     6.3   9.5  12.7  15.8  19.0  22.2  25.3

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.649 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     787.11        342.5        0.0582690
       9.95        390.0        0.1504015


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     14.32         441.9        0.1008983
     233.20        329.0        0.1045385
AT  50.00 RPM &   90.00 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  4501. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
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1MF100
    EXPERIMENT NUMBER    1.00       SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM      OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD   BAR.    FLT.   NO OF    HOLE
      #       (IN)   SOLID  MELT  SOLID MELT          DIAM    WIDTH  HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)   (IN)   (IN)    (IN)          (SQIN)
      1     19.800  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      2     27.550  0.150  0.000 2.061 0.000  2.475  2.500  0.300
      3     16.600  0.150  0.450 1.354 1.354  3.450  2.500  0.300
      4      2.475  0.387  0.000 2.061 0.000  2.475  2.500  0.300
      5      9.900  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      6      3.125  0.237  0.000 2.604 0.000  3.125  2.500  0.300
      7     16.600  0.213  0.000 2.859 0.000  3.450  2.500  0.300  1.000  0.914
      8      4.950  0.213  0.000 2.061 0.000  2.475  2.500  0.300

                             HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
      INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI


                      SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      67.00 DEG.F      AND      SCREW =     207.00 DEG.F


    LOCATION PHI    ROBP    FRIB  FRIS TEMPERATURE,DEG F  POWER     PRESSURE
       IN    DEG LB/CU.FT               BARREL    SCREW     HP         PSI
       1.00  13.7  21.13  0.059 0.003     67.0    207.0    0.00       0.51
       2.00  13.6  21.22  0.065 0.008     67.0    207.0    0.00       0.79
       3.00  13.5  21.33  0.072 0.014     67.0    207.0    0.00       1.25
       4.00  13.3  21.53  0.084 0.025     67.0    207.0    0.00       2.00
       5.00  12.9  21.92  0.101 0.044     75.0    207.0    0.00       3.28
       6.00  12.7  22.12  0.072 0.054     67.0    207.0    0.01       4.03
       7.00  12.5  22.39  0.083 0.067     67.0    207.0    0.01       4.94
       8.00  12.2  22.66  0.093 0.078     67.0    207.0    0.01       5.89
       9.00  12.0  22.96  0.105 0.091     67.0    207.0    0.01       6.98
      10.00  11.7  23.31  0.117 0.104     67.0    207.0    0.02       8.23
      10.90  11.4  23.66  0.129 0.117    330.0    207.0    0.03       9.53


    L     TOUT  X/W   X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI       HP     IN  DEG F LB.SEC BTU/IN TEMP
                                  REAL  FULL                     /SQ.IN  .MIN  DEG F
    13.10 342.5                    471.  471.       0.437 349.0 0.0811
    15.10 364.4                    837.  837.       0.437 380.8 0.0839
    17.10 371.3                   1071. 1071.       0.437 390.6 0.0903
    18.10 359.9 .879 .879 .732 1111. 1111.   0.2 0.437 390.6 0.1863 -32.5   391.
    19.80 361.7 .830 .830 .691 1179. 1179.   0.4 0.437 390.6 0.1851  -2.2   391.
    24.80 373.3 .763 .763 .655 1379. 1379.   1.1 0.385 394.7 0.1522   2.8   394.
    26.10 378.0 .746 .746 .645 1431. 1431.   1.2 0.372 395.5 0.1232   3.5   395.
    31.10 391.2 .674 .674 .601 1646. 1646.   1.9 0.320 398.6 0.1098   2.1   398.
    36.10 398.9 .596 .596 .546 1899. 1899.   2.5 0.267 401.5 0.1027   1.0   401.
    41.10 403.6 .508 .508 .478 2200. 2200.   3.1 0.215 404.4 0.0985  -0.5   404.
    46.10 406.3 .402 .402 .390 2527. 2527.   3.7 0.163 407.2 0.0964  -2.6   407.
    47.35 406.7 .373 .373 .363 2599. 2599.   3.8 0.150 408.1 0.0960  -4.0   408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 404.0 .185 .374 .185 2953. 2953.   4.3 0.150 410.6 0.1020  -8.2   410.
    57.35 408.0 .077 .188 .077 3282. 3282.   4.6 0.150 413.5 0.1001  -2.7   413.
    62.35 413.1 .003 .010 .003 3520. 3520.   5.6 0.150 416.3 0.0959   3.4   416.
    63.95 415.3 .000 .000 .000 3576. 3576.   5.6 0.150 417.4 0.0944   1.8   417.
    -------------------------SECONDARY CHANNEL ENDS---------------------------
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  65.19 417.6 .000 .000 .000 3644. 3644.  5.7 0.269 418.2 0.0876   2.2   417.
  66.42 419.1 .000 .000 .000 3687. 3687.  5.8 0.387 418.9 0.0932   1.7   417.
  71.37 422.9 .000 .000 .000 3820. 3820.  6.0 0.412 421.6 0.0925   1.6   417.
  76.32 426.1 .000 .000 .000 3939. 3939.  6.1 0.437 424.4 0.0915   1.5   417.
  77.89 427.2 .000 .000 .000 3981. 3981.  6.2 0.338 425.4 0.0862   1.7   417.
  79.45 428.7 .000 .000 .000 4040. 4040.  6.3 0.238 426.3 0.0815   2.1   417.
  ----------------------------------------------------------------------------
               FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 428.7 .000 .000 .000 4039. 4039.  6.3 0.213.431.1 0.0815   2.1   417.
  ---------------------------------------------------------------------------
 101.00 437.9 .000 .000 .000 4288. 4288.  6.6 0.213 438.3 0.0803   2.1   417.


 MINIMUM TEMPERATURE=   437.908 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.763
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.050008345 HRS


 TORQUE  =        8303.5 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.027 HP
 MELTING      =   3.545 HP
 MIXING       =   1.463 HP
 FLIGHT CLEAR =   1.313 HP
 COMPRESSION  =   0.195 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=       170.41 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -89.1 TO      -21.0 BTU/MIN  OR
                                         -2.10 TO      -0.49 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    6.6   9.9  13.2  16.5  19.8  23.1  26.3


 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.641 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
      770.55       342.5        0.0588104
        8.18       390.6        0.1541261


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
       14.32       441.3        0.1012381
      230.69       329.0        0.1049526
 AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  4288. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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1MF110
    EXPERIMENT NUMBER     1.00       SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM      OUTPUT=  110.00 LB/HR      SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
       #      (IN)    SOLID  MELT   SOLID MELT            DIAM    WIDTH  HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)    (IN)    (IN)    (IN)           (SQIN)
       1     19.800  0.437  0.000 2.061 0.000   2.475   2.500   0.300
       2     27.550  0.150  0.000 2.061 0.000   2.475   2.500   0.300
       3     16.600  0.150  0.450 1.354 1.354   3.450   2.500   0.300
       4      2.475  0.387  0.000 2.061 0.000   2.475   2.500   0.300
       5      9.900  0.437  0.000 2.061 0.000   2.475   2.500   0.300
       6      3.125  0.237  0.000 2.604 0.000   3.125   2.500   0.300
       7     16.600  0.213  0.000 2.859 0.000   3.450   2.500   0.300  1.000  0.914
       8      4.950  0.213  0.000 2.061 0.000   2.475   2.500   0.300

                                HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =     0.33 PSI
       INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =     0.75 PSI

                          SOLIDS CONVEYING ZONE ANALYSIS

    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      67.50 DEG.F      AND      SCREW =     213.50 DEG.F


     LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN    DEG LB/CU.FT                BARREL    SCREW    HP        PSI
       1.00  16.3  21.12  0.057 0.003      67.5    213.5    0.00      0.50
       2.00  16.2  21.19  0.061 0.006      67.5    213.5    0.00      0.75
       3.00  16.0  21.32  0.070 0.013      67.5    213.5    0.00      1.15
       4.00  15.7  21.50  0.081 0.023      67.5    213.5    0.00      1.79
       5.00  15.4  21.79  0.093 0.038      75.3    213.5    0.00      2.82
       6.00  15.2  21.95  0.063 0.046      67.5    213.5    0.00      3.38
       7.00  15.0  22.11  0.068 0.053      67.5    213.5    0.01      3.92
       8.00  14.8  22.26  0.074 0.060      67.5    213.5    0.01      4.52
       9.00  14.6  22.44  0.080 0.068      67.5    213.5    0.01      5.15
      10.00  14.4  22.63  0.087 0.077      67.5    213.5    0.01      5.83
      11.00  14.2  22.83  0.095 0.085      67.5    213.5    0.02      6.55

      11.10  14.1  22.87  0.097 0.087     330.0    213.5    0.02      6.63


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID         PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                   /SQ.IN  .MIN  DEG F
    13.10 342.5                  418.  418.      0.437 349.0 0.0775
    15.10 364.4                  806.  806.      0.437 380.8 0.0816
    17.10 371.3                 1051. 1051.      0.437 390.6 0.0885
    18.60 359.4 .892 .892 .752 1144. 1144.   0.2 0.437 390.9 0.1932 -34.6    391.
    19.80 360.5 .860 .860 .724 1191. 1191.   0.3 0.437 390.9 0.1954  -3.0    391.
    24.80 371.1 .809 .809 .702 1389. 1389.   1.0 0.385 394.7 0.1638   3.7    394.
    26.60 378.0 .790 .790 .693 1460. 1460.   1.2 0.367 395.8 0.1258   4.4    395.
    31.60 392.0 .737 .737 .665 1671. 1671.   1.9 0.314 398.9 0.1116   3.3    398.
    36.60 400.6 .678 .678 .630 1916. 1916.   2.6 0.262 401.8 0.1036   2.3    401.
    41.60 405.6 .611 .611 .584 2199. 2199.   3.2 0.210 404.7 0.0993   1.1    404.
    46.60 408.2 .530 .530 .520 2477. 2477.   3.8 0.158 407.5 0.0971  -1.0    407.
    47.35 408.4 .516 .516 .508 2511. 2511.   3.9 0.150 408.0 0.0970  -1.5    408.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 400.2 .296 .598 .296 2813. 2813.   4.4 0.150 410.6 0.1075 -12.5    410.
    57.35 402.8 .145 .353 .145 3114. 3114.   4.8 0.150 413.4 0.1063  -5.9    413.
    62.35 408.6 .067 .204 .067 3338. 3338.   5.1 0.150 416.3 0.1014  -2.1    416.
    63.95 409.6 .028 .093 .028 3392. 3392.   5.6 0.150 417.3 0.1002  -6.3    417.
    -------------------------SECONDARY CHANNEL ENDS--------------------------
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  65.19 411.9 .020 .020 .020 3456. 3456.  5.8 0.269 418.1 0.0930   4.4   418.
         FILM THICKNESS IS 0 - TBAR=  0.4184E+03
         FILM THICKNESS IS 0 - TBAR=  0.4184E+03
  66.42 413.4 .015 .015 .013 3499. 3499.  6.1 0.387 418.8 0.0988   3.6   419.
  71.37 418.5 .001 .001 .001 3632. 3632.  6.6 0.412 421.5 0.0973   1.1   421.
         FILM THICKNESS IS 0 - TBAR=  0.4220E+03
         FILM THICKNESS IS 0 - TBAR=  0.4220E+03
  76.32 423.3 .000 .000 .000 3749. 3749.  6.8 0.437 424.3 0.0951   1.5   422.
  77.89 424.7 .000 .000 .000 3790. 3790.  6.8 0.338 425.4 0.0895   1.7   422.
  79.45 426.5 .000 .000 .000 3848. 3848.  6.9 0.238 426.3 0.0845   2.1   422.
 ------------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 426.5 .000 .000 .000 3847. 3847.  7.0 0.213 431.1 0.0845   2.1   422.
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 101.00 435.8 .000 .000 .000 4079. 4079.  7.2 0.213 438.3 0.0831   2.1   422.


 MINIMUM TEMPERATURE=   435.849 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.768
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
     MELT POOL=   0.045023140 HRS


 TORQUE  =         9111.0 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.017 HP
 MELTING      =   4.325 HP
 MIXING       =   1.361 HP
 FLIGHT CLEAR =   1.301 HP
 COMPRESSION  =   0.178 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=       160.29 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=     -96.7 TO      -28.2 BTU/MIN  OR
                                          -2.28 TO      -0.66 HP


 MAXIMUM SCREW SPEED,RPM:               50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:      7.2  10.8  14.5  18.1  21.7  25.3  28.9

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.623 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
      884.32       375.5         0.0447617
        6.39       390.9         0.1588934


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
      14.32        440.3         0.1018387
     442.16        329.0         0.0816959
 AT  50.00 RPM &  110.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  4079. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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1MF120
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM       OUTPUT=  120.00 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH     CH.DEPTH        WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
       #      (IN)   SOLID  MELT   SOLID MELT              DIAM    WIDTH  HOLES    AREA
                      (IN)  (IN)    (IN)  (IN)    (IN)    (IN)    (IN)           (SQIN)
     1      19.800  0.437   0.000 2.061 0.000  2.475   2.500   0.300
     2      27.550  0.150   0.000 2.061 0.000  2.475   2.500   0.300
     3      16.600  0.150   0.450 1.354 1.354  3.450   2.500   0.300
     4       2.475  0.387   0.000 2.061 0.000  2.475   2.500   0.300
     5       9.900  0.437   0.000 2.061 0.000  2.475   2.500   0.300
     6       3.125  0.237   0.000 2.604 0.000  3.125   2.500   0.300
     7      16.600  0.213   0.000 2.859 0.000  3.450   2.500   0.300  1.000   0.914
     8       4.950  0.213   0.000 2.061 0.000  2.475   2.500   0.300

                                 HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =      36.00 IN. BASE PRESSURE =      0.33 PSI
      INCREASE HEIGHT TO =     186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                           SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      89.50 DEG.F      AND      SCREW =     226.50 DEG.F

    LOCATION PHI    ROBF   FRIB   FRIS TEMPERATURE,DEG F  POWER     PRESSURE
       IN    DEG LB/CU.FT                 BARREL    SCREW     HP         PSI
      1.00   19.1   21.13  0.052 0.002     93.7    226.5    0.00        0.48
      2.00   19.0   21.19  0.056 0.006     94.7    226.5    0.00        0.69
      3.00   18.9   21.28  0.061 0.011     96.1    226.5    0.00        0.99
      4.00   18.7   21.39  0.068 0.017     95.8    226.5    0.00        1.44
      5.00   18.4   21.57  0.077 0.026     87.9    226.5    0.00        2.12
      6.00   18.2   21.68  0.046 0.032     70.0    226.5    0.00        2.47
      7.00   18.1   21.78  0.049 0.037     70.0    226.5    0.00        2.76
      8.00   18.0   21.85  0.050 0.040     70.0    226.5    0.00        3.04
      9.00   17.8   21.94  0.053 0.045     70.0    226.5    0.01        3.31
     10.00   17.7   22.00  0.055 0.048     70.0    226.5    0.01        3.57
     10.70   17.6   22.06  0.057 0.050    329.0    226.5    0.01        3.75


    L     TOUT  X/W   X/W GRATIO PRESSURE  POWER  HOUT   TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI      HP     IN   DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                      /SQ.IN  .MIN  DEG F
    13.10 342.5                   0.   507.       0.437 349.0 0.0796
    15.10 364.4                   0.   887.       0.437 380.8 0.0818
    17.10 371.3                   0.  1132.       0.437 390.6 0.0881
    18.10 358.5 .907  .907  .776   0.  1170.  0.1 0.437 390.6 0.2009 -35.2    391.
    19.80 359.8 .866  .866  .740   0.  1235.  0.4 0.437 390.6 0.2021  -2.2    391.
    24.80 370.4 .829  .829  .730   0.  1424.  1.0 0.385 394.7 0.1700   4.5    394.
    26.10 375.5 .819  .819  .727   0.  1474.  1.2 0.372 395.5 0.1311   5.2    395.
    31.10 391.3 .780  .780  .713   0.  1675.  1.9 0.320 398.6 0.1147   4.5    398.
    36.10 401.9 .741  .741  .696   0.  1903.  2.6 0.267 401.5 0.1050   3.9    401.
    41.10 408.6 .697  .697  .674   0.  2157.  3.2 0.215 404.5 0.0995   3.2    404.
    46.10 412.4 .647  .647  .642   0.  2398.  3.9 0.163 407.3 0.0964   1.9    407.
    47.35 413.0 .633  .633  .631   0.  2443.  4.0 0.150 408.2 0.0958   1.2    408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 397.3 .398  .806  .398   0.  2698.  4.6 0.150 410.5 0.1126 -15.9    410.
    57.35 398.5 .218  .531  .218   0.  2970.  5.0 0.150 413.3 0.1122  -8.9    413.
    62.35 404.1 .113  .345  .113   0.  3182.  5.3 0.150 416.2 0.1070  -4.3    416.
    63.95 406.1 .091  .303  .091   0.  3233.  5.4 0.150 417.2 0.1053  -3.5    417.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
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 65.19 408.4 .077 .077 .077     0. 3293.  5.6 0.269 418.1 0.0971   5.3   418.
 66.42 410.1 .080 .080 .070     0. 3335.  5.8 0.387 418.8 0.1028   0.3   419.
          FILM THICKNESS IS 0 - TBAR=  0.4188E+03
          FILM THICKNESS IS 0 - TBAR=  0.4188E+03
 71.37 414.2 .034 .034 .029     0. 3466.  6.8 0.412 421.4 0.1019   2.8   421.
          FILM THICKNESS IS 0 - TBAR=  0.4237E+03
          FILM THICKNESS IS 0 - TBAR=  0.4237E+03
 76.32 418.8 .008 .008 .007     0. 3582.  7.7 0.437 424.2 0.0997  17.6   424.
 77.89 420.5 .005 .005 .005     0. 3622.  7.9 0.338 425.3 0.0938   4.7   425.
          FILM THICKNESS IS 0 - TBAR=  0.4259E+03
          FILM THICKNESS IS 0 - TBAR=  0.4259E+03
 79.45 422.4 .001 .001 .001     0. 3679.  8.0 0.238 426.2 0.0885   0.9   426.
 ----------------------------------------------------------------------------
               FLUTED SECTION WITH  1. PAIRS OF FLUTES
 96.05 438.0 .001 .001 .001     0. 3678.  8.1 0.213 431.0 0.0885   0.9   426.
 ---------------------------------------------------------------------------
101.00 441.9 .000 .000 .000     0. 3882.  8.3 0.213 438.4 0.0817   2.0   431.


MINIMUM TEMPERATURE=   441.932 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.775
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=    0.041631229 HRS


TORQUE  =       10507.7 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.008 HP
MELTING      =   5.548 HP
MIXING       =   1.263 HP
FLIGHT CLEAR =   1.310 HP
COMPRESSION  =   0.162 HP
MIXING DEVICE=   0.061 HP
PRESSURE FLUCTUATION=        143.29 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=     -93.0 TO      -15.7 BTU/MIN  OR
                                         -2.19 TO      -0.37 HP


MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:     8.3  12.5  16.7  20.8  25.0  29.2  33.3

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.593 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
    870.15         380.0        0.0438751
      4.84         390.6        0.1644468


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     43.90         441.7        0.0815906
    435.08         329.0        0.0822313
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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# OUTPUT OF SIMULATION

## (III) Varying the IPFC

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1MBF05
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM       OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH     CH.DEPTH        WIDTH       LEAD    BAR.     FLT.   NO OF    HOLE
      #      (IN)    SOLID  MELT  SOLID MELT               DIAM    WIDTH   HOLES    AREA
                     (IN)   (IN)   (IN)  (IN)      (IN)    (IN)     (IN)           (SQIN)
      1     19.800  0.437   0.000 2.061 0.000    2.475   2.500   0.300
      2     27.550  0.150   0.000 2.061 0.000    2.475   2.500   0.300
      3     16.600  0.150   0.450 1.354 1.354    3.450   2.500   0.300
      4      2.475  0.387   0.000 2.061 0.000    2.475   2.500   0.300
      5      9.900  0.437   0.000 2.061 0.000    2.475   2.500   0.300
      6      3.125  0.237   0.000 2.604 0.000    3.125   2.500   0.300
      7     16.600  0.213   0.000 2.859 0.000    3.450   2.500   0.300   1.000   0.914
      8      4.950  0.213   0.000 2.061 0.000    2.475   2.500   0.300

                              HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN.  BASE PRESSURE =      0.33 PSI
      INCREASE HEIGHT TO =    186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                         SOLIDS CONVEYING ZONE ANALYSIS


  OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
  BARREL =     270.00 DEG.F      AND      SCREW =    190.50 DEG.F


   LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN   DEG LB/CU.FT                 BARREL    SCREW     HP         PSI
  FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
  FRIS=     0.839140E-01 FRIB=     0.401214E-01
      1.00  13.8   21.10   0.086 0.084    315.0    190.5     0.00        0.30
      2.00  13.8   21.10   0.113 0.084    329.5    190.5     0.00        0.36
      2.00  13.8   21.10   0.113 0.084    329.5    190.5     0.00        0.36


   L     TOUT  X/W  X/W GRATIO PRESSURE   POWER  HOUT   TBAR   TVISC D.HEAT  FILM
   IN    DEG F      SOLID          PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                     /SQ.IN  .MIN  DEG F
    4.45 342.5                  0.   520.       0.437 349.0 0.0833
    6.45 342.5                  0.   906.       0.437 349.0 0.0963
    8.95 337.8 .907 .907 .779   0.  1179.   0.2 0.437 339.0 0.2403 -23.9    343.
   13.95 336.2 .756 .756 .633   0.  1343.   2.0 0.437 344.8 0.2075  33.0    343.
   16.95 350.3 .688 .688 .586   0.  1441.   2.4 0.437 389.9 0.1809  -0.6    389.
   19.80 361.8 .616 .616 .524   0.  1534.   2.8 0.437 391.8 0.1579  -1.9    391.
   24.80 380.1 .550 .550 .483   0.  1713.   3.4 0.385 394.8 0.1219   1.9    394.
   29.80 391.1 .481 .481 .435   0.  1915.   3.9 0.333 397.8 0.1106   1.1    397.
   34.80 397.9 .407 .407 .379   0.  2153.   4.5 0.281 400.8 0.1040   0.1    400.
   39.80 402.6 .327 .327 .314   0.  2438.   5.0 0.229 403.6 0.0997  -0.9    403.
   44.80 406.2 .240 .240 .236   0.  2759.   5.4 0.177 406.5 0.0969  -2.0    406.
   47.35 407.7 .192 .192 .192   0.  2909.   5.7 0.150 408.0 0.0958  -2.8    408.
  ------------------------SECONDARY CHANNEL BEGINS--------------------------
   52.35 408.8 .082 .167 .082   0.  3251.   6.0 0.150 410.7 0.0985  -3.2    410.
   57.35 412.9 .001 .003 .001   0.  3578.   7.0 0.150 413.6 0.0966   0.7    413.
   62.35 418.6 .000 .000 .000   0.  3811.   7.2 0.150 416.5 0.0925   1.9    414.
   63.95 419.9 .000 .000 .000   0.  3865.   7.3 0.150 417.5 0.0916   1.7    414.
  -------------------------SECONDARY CHANNEL ENDS---------------------------
   65.19 421.5 .000 .000 .000   0.  3931.   7.4 0.269 418.3 0.0855   2.1    414.
   66.42 422.4 .000 .000 .000   0.  3974.   7.4 0.387 419.0 0.0913   1.7    414.
   71.37 424.8 .000 .000 .000   0.  4105.   7.6 0.412 421.6 0.0915   1.6    414.
   76.32 427.1 .000 .000 .000   0.  4222.   7.8 0.437 424.4 0.0909   1.5    414.
   77.89 428.0 .000 .000 .000   0.  4264.   7.9 0.338 425.5 0.0858   1.7    414.
   79.45 429.4 .000 .000 .000   0.  4323.   7.9 0.238 426.4 0.0812   2.1    414.
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               FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 429.4 .000 .000 .000     0. 4322.  8.0 0.213 431.1 0.0812   2.1   414.
  --------------------------------------------------------------------------
 101.00 438.3 .000 .000 .000     0. 4571.  8.3 0.213 438.3 0.0801   2.1   414.


 MINIMUM TEMPERATURE=   438.261 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.763
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.059739724 HRS


 TORQUE  =        10404.7 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.000 HP
 MELTING      =   4.736 HP
 MIXING       =   1.670 HP
 FLIGHT CLEAR =   1.569 HP
 COMPRESSION  =   0.234 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=       170.05 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=     -18.7 TO      58.6 BTU/MIN  OR
                                          -0.44 TO      1.38 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    8.3  12.4  16.5  20.6  24.8  28.9  33.0

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.595 INCHES



  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
      968.41        334.0        0.0563521
        6.00        339.0        0.2426229


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
       14.32        441.6        0.1010565
       12.91        293.7        0.2909913
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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1MBF10
    EXPERIMENT NUMBER    1.00       SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM      OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH      WIDTH     LEAD   BAR.   FLT.   NO OF   HOLE
      #       (IN)  SOLID  MELT  SOLID MELT           DIAM   WIDTH HOLES    AREA
                    (IN)   (IN)  (IN)  (IN)   (IN)   (IN)   (IN)          (SQIN)
      1     19.800  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      2     27.550  0.150  0.000 2.061 0.000  2.475  2.500  0.300
      3     16.600  0.150  0.450 1.354 1.354  3.450  2.500  0.300
      4      2.475  0.387  0.000 2.061 0.000  2.475  2.500  0.300
      5      9.900  0.437  0.000 2.061 0.000  2.475  2.500  0.300
      6      3.125  0.237  0.000 2.604 0.000  3.125  2.500  0.300
      7     16.600  0.213  0.000 2.859 0.000  3.450  2.500  0.300  1.000  0.914
      8      4.950  0.213  0.000 2.061 0.000  2.475  2.500  0.300

                               HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =    36.00 IN. BASE PRESSURE =     0.29 PSI
      INCREASE HEIGHT TO =   124.00 IN. MAXIMUM PRESSURE =      0.50 PSI

                         SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      67.00 DEG.F     AND     SCREW =    229.00 DEG.F

    LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN   DEG LB/CU.FT              BARREL   SCREW    HP        PSI
       1.00  13.7  21.11  0.135 0.076    67.0   229.0    0.00      0.47
       2.00  13.6  21.22  0.142 0.082    67.0   229.0    0.00      0.77
       3.00  13.5  21.35  0.151 0.089    67.0   229.0    0.00      1.26
       4.00  13.2  21.59  0.165 0.101    67.0   229.0    0.00      2.11
       5.00  12.8  22.00  0.183 0.121    74.9   229.0    0.01      3.58
       6.00  12.6  22.26  0.157 0.134    67.0   229.0    0.01      4.57
       7.00  12.3  22.59  0.170 0.148    67.0   229.0    0.02      5.67
       8.00  12.0  22.95  0.184 0.163    67.0   229.0    0.02      6.95
       9.00  11.6  23.36  0.198 0.178    67.0   229.0    0.03      8.42
      10.00  11.3  23.81  0.213 0.194    67.0   229.0    0.05     10.09
      10.70  11.0  24.17  0.224 0.205   329.4   229.0    0.06     11.37

    L    TOUT  X/W  X/W GRATIO PRESSURE   POWER   HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F      SOLID         PSI      HP     IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                     /SQ.IN  .MIN  DEG F
    13.10 342.5                490.  490.       0.437 349.0 0.0830
    15.10 364.4                847.  847.       0.437 380.8 0.0847
    17.10 371.3               1077. 1077.       0.437 390.6 0.0907
    18.10 359.9 .878 .878 .730 1117. 1117.   0.2 0.437 390.6 0.1860 -32.8    391.
    19.80 361.7 .828 .828 .686 1185. 1185.   0.4 0.437 390.6 0.1848  -2.2    391.
    24.80 373.3 .762 .762 .653 1386. 1386.   1.1 0.385 394.7 0.1521   2.8    394.
    26.10 378.0 .744 .744 .643 1438. 1438.   1.3 0.372 395.5 0.1232   3.5    395.
    31.10 391.2 .673 .673 .598 1653. 1653.   1.9 0.320 398.6 0.1099   2.1    398.
    36.10 398.9 .595 .595 .544 1905. 1905.   2.6 0.267 401.5 0.1027   0.9    401.
    41.10 403.5 .506 .506 .476 2207. 2207.   3.2 0.215 404.4 0.0986  -0.5    404.
    46.10 406.3 .401 .401 .388 2533. 2533.   3.7 0.163 407.2 0.0964  -2.6    407.
    47.35 406.7 .371 .371 .361 2606. 2606.   3.9 0.150 408.1 0.0960  -4.0    408.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------------
    52.35 404.1 .184 .372 .184 2959. 2959.   4.3 0.150 410.6 0.1020  -8.2    410.
    57.35 408.1 .076 .186 .076 3288. 3288.   4.7 0.150 413.5 0.1000  -2.7    413.
    62.35 413.2 .003 .010 .003 3526. 3526.   5.6 0.150 416.3 0.0959   3.4    416.
    63.95 415.3 .000 .000 .000 3582. 3582.   5.7 0.150 417.4 0.0943   1.8    417.
    -------------------------SECONDARY CHANNEL ENDS--------------------------------
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  65.19 417.7 .000 .000 .000 3650. 3650.  5.7 0.269 418.2 0.0876   2.2   417.
  66.42 419.1 .000 .000 .000 3693. 3693.  5.8 0.387 418.9 0.0932   1.7   417.
  71.37 423.0 .000 .000 .000 3826. 3826.  6.0 0.412 421.6 0.0925   1.6   417.
  76.32 426.1 .000 .000 .000 3945. 3945.  6.2 0.437 424.4 0.0915   1.5   417.
  77.89 427.2 .000 .000 .000 3987. 3987.  6.2 0.338 425.4 0.0862   1.7   417.
  79.45 428.7 .000 .000 .000 4046. 4046.  6.3 0.238 426.3 0.0815   2.1   417.
  ---------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 428.7 .000 .000 .000 4045. 4045.  6.4 0.213 431.1 0.0815   2.1   417.
  --------------------------------------------------------------------------
 101.00 437.9 .000 .000 .000 4294. 4294.  6.6 0.213 438.3 0.0803   2.1   417.


MINIMUM TEMPERATURE=   437.910 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.763
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.050001115 HRS


TORQUE  =         8334.4 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.057 HP
MELTING      =   3.538 HP
MIXING       =   1.464 HP
FLIGHT CLEAR =   1.313 HP
COMPRESSION  =   0.195 HP
MIXING DEVICE=   0.060 HP
PRESSURE FLUCTUATION=        170.40 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=    -88.1 TO     -20.8 BTU/MIN  OR
                                        -2.08 TO     -0.49 HP


MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:    6.6   9.9  13.2  16.5  19.8  23.1  26.4


STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.641 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE       TEMP.        VISCOSITY
   1/SEC          DEG.F       LB.SEC/SQ.IN
    779.85        342.5        0.0585047
      8.28        390.6        0.1538658


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE       TEMP.        VISCOSITY
   1/SEC          DEG.F       LB.SEC/SQ.IN
     14.32        441.3        0.1012367
    230.72        329.0        0.1049472
AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  4294. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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1MBΓ15
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM       OUTPUT=  100.00 LB/HR       SOAK TIME=  0.00 SECONDS



   SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD   BAR.    FLT.   NO OF    HOLE
      #      (IN)    SOLID  MELT  SOLID MELT          DIAM   WIDTH  HOLES    AREA
                     (IN)   (IN)   (IN)  (IN)   (IN)   (IN)    (IN)          (SQIN)
      1     19.800  0.437   0.000 2.061 0.000  2.475  2.500  0.300
      2     27.550  0.150   0.000 2.061 0.000  2.475  2.500  0.300
      3     16.600  0.150   0.450 1.354 1.354  3.450  2.500  0.300
      4      2.475  0.387   0.000 2.061 0.000  2.475  2.500  0.300
      5      9.900  0.437   0.000 2.061 0.000  2.475  2.500  0.300
      6      3.125  0.237   0.000 2.604 0.000  3.125  2.500  0.300
      7     16.600  0.213   0.000 2.859 0.000  3.450  2.500  0.300  1.000   0.914
      8      4.950  0.213   0.000 2.061 0.000  2.475  2.500  0.300

                           HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.21 PSI
      INCREASE HEIGHT TO =     64.55 IN. MAXIMUM PRESSURE =      0.26 PSI


                      SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      67.00 DEG.F      AND      SCREW =     229.00 DEG.F


    LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                BARREL    SCREW     HP        PSI
      1.00   13.7   21.13  0.186 0.077    67.0     229.0    0.00        0.50
      2.00   13.5   21.32  0.199 0.087    67.0     229.0    0.00        1.17
      3.00   13.1   21.77  0.227 0.111    67.0     229.0    0.00        2.83
      4.00   12.0   22.93  0.289 0.162    67.0     229.0    0.01        7.14
      4.75   10.4   25.07  0.370 0.227   117.3     229.0    0.03       14.98
      5.25    9.4   26.71  0.337 0.248   275.7     229.0    0.05       21.11
      5.75    8.5   28.78  0.332 0.244   284.8     229.0    0.08       29.28
      6.25    7.4   31.72  0.331 0.243   291.4     229.0    0.11       41.36
      6.75    6.2   35.88  0.330 0.241   297.6     229.0    0.17       59.72
      7.25    5.1   41.75  0.330 0.239   303.8     229.0    0.25       88.21
      7.75    4.1   49.65  0.329 0.238   311.4     229.0    0.37      133.21
      8.25    3.3   59.52  0.329 0.236   320.0     229.0    0.55      204.78
      8.75    2.7   70.15  0.327 0.235   330.0     229.0    0.83      318.14
      8.75    2.7   70.15  0.327 0.235   330.0     229.0    0.83      318.14


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID         PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                    /SQ.IN  .MIN  DEG F
    11.20 342.5                938.  938.       0.437 349.0 0.0829
    13.10 342.5               1303. 1303.       0.437 349.0 0.0957
    15.10 364.4               1591. 1591.       0.437 380.8 0.0908
    16.10 354.7 .891 .891 .752 1629. 1629.  1.0 0.437 380.8 0.1985 -29.3   381.
    19.80 360.4 .789 .789 .665 1768. 1768.  1.5 0.437 391.8 0.1781  -1.6   391.
    24.10 374.1 .732 .732 .633 1931. 1931.  2.1 0.393 394.3 0.1278   3.5   394.
    29.10 388.5 .663 .663 .591 2133. 2133.  2.7 0.340 397.4 0.1127   2.2   397.
    34.10 397.0 .588 .588 .539 2367. 2367.  3.4 0.288 400.3 0.1046   1.2   400.
    39.10 402.2 .504 .504 .476 2647. 2647.  3.9 0.236 403.2 0.0998  -0.1   403.
    44.10 405.4 .408 .408 .396 2971. 2971.  4.5 0.184 406.1 0.0971  -1.8   406.
    47.35 406.8 .335 .335 .331 3170. 3170.  4.8 0.150 408.1 0.0960  -4.0   408.
    -------------------------SECONDARY CHANNEL BEGINS--------------------------
    52.35 404.9 .162 .328 .162 3521. 3521.  5.3 0.150 410.6 0.1014  -7.2   410.
    57.35 409.0 .066 .161 .066 3850. 3850.  5.6 0.150 413.5 0.0993  -2.1   413.
    62.35 414.2 .001 .002 .001 4088. 4088.  6.5 0.150 416.4 0.0952   0.8   416.
    63.95 416.3 .000 .000 .000 4143. 4143.  6.6 0.150 417.4 0.0937   1.8   416.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
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  65.19 418.5 .000 .000 .000 4211. 4211.  6.7 0.269 418.2 0.0871   2.2   416.
  66.42 419.8 .000 .000 .000 4254. 4254.  6.7 0.387 419.0 0.0927   1.7   416.
  71.37 423.4 .000 .000 .000 4387. 4387.  6.9 0.412 421.6 0.0923   1.6   416.
  76.32 426.3 .000 .000 .000 4505. 4505.  7.1 0.437 424.4 0.0914   1.5   416.
  77.89 427.4 .000 .000 .000 4547. 4547.  7.2 0.338 425.5 0.0861   1.7   416.
  79.45 428.9 .000 .000 .000 4606. 4606.  7.2 0.238 426.3 0.0814   2.1   416.
  --------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 428.9 .000 .000 .000 4605. 4605.  7.3 0.213 431.1 0.0814   2.1   416.
  -------------------------------------------------------------------------
 101.00 438.0 .000 .000 .000 4854. 4854.  7.6 0.213 438.3 0.0802   2.1   416.


 MINIMUM TEMPERATURE=   437.987 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.763
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.052353885 HRS


 TORQUE  =        9534.4 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.829 HP
 MELTING      =   3.618 HP
 MIXING       =   1.511 HP
 FLIGHT CLEAR =   1.358 HP
 COMPRESSION  =   0.202 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=        170.33 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -47.7 TO      -14.9 BTU/MIN  OR
                                         -1.13 TO      -0.35 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    7.6  11.3  15.1  18.9  22.7  26.5  30.3

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.613 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
     1077.25        342.5        0.0506723
        7.29        380.8        0.1684484


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
      14.32         441.4       0.1011971
     230.45         329.0       0.1049915
 AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  4854. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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1MBF20
  EXPERIMENT NUMBER    1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


  N= 50.0 RPM      OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


  SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD   BAR.    FLT.    NO OF    HOLE
     #      (IN)    SOLID  MELT  SOLID MELT          DIAM    WIDTH   HOLES    AREA
                    (IN)  (IN)   (IN)  (IN)    (IN)   (IN)    (IN)           (SQIN)
     1     19.800  0.437  0.000 2.061 0.000   2.475  2.500   0.300
     2     27.550  0.150  0.000 2.061 0.000   2.475  2.500   0.300
     3     16.600  0.150  0.450 1.354 1.354   3.450  2.500   0.300
     4      2.475  0.387  0.000 2.061 0.000   2.475  2.500   0.300
     5      9.900  0.437  0.000 2.061 0.000   2.475  2.500   0.300
     6      3.125  0.237  0.000 2.604 0.000   3.125  2.500   0.300
     7     16.600  0.213  0.000 2.859 0.000   3.450  2.500   0.300   1.000   0.914
     8      4.950  0.213  0.000 2.061 0.000   2.475  2.500   0.300

                                HOPPER ANALYSIS

    ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

    SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.14 PSI
    INCREASE HEIGHT TO =     37.27 IN. MAXIMUM PRESSURE =      0.15 PSI

                           SOLIDS CONVEYING ZONE ANALYSIS

  OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
  BARREL =      67.00 DEG.F      AND      SCREW =     229.00 DEG.F


   LOCATION PHI    ROBF    FRIB   FRIS TEMPERATURE,DEG F  POWER     PRESSURE
      IN    DEG LB/CU.FT                 BARREL    SCREW     HP          PSI
     1.00   13.7  21.13  0.236 0.077     67.0     229.0     0.00        0.48
     2.00   13.4  21.44  0.256 0.094     67.0     229.0     0.00        1.65
     3.00   12.3  22.56  0.321 0.147     67.0     229.0     0.01        5.85
     3.65   10.6  24.75  0.411 0.220     67.8     229.0     0.02       13.87
     4.15    8.7  28.33  0.445 0.245     70.2     229.0     0.05       28.02
     4.65    6.2  35.79  0.447 0.241    106.6     229.0     0.11       60.55
     5.13    4.6  45.47  0.386 0.238    285.3     229.0     0.22      109.47
     5.63    3.3  59.63  0.406 0.236    300.4     229.0     0.41      208.68
     6.13    2.5  75.00  0.380 0.234    317.1     229.0     0.78      400.04
     6.43    2.3  81.83  0.378 0.234    330.0     229.0     1.15      590.87


  L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
  IN    DEG F     SOLID          PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                  /SQ.IN  .MIN  DEG F
   8.87 342.5                 1211. 1211.     0.437 349.0 0.0828
  10.87 342.5                 1590. 1590.     0.437 349.0 0.0962
  13.37 336.3 .909 .909 .782 1860. 1860.  1.4 0.437 330.2 0.2425 -23.4   339.
  18.37 354.1 .775 .775 .658 2037. 2037.  2.1 0.437 390.8 0.1860  -1.8   390.
  19.80 359.0 .736 .736 .625 2088. 2088.  2.3 0.437 391.8 0.1707  -2.3   391.
  21.37 366.5 .715 .715 .614 2144. 2144.  2.5 0.421 392.7 0.1372   3.6   392.
  26.37 383.6 .648 .648 .573 2331. 2331.  3.1 0.369 395.8 0.1179   2.3   395.
  31.37 393.7 .576 .576 .525 2544. 2544.  3.7 0.317 398.8 0.1079   1.4   398.
  36.37 399.8 .498 .498 .467 2797. 2797.  4.3 0.265 401.7 0.1020   0.3   401.
  41.37 403.9 .410 .410 .396 3099. 3099.  4.9 0.212 404.5 0.0985  -1.1   404.
  46.37 406.6 .309 .309 .307 3420. 3420.  5.4 0.160 407.4 0.0963  -2.8   407.
  47.35 407.0 .288 .288 .287 3475. 3475.  5.5 0.150 407.9 0.0961  -3.3   407.
  ------------------------SECONDARY CHANNEL BEGINS------------------------
  52.35 406.0 .134 .272 .134 3823. 3823.  5.9 0.150 410.7 0.1005  -5.9   410.
  57.35 409.3 .023 .056 .023 4151. 4151.  6.7 0.150 413.5 0.0988  -3.3   413.
  62.35 415.9 .000 .000 .000 4389. 4389.  7.1 0.150 416.4 0.0941   1.9   415.
  63.95 417.7 .000 .000 .000 4443. 4443.  7.2 0.150 417.4 0.0929   1.8   415.
  -------------------------SECONDARY CHANNEL ENDS-------------------------
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  65.19 419.7 .000 .000 .000 4511. 4511.  7.3 0.269 418.3 0.0865   2.2   415.
  66.42 420.8 .000 .000 .000 4554. 4554.  7.3 0.387 419.0 0.0922   1.7   415.
  71.37 423.9 .000 .000 .000 4686. 4686.  7.5 0.412 421.6 0.0920   1.6   415.
  76.32 426.6 .000 .000 .000 4804. 4804.  7.7 0.437 424.4 0.0912   1.5   415.
  77.89 427.6 .000 .000 .000 4845. 4845.  7.8 0.338 425.5 0.0860   1.7   415.
  79.45 429.1 .000 .000 .000 4905. 4905.  7.8 0.238 426.4 0.0813   2.1   415.
  ---------------------------------------------------------------------------
                FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 429.1 .000 .000 .000 4904. 4904.  7.9 0.213 431.1 0.0813   2.1   415.
  --------------------------------------------------------------------------
 101.00 438.1 .000 .000 .000 5152. 5152.  8.2 0.213 438.3 0.0802   2.1   415.


 MINIMUM TEMPERATURE=   438.093 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.763
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.055453643 HRS


 TORQUE  =       10282.6 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   1.148 HP
 MELTING      =   3.745 HP
 MIXING       =   1.580 HP
 FLIGHT CLEAR =   1.428 HP
 COMPRESSION  =   0.212 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=        170.22 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=     -22.7 TO      -0.7 BTU/MIN  OR
                                          -0.53 TO     -0.02 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     8.2  12.2  16.3  20.4  24.5  28.6  32.6

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.597 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
     1099.72        342.5        0.0501981
        5.71        355.9        0.2118465


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
       14.32       441.5        0.1011423
      230.26       329.0        0.1050236
 AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  5152. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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1MBF25
   EXPERIMENT NUMBER    1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM       OUTPUT=  100.00 LB/HR      SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
      #      (IN)   SOLID  MELT  SOLID MELT             DIAM    WIDTH  HOLES    AREA
                    (IN)   (IN)   (IN)  (IN)    (IN)    (IN)    (IN)           (SQIN)
      1     19.800  0.437  0.000 2.061 0.000  2.475   2.500   0.300
      2     27.550  0.150  0.000 2.061 0.000  2.475   2.500   0.300
      3     16.600  0.150  0.450 1.354 1.354  3.450   2.500   0.300
      4      2.475  0.387  0.000 2.061 0.000  2.475   2.500   0.300
      5      9.900  0.437  0.000 2.061 0.000  2.475   2.500   0.300
      6      3.125  0.237  0.000 2.604 0.000  3.125   2.500   0.300
      7     16.600  0.213  0.000 2.859 0.000  3.450   2.500   0.300   1.000   0.914
      8      4.950  0.213  0.000 2.061 0.000  2.475   2.500   0.300

                          HOPPER ANALYSIS

     ATTENTION - KEEP SOLIDS  LEVEL IN HOPPER ABOVE   24.47 IN.
     BASE PRESSURE =       0.10 PSI

                     SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      67.50 DEG.F      AND      SCREW =     229.00 DEG.F


    LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                   BARREL   SCREW     HP        PSI
      1.00  13.7   21.13   0.286 0.077      67.5     229.0     0.00       0.48
      2.00  13.2   21.63   0.318 0.104      67.5     229.0     0.00       2.40
      2.85  11.4   23.63   0.421 0.188      67.5     229.0     0.01       9.73
      3.35   9.3   27.03   0.498 0.249      70.5     229.0     0.04      22.98
      3.85   6.4   35.26   0.496 0.241      77.7     229.0     0.10      58.60
      4.35   3.8   53.32   0.491 0.237      99.9     229.0     0.26     162.05
      4.85   2.5   77.06   0.481 0.234     114.2     229.0     0.70     451.66
      5.00   2.3   82.03   0.428 0.234     330.0     229.0     0.93     605.03


    L     TOUT  X/W   X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F       SOLID          PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                                 REAL  FULL                    /SQ.IN  .MIN  DEG F
    7.45 342.5                   1225. 1225.      0.437 349.0 0.0828
    9.45 342.5                   1603. 1603.      0.437 349.0 0.0962
   11.95 337.8 .907 .907 .779 1868. 1868.  1.1 0.437 339.0 0.2403 -23.9   343.
   16.95 350.2 .773 .773 .657 2020. 2020.  2.1 0.437 389.9 0.1925  -1.0   389.
   19.80 360.7 .696 .696 .592 2107. 2107.  2.4 0.437 391.7 0.1654  -1.6   391.
   24.80 379.8 .630 .630 .552 2288. 2288.  3.1 0.385 394.8 0.1220   2.4   394.
   29.80 391.2 .560 .560 .506 2490. 2490.  3.7 0.333 397.8 0.1104   1.5   397.
   34.80 398.1 .484 .484 .450 2729. 2729.  4.3 0.281 400.8 0.1037   0.5   400.
   39.80 402.7 .401 .401 .384 3015. 3015.  4.8 0.229 403.6 0.0995  -0.7   403.
   44.80 405.9 .307 .307 .302 3338. 3338.  5.3 0.177 406.5 0.0969  -2.2   406.
   47.35 407.2 .254 .254 .253 3490. 3490.  5.5 0.150 408.0 0.0960  -3.3   408.
   -----------------------SECONDARY CHANNEL BEGINS------------------------
   52.35 407.0 .115 .233 .115 3836. 3836.  5.9 0.150 410.7 0.0999  -5.0   410.
   57.35 410.5 .013 .031 .013 4163. 4163.  6.8 0.150 413.5 0.0982   1.9   413.
   62.35 416.9 .000 .000 .000 4399. 4399.  7.2 0.150 416.4 0.0935   1.9   415.
   63.95 418.6 .000 .000 .000 4454. 4454.  7.2 0.150 417.5 0.0924   1.8   415.
   ------------------------SECONDARY CHANNEL ENDS------------------------
   65.19 420.4 .000 .000 .000 4521. 4521.  7.3 0.269 418.3 0.0861   2.2   415.
   66.42 421.4 .000 .000 .000 4563. 4563.  7.4 0.387 419.0 0.0918   1.7   415.
   71.37 424.2 .000 .000 .000 4695. 4695.  7.6 0.412 421.6 0.0918   1.6   415.
   76.32 426.8 .000 .000 .000 4813. 4813.  7.7 0.437 424.4 0.0911   1.5   415.
   77.89 427.8 .000 .000 .000 4854. 4854.  7.8 0.338 425.5 0.0859   1.7   415.
   79.45 429.2 .000 .000 .000 4914. 4914.  7.9 0.238 426.4 0.0813   2.1   415.
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               FLUTED SECTION WITH  1. PAIRS OF FLUTES
  96.05 429.2 .000 .000 .000 4913. 4913.  7.9 0.213 431.1 0.0813   2.1   415.
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 101.00 438.2 .000 .000 .000 5162. 5162.  8.2 0.213 438.3 0.0802   2.1   415.


 MINIMUM TEMPERATURE=  438.157 DEG F
 TEMP FLUCTUATION=       0.000 DEG F
 FLOW INDEX (N)=         0.763
 GRATIO INJ.=            0.000
 RESIDENCE TIME:
      MELT POOL=   0.056831159 HRS


 TORQUE  =       10317.5 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.932 HP
 MELTING      =   3.916 HP
 MIXING       =   1.606 HP
 FLIGHT CLEAR =   1.468 HP
 COMPRESSION  =   0.219 HP
 MIXING DEVICE=   0.060 HP
 PRESSURE FLUCTUATION=       170.16 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -21.5 TO      11.5 BTU/MIN  OR
                                         -0.51 TO      0.27 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    8.2  12.3  16.4  20.5  24.6  28.6  32.7

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  1.100 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.597 INCHES



  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
     1100.22        342.5        0.0501876
        6.00        339.0        0.2426229


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
       14.32        441.5        0.1011094
      230.27        329.0        0.1050221
 AT  50.00 RPM &  100.00 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  5162. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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2MBF05
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   87.80 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD    BAR.     FLT.   NO OF    HOLE
       #      (IN)   SOLID  MELT  SOLID MELT             DIAM    WIDTH  HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)    (IN)    (IN)     (IN)          (SQIN)
      1     19.800  0.437   0.000 1.822 0.000   2.225   2.250   0.300
      2     27.550  0.150   0.000 1.822 0.000   2.225   2.250   0.300
      3     16.600  0.150   0.450 1.324 1.324   3.450   2.250   0.300
      4      2.225  0.387   0.000 1.822 0.000   2.225   2.250   0.300
      5      9.900  0.437   0.000 1.822 0.000   2.225   2.250   0.300
      6      3.125  0.237   0.000 2.558 0.000   3.125   2.250   0.300
      7     16.600  0.213   0.000 2.800 0.000   3.450   2.250   0.300  1.000   0.914
      8      4.950  0.213   0.000 1.822 0.000   2.225   2.250   0.300

                            HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =     0.33 PSI
       INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =     0.75 PSI


                      SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =    272.50 DEG.F      AND      SCREW =    204.50 DEG.F


     LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
         IN   DEG LB/CU.FT               BARREL   SCREW     HP        PSI
    FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
    FRIS=     0.794804E-01 FRIB=     0.378638E-01
        1.00  17.2   21.10  0.086 0.079    317.7    204.5     0.00        0.30
        1.80  17.2   21.10  0.110 0.079    330.0    204.5     0.00        0.36


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI      HP     IN   DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                      /SQ.IN  .MIN  DEG F
     4.28 342.5                     0.   507.        0.437 349.0 0.0843
     6.78 335.3 .867  .867  .740    0.   810.   0.3 0.437 339.0 0.2385 -15.9    340.
    11.78 322.7 .749  .749  .621    0.   820.   1.2 0.437 290.1 0.2743  -4.2    342.
    13.98 326.1 .692  .692  .568    0.   824.   2.0 0.437 345.6 0.2647   4.9    337.
    18.98 352.5 .578  .578  .475    0.   941.   2.5 0.437 391.1 0.1828  -1.7    390.
    19.80 355.9 .559  .559  .460    0.   964.   2.6 0.437 391.7 0.1757  -1.8    391.
    24.80 375.3 .491  .491  .419    0.  1124.   3.0 0.385 394.7 0.1352   1.0    394.
    29.80 387.0 .423  .423  .373    0.  1303.   3.4 0.333 397.8 0.1214   0.4    397.
    34.80 394.4 .351  .351  .320    0.  1512.   3.8 0.281 400.7 0.1133  -0.3    400.
    39.80 399.1 .270  .270  .255    0.  1756.   4.1 0.229 403.6 0.1083  -1.4    403.
    44.80 401.8 .174  .174  .171    0.  2015.   4.5 0.177 406.4 0.1055  -3.0    406.
    47.35 402.9 .119  .119  .115    0.  2123.   4.7 0.150 408.0 0.1046  -2.1    408.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 407.1 .019  .038  .019    0.  2382.   5.3 0.150 410.7 0.1042   0.9    410.
    57.35 413.3 .000  .000  .000    0.  2648.   5.6 0.150 413.6 0.1002   1.7    412.
    62.35 418.1 .000  .000  .000    0.  2842.   5.8 0.150 416.4 0.0965   1.4    412.
    63.95 419.2 .000  .000  .000    0.  2887.   5.8 0.150 417.5 0.0957   1.3    412.
    -------------------------SECONDARY CHANNEL ENDS--------------------------
    65.06 420.5 .000  .000  .000    0.  2937.   5.9 0.269 418.2 0.0899   1.6    412.
    66.17 421.2 .000  .000  .000    0.  2970.   5.9 0.387 418.9 0.0975   1.3    412.
    71.12 423.3 .000  .000  .000    0.  3084.   6.1 0.412 421.4 0.0981   1.2    412.
    76.07 425.5 .000  .000  .000    0.  3186.   6.2 0.437 424.2 0.0977   1.1    412.
    77.64 426.5 .000  .000  .000    0.  3222.   6.3 0.338 425.3 0.0908   1.3    412.
    79.20 427.8 .000  .000  .000    0.  3272.   6.3 0.238 426.2 0.0850   1.6    412.
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                 FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.80 427.8 .000 .000 .000     0. 3271.  6.4 0.213 431.0 0.0850   1.6   412.
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 100.75 436.5 .000 .000 .000     0. 3480.  6.5 0.213 438.1 0.0851   1.6   412.


 MINIMUM TEMPERATURE=   436.472 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.776
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.060664140 HRS


 TORQUE  =        8252.5 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.000 HP
 MELTING      =   3.789 HP
 MIXING       =   1.213 HP
 FLIGHT CLEAR =   1.340 HP
 COMPRESSION  =   0.174 HP
 MIXING DEVICE=   0.042 HP
 PRESSURE FLUCTUATION=       134.22 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -44.7 TO      35.9 BTU/MIN  OR
                                         -1.05 TO      0.85 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     6.5   9.8  13.1  16.4  19.6  22.9  26.2

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.900 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.518 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
      991.08       334.0       0.0557660
        5.78       265.0       0.3343562


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
       12.89       436.8       0.1044811
        9.11       236.1       0.3105899
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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2MBF10
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   87.80 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH        WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
       #      (IN)    SOLID  MELT   SOLID MELT             DIAM   WIDTH   HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)     (IN)    (IN)    (IN)           (SQIN)
      1      19.800  0.437  0.000 1.822 0.000   2.225   2.250   0.300
      2      27.550  0.150  0.000 1.822 0.000   2.225   2.250   0.300
      3      16.600  0.150  0.450 1.324 1.324   3.450   2.250   0.300
      4       2.225  0.387  0.000 1.822 0.000   2.225   2.250   0.300
      5       9.900  0.437  0.000 1.822 0.000   2.225   2.250   0.300
      6       3.125  0.237  0.000 2.558 0.000   3.125   2.250   0.300
      7      16.600  0.213  0.000 2.800 0.000   3.450   2.250   0.300   1.000   0.914
      8       4.950  0.213  0.000 1.822 0.000   2.225   2.250   0.300

                                HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =    36.00 IN. BASE PRESSURE =     0.29 PSI
      INCREASE HEIGHT TO =   124.00 IN. MAXIMUM PRESSURE =     0.50 PSI

                           SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      68.50 DEG.F      AND      SCREW =     229.00 DEG.F


     LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN    DEG LB/CU.FT                BARREL   SCREW     HP        PSI
       1.00  17.1  21.11  0.131 0.076     68.5    229.0    0.00       0.45
       2.00  17.0  21.18  0.135 0.080     68.5    229.0    0.00       0.70
       3.00  16.9  21.28  0.141 0.085     68.5    229.0    0.00       1.08
       4.00  16.6  21.46  0.152 0.095     68.5    229.0    0.00       1.71
       5.00  16.2  21.76  0.165 0.110     76.0    229.0    0.00       2.72
       6.00  16.0  21.93  0.138 0.118     68.5    229.0    0.01       3.33
       7.00  15.7  22.11  0.145 0.127     68.5    229.0    0.01       3.97
       8.00  15.5  22.31  0.152 0.136     68.5    229.0    0.01       4.66
       9.00  15.2  22.52  0.160 0.145     68.5    229.0    0.02       5.41
      10.00  15.0  22.73  0.167 0.154     68.5    229.0    0.02       6.21
      11.00  14.7  22.96  0.176 0.164     68.5    229.0    0.03       7.04
      11.50  14.6  23.11  0.181 0.169    329.5    229.0    0.03       7.47


     L    TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
     IN   DEG F      SOLID         PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                   /SQ.IN  .MIN  DEG F
     13.78 342.5                 485.  485.      0.437 349.0 0.0825
     16.28 356.1 .875 .875 .720  778.  778. 0.14 0.437 385.5 0.2028 -32.6   385.
     19.80 361.5 .779 .779 .639  891.  891. 0.50 0.437 391.9 0.1880  -2.1   391.
     23.48 372.5 .730 .730 .615 1010. 1010. 0.87 0.399 394.0 0.1384   2.5   393.
     28.48 385.7 .662 .662 .577 1182. 1182.  1.4 0.347 397.0 0.1227   1.6   396.
     33.48 394.0 .589 .589 .532 1383. 1383.  1.8 0.295 399.9 0.1136   0.8   399.
     38.48 399.3 .511 .511 .476 1619. 1619.  2.3 0.243 402.8 0.1081  -0.2   402.
     43.48 402.7 .421 .421 .405 1884. 1884.  2.7 0.190 405.7 0.1046  -1.5   405.
     47.35 404.5 .341 .341 .336 2066. 2066.  3.0 0.150 407.9 0.1030  -2.9   407.
     -------------------------SECONDARY CHANNEL BEGINS--------------------------
     52.35 402.5 .168 .334 .168 2338. 2338.  3.3 0.150 410.6 0.1078  -6.8   410.
     57.35 407.0 .071 .173 .071 2610. 2610.  3.6 0.150 413.5 0.1049  -2.1   413.
     62.35 412.4 .003 .008 .003 2809. 2809.  4.4 0.150 416.3 0.1003   3.2   416.
     63.95 414.5 .000 .000 .000 2855. 2855.  4.5 0.150 417.4 0.0988   1.3   417.
     --------------------------SECONDARY CHANNEL ENDS---------------------------
     65.06 416.5 .000 .000 .000 2907. 2907.  4.5 0.269 418.1 0.0921   1.6   417.
     66.17 417.7 .000 .000 .000 2940. 2940.  4.6 0.387 418.8 0.0997   1.3   417.
     71.12 421.4 .000 .000 .000 3056. 3056.  4.7 0.412 421.4 0.0993   1.2   417.
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  76.07 424.5 .000 .000 .000 3160. 3160.  4.9 0.437 424.2 0.0983   1.2   417.
  77.64 425.6 .000 .000 .000 3195. 3195.  4.9 0.338 425.3 0.0913   1.3   417.
  79.20 427.1 .000 .000 .000 3246. 3246.  5.0 0.238 426.2 0.0853   1.6   417.
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              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.80 427.1 .000 .000 .000 3244. 3244.  5.0 0.213 431.0 0.0853   1.6   417.
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 100.75 436.1 .000 .000 .000 3454. 3454.  5.2 0.213 438.1 0.0853   1.6   417.


 MINIMUM TEMPERATURE=   436.120 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.775
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=    0.051764593 HRS


 TORQUE  =         6544.8 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.031 HP
 MELTING      =   2.812 HP
 MIXING       =   1.075 HP
 FLIGHT CLEAR =   1.096 HP
 COMPRESSION  =   0.148 HP
 MIXING DEVICE=   0.042 HP
 PRESSURE FLUCTUATION=        134.51 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=   -101.9 TO     -38.5 BTU/MIN  OR
                                         -2.40 TO     -0.91 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     5.2   7.8  10.4  13.0  15.6  18.2  20.8

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.900 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.562 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
      813.70        342.5       0.0574303
        5.41        385.5       0.1687969


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.       VISCOSITY
     1/SEC          DEG.F      LB.SEC/SQ.IN
       12.89        438.4       0.1046804
      205.68        329.0       0.1093994
AT  50.00 RPM &    87.80 LB/HR PRODUCTION RATE
HEAD PRESSURE IS   3454. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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2MBF15
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   87.80 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF   HOLE
       #      (IN)   SOLID  MELT  SOLID MELT              DIAM    WIDTH  HOLES   AREA
                     (IN)   (IN)   (IN)  (IN)     (IN)    (IN)    (IN)          (SQIN)
       1     19.800  0.437  0.000 1.822 0.000   2.225   2.250   0.300
       2     27.550  0.150  0.000 1.822 0.000   2.225   2.250   0.300
       3     16.600  0.150  0.450 1.324 1.324   3.450   2.250   0.300
       4      2.225  0.387  0.000 1.822 0.000   2.225   2.250   0.300
       5      9.900  0.437  0.000 1.822 0.000   2.225   2.250   0.300
       6      3.125  0.237  0.000 2.558 0.000   3.125   2.250   0.300
       7     16.600  0.213  0.000 2.800 0.000   3.450   2.250   0.300   1.000   0.914
       8      4.950  0.213  0.000 1.822 0.000   2.225   2.250   0.300

                             HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.21 PSI
       INCREASE HEIGHT TO =    64.55 IN. MAXIMUM PRESSURE =      0.26 PSI

                        SOLIDS CONVEYING ZONE ANALYSIS

    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      69.00 DEG.F      AND     SCREW =    229.00 DEG.F

     LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN    DEG LB/CU.FT                BARREL   SCREW    HP       PSI
       1.00  17.1  21.12  0.181 0.077    69.0    229.0    0.00       0.47
       2.00  16.9  21.27  0.191 0.085    69.0    229.0    0.00       1.05
       3.00  16.4  21.65  0.214 0.105    69.0    229.0    0.00       2.37
       4.00  15.2  22.51  0.263 0.145    69.1    229.0    0.01       5.55
       4.90  13.3  24.40  0.308 0.211   203.5    229.0    0.02      12.35
       5.40  12.3  25.56  0.319 0.236   270.7    229.0    0.03      16.65
       5.90  11.2  27.05  0.331 0.249   278.0    229.0    0.05      22.38
       6.40  10.0  29.10  0.327 0.244   284.5    229.0    0.07      30.54
       6.90   8.7  32.04  0.327 0.243   289.8    229.0    0.10      42.76
       7.40   7.2  36.29  0.326 0.241   295.5    229.0    0.14      61.56
       7.90   5.9  42.29  0.325 0.239   302.2    229.0    0.21      91.09
       8.40   4.7  50.49  0.326 0.238   308.8    229.0    0.31     138.54
       8.90   3.7  60.73  0.325 0.236   317.2    229.0    0.46     215.37
       9.40   3.1  71.58  0.324 0.235   326.5    229.0    0.69     336.78
       9.50   3.0  73.61  0.324 0.235   329.4    229.0    0.75     371.30

    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F      SOLID          PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                   /SQ.IN  .MIN  DEG F
    11.80 342.5                 950.  950.      0.437 349.0 0.0329
    14.30 336.0 .863 .863 .734 1288. 1288.  1.0 0.437 349.0 0.2366 -17.0   349.
    19.30 350.3 .750 .750 .616 1448. 1448.  1.6 0.437 391.2 0.2045  -1.9   391.
    19.80 352.3 .737 .737 .605 1465. 1465.  1.6 0.437 391.7 0.1966  -2.2   391.
    21.50 360.5 .714 .714 .594 1519. 1519.  1.8 0.420 392.6 0.1540   2.6   392.
    26.50 378.6 .647 .647 .557 1687. 1687.  2.3 0.368 395.8 0.1306   1.7   395.
    31.50 389.7 .576 .576 .514 1877. 1877.  2.7 0.315 398.8 0.1180   0.9   398.
    36.50 396.7 .501 .501 .461 2099. 2099.  3.2 0.263 401.7 0.1107   0.1   401.
    41.50 401.2 .417 .417 .396 2356. 2356.  3.6 0.211 404.5 0.1061  -1.0   404.
    46.50 404.1 .320 .320 .313 2608. 2608.  4.0 0.159 407.4 0.1035  -2.5   407.
    47.35 404.5 .302 .302 .297 2642. 2642.  4.0 0.150 407.9 0.1031  -2.9   407.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 403.5 .144 .288 .144 2911. 2911.  4.3 0.150 410.6 0.1070  -5.8   410.
    57.35 407.6 .035 .085 .035 3183. 3183.  5.0 0.150 413.5 0.1042  11.1   413.
    62.35 413.5 .000 .001 .000 3382. 3382.  5.5 0.150 416.4 0.0995   0.8   416.
    63.95 415.5 .000 .000 .000 3427. 3427.  5.5 0.150 417.4 0.0980   1.3   416.
    -------------------------SECONDARY CHANNEL ENDS--------------------------
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  65.06 417.4 .000 .000 .000 3479. 3479.  5.6 0.269 418.2 0.0916   1.6   416.
  66.17 418.4 .000 .000 .000 3512. 3512.  5.6 0.387 418.8 0.0992   1.3   416.
  71.12 421.8 .000 .000 .000 3628. 3628.  5.7 0.412 421.4 0.0990   1.2   416.
  76.07 424.8 .000 .000 .000 3731. 3731.  5.9 0.437 424.2 0.0982   1.1   416.
  77.64 425.8 .000 .000 .000 3767. 3767.  5.9 0.338 425.3 0.0912   1.3   416.
  79.20 427.3 .000 .000 .000 3817. 3817.  6.0 0.238 426.2 0.0852   1.6   416.
  ---------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.80 427.3 .000 .000 .000 3815. 3815.  6.0 0.213 431.0 0.0852   1.6   416.
  --------------------------------------------------------------------------
 100.75 436.2 .000 .000 .000 4025. 4025.  6.2 0.213 438.1 0.0852   1.6   416.


 MINIMUM TEMPERATURE=   436.196 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.775
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.054166913 HRS


 TORQUE  =         7828.4 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.750 HP
 MELTING      =   3.017 HP
 MIXING       =   1.114 HP
 FLIGHT CLEAR =   1.144 HP
 COMPRESSION  =   0.155 HP
 MIXING DEVICE=   0.042 HP
 PRESSURE FLUCTUATION=       134.44 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -58.7 TO      -20.5 BTU/MIN  OR
                                         -1.38 TO      -0.48 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:   6.2    9.3  12.4  15.5  18.6  21.7  24.8

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.900 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.528 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE         TEMP.        VISCOSITY
     1/SEC           DEG.F       LB.SEC/SQ.IN
     1022.47         342.5         0.0518853
        6.51         349.0         0.2203923


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE         TEMP.        VISCOSITY
     1/SEC           DEG.F       LB.SEC/SQ.IN
       12.89         438.5        0.1046373
      205.66         329.0        0.1094019
 AT  50.00 RPM &    87.80 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  4025. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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2MBF20
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

   N= 50.0 RPM       OUTPUT=   87.80 LB/HR       SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH    CH.DEPTH        WIDTH       LEAD    BAR.    FLT.   NO OF   HOLE
      #      (IN)   SOLID  MELT   SOLID MELT              DIAM   WIDTH   HOLES   AREA
                    (IN)   (IN)    (IN)  (IN)     (IN)    (IN)    (IN)          (SQIN)
      1     19.800  0.437  0.000 1.822 0.000   2.225   2.250   0.300
      2     27.550  0.150  0.000 1.822 0.000   2.225   2.250   0.300
      3     16.600  0.150  0.450 1.324 1.324   3.450   2.250   0.300
      4      2.225  0.387  0.000 1.822 0.000   2.225   2.250   0.300
      5      9.900  0.437  0.000 1.822 0.000   2.225   2.250   0.300
      6      3.125  0.237  0.000 2.558 0.000   3.125   2.250   0.300
      7     16.600  0.213  0.000 2.800 0.000   3.450   2.250   0.300  1.000   0.914
      8      4.950  0.213  0.000 1.822 0.000   2.225   2.250   0.300

                          HOPPER ANALYSIS

     ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

     SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.14 PSI
     INCREASE HEIGHT TO =     37.27 IN. MAXIMUM PRESSURE =     0.15 PSI

                    SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      69.00 DEG.F      AND      SCREW =     229.00 DEG.F


    LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT               BARREL    SCREW    HP        PSI
      1.00  17.2  21.10  0.230 0.076     69.0    229.0    0.00       0.45
      2.00  16.7  21.39  0.249 0.091     69.0    229.0    0.00       1.45
      3.00  15.5  22.28  0.301 0.135     69.2    229.0    0.01       4.79
      3.75  13.3  24.32  0.391 0.209     69.6    229.0    0.02      12.21
      4.25  11.1  27.26  0.442 0.249     71.3    229.0    0.03      23.65
      4.75   6.2  33.33  0.440 0.242    117.3    229.0    0.07      49.31
      5.25   5.9  42.31  0.383 0.239    276.7    229.0    0.14      92.19
      5.75   4.2  55.55  0.381 0.237    288.8    229.0    0.27     175.22
      6.25   3.1  71.57  0.388 0.235    303.6    229.0    0.52     342.83
      6.75   2.6  83.41  0.375 0.234    325.7    229.0    1.00     671.39
      6.85   2.5  84.73  0.373 0.234    330.0    229.0    1.14     766.92


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID         PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                   /SQ.IN  .MIN  DEG F
     9.33 342.5                 1386. 1386.     0.437 349.0 0.0836
    11.83 336.0 .863 .863 .734 1704. 1704.  1.4 0.437 349.0 0.2366 -17.0   349.
    16.83 346.5 .754 .754 .620 1818. 1818.  2.0 0.437 389.8 0.2087  -1.2   389.
    19.03 356.6 .697 .697 .572 1868. 1868.  2.2 0.437 391.2 0.1862  -1.6   391.
    19.80 359.1 .677 .677 .556 1867. 1887.  2.3 0.437 391.7 0.1794  -2.1   391.
    24.80 377.1 .610 .610 .520 2045. 2045.  2.7 0.385 394.8 0.1330   1.6   394.
    29.80 388.3 .541 .541 .477 2223. 2223.  3.2 0.333 397.8 0.1200   0.9   397.
    34.80 395.4 .468 .468 .427 2431. 2431.  3.6 0.281 400.7 0.1122   0.1   400.
    39.80 400.2 .389 .389 .366 2676. 2676.  4.0 0.229 403.6 0.1073  -0.8   403.
    44.80 403.5 .300 .300 .291 2936. 2936.  4.4 0.177 406.4 0.1041  -2.0   406.
    47.35 404.9 .250 .250 .247 3048. 3048.  4.5 0.150 408.0 0.1029  -2.8   408.
   ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 405.0 .115 .229 .115 3314. 3314.  4.8 0.150 410.6 0.1059  -4.6   410.
    57.35 408.6 .020 .047 .020 3584. 3584.  5.5 0.150 413.5 0.1033  -1.9   413.
    62.35 415.0 .000 .000 .000 3782. 3782.  5.9 0.150 416.4 0.0984   1.4   415.
    63.95 416.7 .000 .000 .000 3828. 3828.  5.9 0.150 417.4 0.0973   1.3   415.
   -------------------------SECONDARY CHANNEL ENDS--------------------------
    65.06 418.4 .000 .000 .000 3878. 3878.  6.0 0.269 418.2 0.0911   1.6   415.
    66.17 419.3 .000 .000 .000 3912. 3912.  6.0 0.387 418.8 0.0986   1.3   415.
    71.12 422.3 .000 .000 .000 4027. 4027.  6.1 0.412 421.4 0.0987   1.2   415.
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  76.07 425.0 .000 .000 .000 4130. 4130.  6.3 0.437 424.2 0.0980   1.1   415.
  77.64 426.0 .000 .000 .000 4166. 4166.  6.3 0.338 425.3 0.0911   1.3   415.
  79.20 427.4 .000 .000 .000 4215. 4215.  6.4 0.238 426.2 0.0852   1.6   415.
  ---------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.80 427.4 .000 .000 .000 4214. 4214.  6.4 0.213 431.0 0.0852   1.6   415.
  --------------------------------------------------------------------------
 100.75 436.3 .000 .000 .000 4423. 4423.  6.6 0.213 438.1 0.0852   1.6   415.


 MINIMUM TEMPERATURE=   436.286 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.776
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.056131452 HRS


 TORQUE  =         8331.7 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   1.142 HP
 MELTING      =   2.950 HP
 MIXING       =   1.137 HP
 FLIGHT CLEAR =   1.189 HP
 COMPRESSION  =   0.161 HP
 MIXING DEVICE=   0.042 HP
 PRESSURE FLUCTUATION=        134.37 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -41.9 TO     -18.2 BTU/MIN  OR
                                         -0.99 TO     -0.43 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    6.6   9.9  13.2  16.5  19.8  23.1  26.4

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.900 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.516 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
     1043.61        342.5        0.0514072
        6.51        349.0        0.2203923


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
       12.89        438.6        0.1045863
      205.60        329.0        0.1094141
 AT  50.00 RPM &   87.80 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  4423.  PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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2MBF25
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   87.80 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.     FLT.    NO OF    HOLE
       #      (IN)    SOLID  MELT  SOLID MELT            DIAM     WIDTH   HOLES    AREA
                      (IN)  (IN)    (IN)  (IN)     (IN)    (IN)     (IN)            (SQIN)
       1      19.800  0.437   0.000 1.822 0.000   2.225   2.250    0.300
       2      27.550  0.150   0.000 1.822 0.000   2.225   2.250    0.300
       3      16.600  0.150   0.450 1.324 1.324   3.450   2.250    0.300
       4       2.225  0.387   0.000 1.822 0.000   2.225   2.250    0.300
       5       9.900  0.437   0.000 1.822 0.000   2.225   2.250    0.300
       6       3.125  0.237   0.000 2.558 0.000   3.125   2.250    0.300
       7      16.600  0.213   0.000 2.800 0.000   3.450   2.250    0.300   1.000   0.914
       8       4.950  0.213   0.000 1.822 0.000   2.225   2.250    0.300

                              HOPPER ANALYSIS

      ATTENTION - KEEP SOLIDS  LEVEL IN HOPPER ABOVE   24.47 IN.
      BASE PRESSURE =       0.10 PSI

                        SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      69.00 DEG.F      AND      SCREW =     229.00 DEG.F


     LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER     PRESSURE
        IN    DEG LB/CU.FT                BARREL    SCREW    HP        PSI
       1.00  17.1   21.12  0.281 0.077     69.0    229.0    0.00       0.45
       2.00  16.5   21.55  0.308 0.100     69.0    229.0    0.00       2.08
       2.90  14.3   23.32  0.402 0.177     69.2    229.0    0.01       8.55
       3.40  11.8   26.14  0.484 0.244     71.5    229.0    0.02      19.38
       3.90   8.4   32.83  0.489 0.243     76.0    229.0    0.06      47.50
       4.40   4.9   48.54  0.488 0.238     91.3    229.0    0.16     130.09
       4.90   3.0   73.06  0.481 0.235     69.0    229.0    0.45     372.94
       5.25   2.6   83.54  0.425 0.234    330.0    229.0    0.85     685.23


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F     SOLID          PSI       HP     IN   DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                     /SQ.IN  .MIN  DEG F
     7.73 342.5                1305. 1305.       0.437 349.0 0.0836
    10.23 335.3 .867  .867 .740 1625. 1625.  1.1 0.437 339.0 0.2385 -15.9   340.
    15.23 340.7 .746  .746 .617 1745. 1745.  2.0 0.437 377.3 0.2188  -5.8   352.
    17.43 350.7 .691  .691 .568 1798. 1798.  2.2 0.437 390.2 0.1955  -1.4   390.
    19.80 359.6 .631  .631 .519 1858. 1858.  2.4 0.437 391.9 0.1736  -2.2   391.
    24.80 377.4 .565  .565 .481 2015. 2015.  2.9 0.385 394.8 0.1328   1.4   394.
    29.80 388.4 .496  .496 .438 2193. 2193.  3.3 0.333 397.8 0.1200   0.7   397.
    34.80 395.5 .424  .424 .387 2401. 2401.  3.7 0.281 400.7 0.1123   0.0   400.
    39.80 400.2 .346  .346 .326 2645. 2645.  4.1 0.229 403.6 0.1073  -0.9   403.
    44.80 403.7 .261  .261 .254 2904. 2904.  4.4 0.177 406.4 0.1041  -1.9   406.
    47.35 405.2 .214  .214 .212 3015. 3015.  4.6 0.150 408.0 0.1027  -2.6   408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 406.0 .096  .191 .096 3279. 3279.  4.9 0.150 410.7 0.1051  -3.7   410.
    57.35 409.8 .010  .024 .010 3548. 3548.  5.7 0.150 413.5 0.1026   2.1   413.
    62.35 416.0 .000  .000 .000 3745. 3745.  5.9 0.150 416.4 0.0978   1.4   415.
    63.95 417.5 .000  .000 .000 3791. 3791.  6.0 0.150 417.4 0.0968   1.3   415.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
    65.06 419.1 .000  .000 .000 3841. 3841.  6.0 0.269 418.2 0.0907   1.6   415.
    66.17 419.9 .000  .000 .000 3874. 3874.  6.0 0.387 418.8 0.0983   1.3   415.
    71.12 422.6 .000  .000 .000 3990. 3990.  6.2 0.412 421.4 0.0985   1.2   415.
    76.07 425.2 .000  .000 .000 4092. 4092.  6.3 0.437 424.2 0.0979   1.1   415.
    77.64 426.2 .000  .000 .000 4128. 4128.  6.4 0.338 425.3 0.0910   1.3   415.
    79.20 427.5 .000  .000 .000 4178. 4178.  6.4 0.238 426.2 0.0851   1.6   415.
    --------------------------------------------------------------------------
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                 FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.80 427.5 .000 .000 .000 4177. 4177.  6.5 0.213 431.0 0.0851   1.6   415.
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 100.75 436.3 .000 .000 .000 4386. 4386.  6.7 0.213 438.1 0.0852   1.6   415.


 MINIMUM TEMPERATURE=   436.345 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.776
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
     MELT POOL=   0.057620168 HRS


 TORQUE  =         8388.6 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.846 HP
 MELTING      =   3.217 HP
 MIXING       =   1.161 HP
 FLIGHT CLEAR =   1.233 HP
 COMPRESSION  =   0.167 HP
 MIXING DEVICE=   0.042 HP
 PRESSURE FLUCTUATION=       134.32 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=     -40.0 TO      -1.5 BTU/MIN  OR
                                          -0.94 TO     -0.03 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     6.7  10.0  13.3  16.6  20.0  23.3  26.6

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.900 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.514 INCHES



  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE         TEMP.        VISCOSITY
     1/SEC           DEG.F       LB.SEC/SQ.IN
    1041.87          342.5        0.0514462
       6.04          339.0        0.2424222


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE         TEMP.        VISCOSITY
     1/SEC           DEG.F       LB.SEC/SQ.IN
      12.89          438.6        0.1045531
       9.11          326.7        0.2533081
AT  50.00 RPM &    87.80 LB/HR PRODUCTION RATE
HEAD PRESSURE IS   4386. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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3MBF05
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=    75.60 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH     CH.DEPTH        WIDTH       LEAD    BAR.    FLT.    NO OF    HOLE
       #      (IN)    SOLID  MELT   SOLID MELT              DIAM    WIDTH   HOLES    AREA
                       (IN)  (IN)    (IN)  (IN)     (IN)    (IN)    (IN)            (SQIN)
      1     19.800  0.437  0.000 1.584 0.000   1.975   2.000   0.300
      2     27.550  0.180  0.000 1.584 0.000   1.975   2.000   0.300
      3     16.600  0.150  0.450 1.286 1.286   3.450   2.000   0.300
      4      1.975  0.387  0.000 1.584 0.000   1.975   2.000   0.300
      5      9.900  0.437  0.000 1.584 0.000   1.975   2.000   0.300
      6      3.125  0.237  0.000 2.498 0.000   3.125   2.000   0.300
      7     16.600  0.213  0.000 2.724 0.000   3.450   2.000   0.300  1.000   0.914
      8      4.950  0.213  0.000 1.584 0.000   1.975   2.000   0.300

                            HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
       INCREASE HEIGHT TO =   186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                      SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =       73.00 DEG.F      AND      SCREW =     231.50 DEG.F


     LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
         IN   DEG LB/CU.FT                 BARREL   SCREW     HP        PSI
    FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
    FRIS=     0.757367E-01 FRIB=     0.748980E-01
        1.00  22.7   21.10  0.075 0.076      73.7     231.5    0.00        0.34
        2.00  22.7   21.10  0.075 0.076      73.8     231.5    0.00        0.34
        3.00  22.7   21.10  0.075 0.076      73.8     231.5    0.00        0.34
        4.00  22.7   21.10  0.075 0.076      74.3     231.5    0.00        0.34
        5.00  22.7   21.10  0.072 0.076      77.6     231.5    0.00        0.35
        6.00  22.7   21.10  0.039 0.076      70.0     231.5    0.00        0.28
        7.00  22.7   21.07  0.035 0.074      70.0     231.5    0.00        0.22
        8.00  22.7   21.07  0.033 0.074      70.0     231.5    0.00        0.17
        9.00  22.8   21.04  0.029 0.073      70.0     231.5    0.00        0.13
       10.00  22.8   21.04  0.027 0.073      70.0     231.5    0.00        0.09
       11.00  22.8   21.04  0.026 0.073      70.0     231.5    0.00        0.07
       12.00  22.8   21.04  0.025 0.073      70.0     231.5    0.00        0.05
       12.10  22.8   21.04  0.025 0.073     330.0     231.5    0.00        0.05
   ATTENTION - SOLIDS CONVEYING CONTROLS OPERATION
   REQUESTED OUTPUT IS UNATTAINABLE


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                    /SQ.IN  .MIN  DEG F
    14.63 356.0                  0.   460.      0.437 368.7 0.0815
    16.63 356.9 .875 .875 .711   0.   636. 0.08 0.437 389.8 0.2108 -31.9   390.
    19.80 361.5 .787 .787 .639   0.   721. 0.31 0.437 392.0 0.2026  -2.8   392.
    23.03 370.2 .743 .743 .620   0.   808. 0.54 0.404 393.7 0.1517   1.7   393.
    28.03 383.0 .675 .675 .588   0.   952. 0.89 0.352 396.7 0.1343   1.1   396.
    33.03 390.9 .603 .603 .546   0.  1119.  1.2 0.299 399.6 0.1241   0.4   399.
    38.03 396.2 .527 .527 .495   0.  1313.  1.6 0.247 402.5 0.1176  -0.3   402.
    43.03 399.7 .441 .441 .430   0.  1520.  1.9 0.195 405.4 0.1134  -1.3   405.
    47.35 401.4 .355 .355 .355   0.  1661.  2.1 0.150 408.0 0.1112  -3.8   408.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 397.1 .159 .311 .159   0.  1856.  2.3 0.150 410.5 0.1172  -7.4   410.
    57.35 404.2 .043 .105 .043   0.  2077.  2.8 0.150 413.4 0.1116  -0.3   413.
             FILM THICKNESS IS 0 - TBAR=  0.4157E+03
             FILM THICKNESS IS 0 - TBAR=  0.4157E+03
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  62.35 411.3 .000 .001 .000     0. 2240.  3.2 0.150 416.3 0.1056  -0.4   416.
  63.95 413.6 .000 .000 .000     0. 2277.  3.3 0.150 417.4 0.1041   1.0   416.
  -----------------------SECONDARY CHANNEL ENDS--------------------------
  64.94 415.2 .000 .000 .000     0. 2314.  3.3 0.269 418.1 0.0974   1.2   416.
  65.92 416.3 .000 .000 .000     0. 2339.  3.3 0.387 418.6 0.1072   0.9   416.
  70.87 420.0 .000 .000 .000     0. 2437.  3.4 0.412 421.2 0.1071   0.9   416.
  75.82 423.1 .000 .000 .000     0. 2524.  3.5 0.437 424.0 0.1062   0.8   416.
  77.39 424.2 .000 .000 .000     0. 2554.  3.5 0.338 425.1 0.0971   0.9   416.
  78.95 425.7 .000 .000 .000     0. 2595.  3.6 0.238 426.0 0.0897   1.1   416.
  -----------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.55 425.7 .000 .000 .000     0. 2594.  3.6 0.213 430.8 0.0897   1.1   416.
  ----------------------------------------------------------------------
 100.50 434.6 .000 .000 .000     0. 2763.  3.7 0.213 438.0 0.0908   1.1   416.


 MINIMUM TEMPERATURE=   434.567 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.790
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=    0.050763860 HRS


 TORQUE  =        4725.6 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.001 HP
 MELTING      =   2.050 HP
 MIXING       =   0.719 HP
 FLIGHT CLEAR =   0.858 HP
 COMPRESSION  =   0.101 HP
 MIXING DEVICE=   0.028 HP
 PRESSURE FLUCTUATION=         100.09 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -117.3 TO      -60.8 BTU/MIN  OR
                                          -2.76 TO      -1.43 HP

 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     3.7   5.6   7.5   9.4  11.2  13.1  15.0

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.700 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.494 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
     659.91         372.4        0.0516510
       3.22         389.8        0.1719828


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
      32.84         438.0        0.0887321
     180.47         329.0        0.1145837
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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3MBF10
    EXPERIMENT NUMBER    1.01       SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   75.60 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD    BAR.    FLT.   NO OF    HOLE
       #      (IN)    SOLID  MELT  SOLID MELT            DIAM   WIDTH  HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)    (IN)    (IN)    (IN)          (SQIN)
      1      19.800  0.437  0.000 1.584 0.000  1.975  2.000  0.300
      2      27.550  0.150  0.000 1.584 0.000  1.975  2.000  0.300
      3      16.600  0.150  0.450 1.286 1.286  3.450  2.000  0.300
      4       1.975  0.387  0.000 1.584 0.000  1.975  2.000  0.300
      5       9.900  0.437  0.000 1.584 0.000  1.975  2.000  0.300
      6       3.125  0.237  0.000 2.498 0.000  3.125  2.000  0.300
      7      16.600  0.213  0.000 2.724 0.000  3.450  2.000  0.300  1.000  0.914
      8       4.950  0.213  0.000 1.584 0.000  1.975  2.000  0.300

                              HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.29 PSI
       INCREASE HEIGHT TO =   124.00 IN. MAXIMUM PRESSURE =      0.50 PSI

                       SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =    101.50 DEG.F      AND      SCREW =    114.00 DEG.F


    LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                BARREL   SCREW     HP        PSI
   FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
   FRIS=    0.119470E+00 FRIB=    0.119404E+00
        1.00  22.7  21.08  0.118 0.119   108.5   114.0    0.00       0.29
        2.00  22.7  21.08  0.117 0.119   111.0   114.0    0.00       0.28
        3.00  22.7  21.08  0.116 0.119   111.7   114.0    0.00       0.27
        4.00  22.7  21.08  0.116 0.119   112.2   114.0    0.00       0.26
        5.00  22.7  21.08  0.118 0.119    95.5   114.0    0.00       0.25
        6.00  22.7  21.08  0.084 0.119    70.0   114.0    0.00       0.20
        6.67  22.8  21.06  0.081 0.118    70.0   114.0    0.00       0.18
        6.92  22.8  21.06  0.080 0.118    70.0   114.0    0.00       0.17
        7.17  22.8  21.06  0.080 0.118    70.0   114.0    0.00       0.16
        7.42  22.8  21.06  0.079 0.118    70.0   114.0    0.00       0.15
        7.68  22.8  21.06  0.079 0.118    70.0   114.0    0.00       0.14
        7.93  22.8  21.06  0.078 0.118    70.0   114.0    0.00       0.13
        8.17  22.8  21.06  0.078 0.118    70.0   114.0    0.00       0.12
        8.42  22.8  21.06  0.077 0.118    70.0   114.0    0.00       0.11
        8.67  22.8  21.06  0.077 0.118    70.0   114.0    0.00       0.10
        8.92  22.8  21.06  0.077 0.118    70.0   114.0    0.00       0.10
        9.17  22.8  21.06  0.076 0.118    70.0   114.0    0.00       0.09
        9.42  22.8  21.03  0.074 0.116    70.0   114.0    0.00       0.08
        9.67  22.8  21.03  0.074 0.116    70.0   114.0    0.00       0.08
        9.75  22.8  21.03  0.074 0.116   329.3   114.0    0.00       0.08
   ATTENTION - SOLIDS CONVEYING CONTROLS OPERATION
   REQUESTED OUTPUT IS UNATTAINABLE


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT   TBAR  TVISC D.HEAT  FILM
    IN    DEG F     SOLID          PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                      /SQ.IN  .MIN  DEG F
    12.00 342.5                  0.   410.       0.437 349.0 0.0838
    14.50 335.6 .864 .864 .728   0.   752. 0.18 0.437 349.0 0.2544 -18.9   349.
    19.50 348.4 .752 .752 .611   0.   887. 0.61 0.437 391.3 0.2242  -2.0   391.
    19.80 349.6 .744 .744 .604   0.   895. 0.63 0.437 391.7 0.2171  -2.4   391.
    20.90 354.8 .729 .729 .597   0.   925. 0.71 0.426 392.2 0.1744   1.8   392.
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  25.90 373.6 .659 .659 .564    0. 1067.  1.1 0.374 395.3 0.1460   1.1    395.
  30.90 385.5 .588 .588 .524    0. 1226.  1.4 0.322 398.3 0.1303   0.5    398.
  35.90 393.0 .514 .514 .476    0. 1410.  1.7 0.269 401.3 0.1212  -0.1    401.
  40.90 397.8 .433 .433 .416    0. 1614.  2.0 0.217 404.1 0.1155  -1.0    404.
  45.90 400.8 .339 .339 .338    0. 1804.  2.3 0.165 407.0 0.1121  -2.4    406.
  47.35 401.0 .307 .307 .307    0. 1839.  2.4 0.150 407.9 0.1116  -3.9    408.
  ------------------------SECONDARY CHANNEL BEGINS------------------------
  52.35 399.0 .127 .248 .127    0. 2032.  2.7 0.150 410.5 0.1160  -3.5    410.
  57.35 405.7 .028 .068 .028    0. 2251.  3.1 0.150 413.4 0.1104   0.5    413.
          FILM THICKNESS IS 0 - TBAR=  0.4152E+03
          FILM THICKNESS IS 0 - TBAR=  0.4152E+03
  62.35 412.8 .000 .000 .000    0. 2414.  3.5 0.150 416.3 0.1046   1.0    415.
  63.95 414.7 .000 .000 .000    0. 2450.  3.5 0.150 417.4 0.1033   1.0    415.
  -------------------------SECONDARY CHANNEL ENDS-------------------------
  64.94 416.3 .000 .000 .000    0. 2488.  3.5 0.269 418.1 0.0968   1.2    415.
  65.92 417.2 .000 .000 .000    0. 2512.  3.6 0.387 418.6 0.1065   0.9    415.
  70.87 420.4 .000 .000 .000    0. 2610.  3.7 0.412 421.2 0.1068   0.9    415.
  75.82 423.3 .000 .000 .000    0. 2697.  3.8 0.437 424.0 0.1060   0.8    415.
  77.39 424.4 .000 .000 .000    0. 2727.  3.8 0.338 425.1 0.0969   0.9    415.
  78.95 425.8 .000 .000 .000    0. 2768.  3.8 0.238 426.0 0.0896   1.1    415.
  ------------------------------------------------------------------------
               FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.55 425.8 .000 .000 .000    0. 2767.  3.9 0.213 430.8 0.0896   1.1    415.
  ------------------------------------------------------------------------
 100.50 434.7 .000 .000 .000    0. 2936.  4.0 0.213 438.0 0.0908   1.1    415.


MINIMUM TEMPERATURE=   434.652 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.790
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.053197451 HRS


TORQUE  =         5054.3 INCH.POUNDS
POWER BREAK-DOWN:

SOLIDS CONV. =    0.001 HP
MELTING      =    2.236 HP
MIXING       =    0.748 HP
FLIGHT CLEAR =    0.899 HP
COMPRESSION  =    0.106 HP
MIXING DEVICE=    0.028 HP
PRESSURE FLUCTUATION=       100.05 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=    -106.3 TO      -43.5 BTU/MIN  OR
                                         -2.50 TO      -1.02 HP


MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:    4.0   6.0   8.0  10.0  12.0  14.0  16.0

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.700 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.482 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.       VISCOSITY
    1/SEC          DEG.F     LB.SEC/SQ.IN
     843.97        339.0       0.0578758
       3.72        349.0       0.2361072


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.       VISCOSITY
    1/SEC          DEG.F     LB.SEC/SQ.IN
      32.85        438.0       0.0887296
     334.90        329.0       0.0912090
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
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3MBF15
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=   75.60 LB/HR       SOAK TIME=   0.00 SECONDS


    SECTION  LENGTH     CH.DEPTH        WIDTH       LEAD    BAR.     FLT.    NO OF    HOLE
       #      (IN)    SOLID  MELT   SOLID MELT             DIAM     WIDTH   HOLES    AREA
                       (IN)   (IN)    (IN)  (IN)     (IN)   (IN)      (IN)             (SQIN)
       1     19.800  0.437   0.000 1.584 0.000   1.975   2.000   0.300
       2     27.550  0.150   0.000 1.584 0.000   1.975   2.000   0.300
       3     16.600  0.150   0.450 1.286 1.286   3.450   2.000   0.300
       4      1.975  0.387   0.000 1.584 0.000   1.975   2.000   0.300
       5      9.900  0.437   0.000 1.584 0.000   1.975   2.000   0.300
       6      3.125  0.237   0.000 2.498 0.000   3.125   2.000   0.300
       7     16.600  0.213   0.000 2.724 0.000   3.450   2.000   0.300   1.000   0.914
       8      4.950  0.213   0.000 1.584 0.000   1.975   2.000   0.300

                                  HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =      36.00 IN. BASE PRESSURE =      0.21 PSI
       INCREASE HEIGHT TO =    64.55 IN. MAXIMUM PRESSURE =      0.26 PSI

                             SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      70.50 DEG.F       AND       SCREW =     229.00 DEG.F


     LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
        IN    DEG LB/CU.FT                  BARREL    SCREW      HP         PSI
       1.00   22.6   21.12   0.176 0.077      70.5     229.0     0.00        0.43
       2.00   22.4   21.22   0.183 0.083      70.8     229.0     0.00        0.86
       3.00   21.8   21.49   0.199 0.097      70.6     229.0     0.00        1.75
       4.00   20.8   22.00   0.230 0.122      71.0     229.0     0.00        3.65
       5.00   18.8   23.13   0.281 0.171      76.5     229.0     0.01        7.81
       6.00   16.9   24.50   0.288 0.215      70.0     229.0     0.02       12.81
       7.00   14.6   26.58   0.322 0.248      70.0     229.0     0.04       20.80
       7.50   13.1   28.24   0.319 0.245      70.0     229.0     0.06       27.04
       8.00   11.6   30.51   0.318 0.244      70.0     229.0     0.08       36.24
       8.50    9.9   33.81   0.319 0.242      70.0     229.0     0.10       50.34
       9.00    8.1   38.57   0.318 0.241      70.0     229.0     0.14       72.33
       9.50    6.5   45.34   0.319 0.239      70.0     229.0     0.20      107.62
      10.00    5.1   54.42   0.318 0.237      70.0     229.0     0.29      165.13
      10.50    4.1   65.26   0.318 0.236      70.0     229.0     0.42      259.49
      10.65    3.8   68.59   0.318 0.235     330.0     229.0     0.48      298.05


     L     TOUT   X/W   X/W GRATIO PRESSURE  POWER   HOUT   TBAR   TVISC D.HEAT   FILM
     IN    DEG F       SOLID           PSI       HP     IN   DEG F LB.SEC BTU/IN TEMP
                                    REAL  FULL                       /SQ.IN  .MIN  DEG F
     13.03 342.5                     874.  874.         0.437 349.0 0.0838
     15.03 337.1 .862 .862 .726 1110. 1110.   0.6 0.437 353.4 0.2491 -19.4    353.
     19.80 348.9 .754 .754 .612 1241. 1241.   1.0 0.437 391.5 0.2223  -2.1    391.
     21.43 356.6 .731 .731 .602 1285. 1285.   1.2 0.421 392.5 0.1713   1.8    392.
     26.43 374.8 .662 .662 .568 1429. 1429.   1.5 0.368 395.6 0.1443   1.1    395.
     31.43 386.3 .591 .591 .528 1591. 1591.   1.9 0.316 398.7 0.1293   0.5    398.
     36.43 393.6 .516 .516 .479 1777. 1777.   2.2 0.264 401.6 0.1205  -0.2    401.
     41.43 398.2 .434 .434 .418 1983. 1983.   2.5 0.212 404.4 0.1151  -1.1    404.
     46.43 401.0 .338 .338 .338 2167. 2167.   2.8 0.160 407.3 0.1119  -2.6    407.
     47.35 401.1 .317 .317 .317 2188. 2188.   2.8 0.150 407.8 0.1116  -3.6    407.
     ------------------------SECONDARY CHANNEL BEGINS---------------------------
     52.35 398.8 .134 .262 .134 2381. 2381.   3.1 0.150 410.5 0.1162  -3.7    410.
     57.35 405.4 .031 .075 .031 2600. 2600.   3.6 0.150 413.4 0.1106   0.4    413.
             FILM THICKNESS IS 0 - TBAR=  0.4152E+03
             FILM THICKNESS IS 0 - TBAR=  0.4152E+03
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  62.35 412.4 .000 .000 .000 2763. 2763.  3.9 0.150 416.3 0.1049   1.0   416.
  63.95 414.4 .000 .000 .000 2800. 2800.  3.9 0.150 417.4 0.1035   1.0   416.
  -------------------------SECONDARY CHANNEL ENDS-------------------------
  64.94 416.0 .000 .000 .000 2837. 2837.  4.0 0.269 418.1 0.0969   1.2   416.
  65.92 416.9 .000 .000 .000 2862. 2862.  4.0 0.387 418.6 0.1067   0.9   416.
  70.87 420.3 .000 .000 .000 2960. 2960.  4.1 0.412 421.2 0.1069   0.9   416.
  75.82 423.3 .000 .000 .000 3047. 3047.  4.2 0.437 424.0 0.1060   0.8   416.
  77.39 424.3 .000 .000 .000 3076. 3076.  4.2 0.338 425.1 0.0970   0.9   416.
  78.95 425.8 .000 .000 .000 3117. 3117.  4.3 0.238 426.0 0.0897   1.1   416.
  ------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.55 425.8 .000 .000 .000 3116. 3116.  4.3 0.213 430.8 0.0897   1.1   416.
  ------------------------------------------------------------------------
 100.50 434.6 .000 .000 .000 3285. 3285.  4.4 0.213 438.0 0.0908   1.1   416.


 MINIMUM TEMPERATURE=   434.629 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.790
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=    0.052846901 HRS


 TORQUE  =        5600.6 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.477 HP
 MELTING      =   2.206 HP
 MIXING       =   0.745 HP
 FLIGHT CLEAR =   0.890 HP
 COMPRESSION  =   0.105 HP
 MIXING DEVICE=   0.026 HP
 PRESSURE FLUCTUATION=       100.06 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -87.9 TO     -46.9 BTU/MIN  OR
                                         -2.07 TO     -1.11 HP

 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     4.4   6.7   8.9  11.1  13.3  15.6  17.8

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.700 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.465 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
     1056.67       342.5        0.0511142
        3.80       353.4        0.2269123


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.        VISCOSITY
     1/SEC         DEG.F       LB.SEC/SQ.IN
      32.85        438.0        0.0887302
     180.38        329.0        0.1146036
 AT  50.00 RPM &   75.60 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  3285. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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3MBF20
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

   N= 50.0 RPM       OUTPUT=    75.60 LB/HR       SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH    CH.DEPTH        WIDTH       LEAD    BAR.    FLT.    NO OF    HOLE
      #      (IN)    SOLID  MELT   SOLID MELT             DIAM    WIDTH   HOLES    AREA
                     (IN)   (IN)    (IN)  (IN)    (IN)    (IN)    (IN)            (SQIN)
     1     19.800  0.437   0.000 1.584 0.000   1.975   2.000   0.300
     2     27.550  0.150   0.000 1.584 0.000   1.975   2.000   0.300
     3     16.600  0.150   0.450 1.286 1.286   3.450   2.000   0.300
     4      1.975  0.387   0.000 1.584 0.000   1.975   2.000   0.300
     5      9.900  0.437   0.000 1.584 0.000   1.975   2.000   0.300
     6      3.125  0.237   0.000 2.498 0.000   3.125   2.000   0.300
     7     16.600  0.213   0.000 2.724 0.000   3.450   2.000   0.300   1.000   0.914
     8      4.950  0.213   0.000 1.584 0.000   1.975   2.000   0.300

                              HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.14 PSI
      INCREASE HEIGHT TO =     37.27 IN. MAXIMUM PRESSURE =      0.15 PSI

                        SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      70.50 DEG.F      AND      SCREW =     229.00 DEG.F


    LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT                 BARREL    SCREW    HP        PSI
       1.00  22.6  21.11  0.226 0.077      70.5     229.0    0.00       0.40
       2.00  22.2  21.31  0.239 0.088      70.9     229.0    0.00       1.15
       3.00  21.0  21.91  0.274 0.118      70.8     229.0    0.00       3.35
       4.00  18.0  23.71  0.362 0.191      71.8     229.0    0.01      10.16
       4.50  15.2  25.92  0.424 0.242      72.2     229.0    0.02      18.32
       5.00  12.1  29.61  0.379 0.244      70.0     229.0    0.04      32.90
       5.50   9.3  35.07  0.377 0.242      70.0     229.0    0.07      56.58
       6.00   6.7  44.41  0.377 0.239      70.0     229.0    0.13     103.61
       6.50   4.6  58.73  0.376 0.236      70.0     229.0    0.24     200.45
       7.00   3.4  74.88  0.374 0.235      70.0     229.0    0.46     398.65
       7.50   3.0  85.04  0.370 0.234      70.0     229.0    0.89     797.53
       7.55   2.9  85.59  0.402 0.234     330.0     229.0    0.96     865.86


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN   DEG F     SOLID           PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                    /SQ.IN  .MIN  DEG F
   10.08 342.5                 1482. 1482.        0.437 349.0 0.0850
   12.00 335.6 .864 .864 .728 1685. 1685.   1.1 0.437 349.0 0.2544 -18.9    349.
   17.00 346.9 .756 .756 .614 1753. 1753.   1.6 0.437 389.9 0.2279  -1.6    389.
   18.40 352.0 .719 .719 .584 1772. 1772.   1.7 0.437 390.8 0.2121  -1.9    390.
   19.80 356.5 .683 .683 .555 1795. 1795.   1.8 0.437 391.8 0.1973  -2.3    391.
   24.80 374.2 .613 .613 .520 1929. 1929.   2.1 0.385 394.7 0.1460   1.0    394.
   29.80 385.5 .543 .543 .480 2081. 2081.   2.4 0.333 397.7 0.1310   0.4    397.
   34.80 392.7 .470 .470 .432 2257. 2257.   2.7 0.281 400.7 0.1220  -0.2    400.
   39.80 397.5 .392 .392 .374 2457. 2457.   3.0 0.229 403.5 0.1162  -0.9    403.
   44.80 400.4 .300 .300 .298 2654. 2654.   3.3 0.177 406.4 0.1127  -2.4    406.
   47.35 400.8 .244 .244 .244 2724. 2724.   3.4 0.150 407.9 0.1119  -4.1    407.
   -------------------------SECONDARY CHANNEL BEGINS--------------------------
   52.35 401.0 .087 .170 .087 2913. 2913.   3.8 0.150 410.6 0.1142  -2.8    410.
   57.35 407.4 .012 .029 .012 3130. 3130.   4.2 0.150 413.5 0.1090   1.7    413.
           FILM THICKNESS IS 0 - TBAR=  0.4146E+03
           FILM THICKNESS IS 0 - TBAR=  0.4146E+03
   62.35 414.1 .000 .000 .000 3291. 3291.   4.4 0.150 416.4 0.1036   1.0    415.
   63.95 415.8 .000 .000 .000 3328. 3328.   4.5 0.150 417.4 0.1024   0.9    415.
   -------------------------SECONDARY CHANNEL ENDS---------------------------
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 64.94 417.2 .000 .000 .000 3365. 3365.  4.5 0.269 418.1 0.0962   1.2   415.
 65.92 418.0 .000 .000 .000 3389. 3389.  4.5 0.387 418.7 0.1060   0.9   415.
 70.87 420.9 .000 .000 .000 3487. 3487.  4.6 0.412 421.2 0.1065   0.9   415.
 75.82 423.6 .000 .000 .000 3573. 3573.  4.7 0.437 424.0 0.1058   0.8   415.
 77.39 424.6 .000 .000 .000 3603. 3603.  4.8 0.338 425.1 0.0968   0.9   415.
 78.95 426.0 .000 .000 .000 3644. 3644.  4.8 0.238 426.0 0.0896   1.1   415.
 --------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
 95.55 426.0 .000 .000 .000 3643. 3643.  4.8 0.213 430.8 0.0896   1.1   415.
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100.50 434.7 .000 .000 .000 3812. 3812.  5.0 0.213 438.0 0.0907   1.1   415.


MINIMUM TEMPERATURE=   434.728 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.790
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.055078730 HRS


TORQUE  =         6258.4 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =    0.961 HP
MELTING      =    2.178 HP
MIXING       =    0.763 HP
FLIGHT CLEAR =    0.935 HP
COMPRESSION  =    0.109 HP
MIXING DEVICE=    0.028 HP
PRESSURE FLUCTUATION=        100.02 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=     -65.8 TO      -43.1 BTU/MIN  OR
                                         -1.55 TO      -1.01 HP


MAXIMUM SCREW SPEED,RPM:               50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:     5.0   7.4   9.9  12.4  14.9  17.4  19.9

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):

MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.620 INCHES
MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.445 INCHES


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
   1/SEC           DEG.F       LB.SEC/SQ.IN
    969.09         342.5        0.0531525
      3.72         349.0        0.2361072


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE        TEMP.        VISCOSITY
   1/SEC           DEG.F       LB.SEC/SQ.IN
     32.85         438.0        0.0887272
    349.48         329.0        0.0897076
AT  50.00 RPM &    75.60 LB/HR PRODUCTION RATE
HEAD PRESSURE IS   3812. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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3MBF25
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM       OUTPUT=    75.60 LB/HR       SOAK TIME=   0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD    BAR.    FLT.   NO OF    HOLE
       #      (IN)   SOLID  MELT  SOLID MELT              DIAM    WIDTH  HOLES    AREA
                     (IN)   (IN)   (IN)  (IN)     (IN)    (IN)    (IN)           (SQIN)
      1      19.800  0.437  0.000 1.584 0.000    1.975   2.000   0.300
      2      27.550  0.150  0.000 1.584 0.000    1.975   2.000   0.300
      3      16.600  0.150  0.450 1.286 1.286    3.450   2.000   0.300
      4       1.975  0.387  0.000 1.584 0.000    1.975   2.000   0.300
      5       9.900  0.437  0.000 1.584 0.000    1.975   2.000   0.300
      6       3.125  0.237  0.000 2.498 0.000    3.125   2.000   0.300
      7      16.600  0.213  0.000 2.724 0.000    3.450   2.000   0.300   1.000   0.914
      8       4.950  0.213  0.000 1.584 0.000    1.975   2.000   0.300

                            HOPPER ANALYSIS

       ATTENTION - KEEP SOLIDS  LEVEL IN HOPPER ABOVE    24.47 IN.
       BASE PRESSURE =        0.10 PSI

                        SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      70.50 DEG.F      AND      SCREW =     229.00 DEG.F


     LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER     PRESSURE
        IN    DEG LB/CU.FT                  BARREL    SCREW    HP          PSI
       1.00   22.7   21.09   0.275 0.076      70.5    229.0    0.00        0.40
       2.00   21.9   21.43   0.296 0.094      71.0    229.0    0.00        1.60
       3.00   19.4   22.76   0.370 0.156      71.0    229.0    0.01        6.64
       3.55   16.2   25.03   0.456 0.227      72.3    229.0    0.01       15.01
       4.05   12.1   29.71   0.482 0.244      74.8    229.0    0.04       33.91
       4.55    7.4   41.32   0.484 0.240      83.0    229.0    0.09       88.68
       5.05    4.3   62.57   0.429 0.236     282.9    229.0    0.23      237.26
       5.55    3.1   81.55   0.423 0.234     308.5    229.0    0.56      586.24
       5.85    2.9   86.37   0.429 0.234     330.0    229.0    0.95     1008.03

     L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT   TBAR  TVISC D.HEAT  FILM
     IN    DEG F      SOLID         PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                     /SQ.IN  .MIN  DEG F
     8.38 342.5                1623. 1623.        0.437 349.0 0.0850
    10.38 335.0 .869  .869 .734 1831. 1831.   1.2 0.437 339.0 0.2562 -17.8    339.
    15.38 339.2 .786  .786 .643 1852. 1852.   1.7 0.437 380.9 0.2477  -0.6    356.
    19.78 356.3 .671  .671 .545 1871. 1871.   2.0 0.437 391.6 0.1987  -2.1    391.
    19.80 356.3 .670  .670 .545 1871. 1871.   2.0 0.437 391.9 0.1951  -7.0    392.
    24.80 374.2 .601  .601 .510 2005. 2005.   2.3 0.385 394.7 0.1461   0.9    394.
    29.80 385.5 .531  .531 .469 2157. 2157.   2.7 0.333 397.7 0.1310   0.4    397.
    34.80 392.7 .458  .458 .421 2333. 2333.   3.0 0.281 400.7 0.1220  -0.2    400.
    39.80 397.5 .381  .381 .363 2533. 2533.   3.2 0.229 403.5 0.1162  -1.0    403.
    44.80 400.3 .288  .288 .286 2729. 2729.   3.5 0.177 406.4 0.1128  -2.5    406.
    47.35 400.8 .231  .231 .231 2799. 2799.   3.6 0.150 407.9 0.1120  -4.2    407.
    -------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 401.9 .079  .155 .079 2987. 2987.   4.0 0.150 410.6 0.1134  -2.6    410.
    57.35 408.1 .009  .022 .009 3203. 3203.   4.5 0.150 413.5 0.1085   1.9    413.
              FILM THICKNESS IS 0 - TBAR=  0.4141E+03
              FILM THICKNESS IS 0 - TBAR=  0.4141E+03
   TBAR WAS CHANGED AT AXIAL LOC=    58.35 IN. TO TBAR= 434.0 F
   IN ORDER TO CONVERGE.
    62.35 414.6 .000  .000 .000 3364. 3364.   4.7 0.150 416.4 0.1032   1.0    434.
    63.95 416.2 .000  .000 .000 3401. 3401.   4.7 0.150 417.4 0.1022   0.9    434.
    --------------------------SECONDARY CHANNEL ENDS--------------------------
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  64.94 417.5 .000 .000 .000 3437. 3437.  4.8 0.269 418.1 0.0960  1.2   434.
  65.92 418.3 .000 .000 .000 3462. 3462.  4.8 0.387 418.7 0.1058  0.9   434.
  70.87 421.0 .000 .000 .000 3559. 3559.  4.9 0.412 421.2 0.1064  0.9   434.
  75.82 423.7 .000 .000 .000 3646. 3646.  5.0 0.437 424.0 0.1058  0.8   434.
  77.39 424.6 .000 .000 .000 3676. 3676.  5.0 0.338 425.1 0.0968  0.9   434.
  78.95 426.0 .000 .000 .000 3716. 3716.  5.1 0.238 426.0 0.0895  1.1   434.
  ----------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.55 426.0 .000 .000 .000 3715. 3715.  5.1 0.213 430.8 0.0895  1.1   434.
  ---------------------------------------------------------------------------
 100.50 434.8 .000 .000 .000 3884. 3884.  5.2 0.213 438.0 0.0907  1.1   434.


 MINIMUM TEMPERATURE=   434.755 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.790
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
     MELT POOL=   0.056170948 HRS


 TORQUE  =        6600.2 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =  0.951 HP
 MELTING      =  2.421 HP
 MIXING       =  0.767 HP
 FLIGHT CLEAR =  0.969 HP
 COMPRESSION  =  0.108 HP
 MIXING DEVICE=  0.028 HP
 PRESSURE FLUCTUATION=         100.01 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -54.3 TO     -30.0 BTU/MIN  OR
                                         -1.28 TO     -0.71 HP


 MAXIMUM SCREW SPEED,RPM:            50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:   5.2   7.9  10.5  13.1  15.7  18.3  20.9

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 !!!CAUTION!!!
 MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.435 INCHES
 YOUR FEED SECTION IS  0.437 INCHES DEEP
 CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
 OR MODIFY SCREW GEOMETRY!

 MAXIMUM PERMITTED COOLING HOLE DIAMETER IS  0.524 INCHES
 MAXIMUM PERMITTED CHANNEL DEPTH WITHOUT CORING SCREW IS  0.435 INCHES


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
      970.38       342.5        0.0531209
        3.50       339.0        0.2590871


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
       32.85       438.0        0.0887264
      742.73       319.0        0.0706424
 AT  50.00 RPM &   75.60 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  3884. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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4MBF05
    EXPERIMENT NUMBER     1.01        SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM       OUTPUT=    63.50 LB/HR       SOAK TIME=   0.00 SECONDS


    SECTION  LENGTH     CH.DEPTH         WIDTH       LEAD    BAR.    FLT.    NO OF    HOLE
       #      (IN)    SOLID  MELT   SOLID MELT               DIAM    WIDTH   HOLES    AREA
                      (IN)   (IN)   (IN)  (IN)      (IN)     (IN)    (IN)            (SQIN)
       1     19.800  0.437  0.000 1.368 0.000   1.750   1.750   0.300
       2     27.550  0.150  0.000 1.368 0.000   1.750   1.750   0.300
       3     16.600  0.150  0.450 1.234 1.234   3.450   1.750   0.300
       4      1.750  0.387  0.000 1.368 0.000   1.750   1.750   0.300
       5      9.900  0.437  0.000 1.368 0.000   1.750   1.750   0.300
       6      3.125  0.237  0.000 2.417 0.000   3.125   1.750   0.300
       7     16.600  0.213  0.000 2.622 0.000   3.450   1.750   0.300   1.000   0.914
       8      4.950  0.213  0.000 1.368 0.000   1.750   1.750   0.300

                                HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.33 PSI
       INCREASE HEIGHT TO =    186.01 IN. MAXIMUM PRESSURE =      0.75 PSI

                          SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      74.50 DEG.F      AND      SCREW =     231.50 DEG.F


     LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
         IN   DEG LB/CU.FT                 BARREL   SCREW     HP         PSI
    FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
    FRIS=     0.762736E-01 FRIB=     0.701721E-01
         1.00  32.8  21.10  0.070 0.076     75.5    231.5     0.00        0.30
         2.00  32.5  21.10  0.070 0.076     75.6    231.5     0.00        0.27
         3.00  32.2  21.10  0.070 0.076     75.9    231.5     0.00        0.25
         4.00  32.2  21.07  0.069 0.074     76.3    231.5     0.00        0.23
         5.00  32.1  21.07  0.066 0.074     78.3    231.5     0.00        0.21
         6.00  32.1  21.07  0.033 0.074     70.0    231.5     0.00        0.16
         7.00  32.2  21.04  0.029 0.073     70.0    231.5     0.00        0.12
         8.00  32.2  21.04  0.027 0.073     70.0    231.5     0.00        0.09
         9.00  32.2  21.04  0.025 0.073     70.0    231.5     0.00        0.06
        10.00  32.2  21.04  0.023 0.073     70.0    231.5     0.00        0.05
        11.00  32.2  21.04  0.022 0.073     70.0    231.5     0.00        0.03
        11.70  32.3  21.01  0.022 0.071    330.0    231.5     0.00        0.03
    ATTENTION - SOLIDS CONVEYING CONTROLS OPERATION
    REQUESTED OUTPUT IS UNATTAINABLE


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT   TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID         PSI        HP    IN   DEG F LB.SEC BTU/IN TEMP
                             REAL  FULL                        /SQ.IN  .MIN  DEG F
    14.28 349.9                 0.   427.      0.437 359.9 0.0855
    16.28 370.9                 0.   703.      0.437 390.1 0.0923
    17.28 350.2 .929  .929 .787  0.   706. 0.05 0.437 390.1 0.2329 -23.3   390.
    19.80 354.2 .858  .858 .726  0.   714. 0.18 0.437 391.7 0.2396  -2.5   390.
    23.88 367.7 .801  .801 .707  0.   726. 0.39 0.395 394.1 0.1665   1.2   393.
    28.88 381.8 .732  .732 .681  0.   845. 0.64 0.343 397.1 0.1450   0.8   397.
    33.88 390.7 .664  .664 .648  0.   982. 0.88 0.291 400.1 0.1324   0.4   400.
    38.88 394.8 .594  .594 .594  0.  1133.  1.1 0.238 403.0 0.1259  -1.2   402.
    43.88 396.9 .516  .516 .516  0.  1283.  1.3 0.186 405.8 0.1225  -1.9   405.
    47.35 398.3 .452  .452 .452  0.  1341.  1.5 0.150 407.9 0.1204  -2.7   407.
    ------------------------SECONDARY CHANNEL BEGINS--------------------------
    52.35 392.8 .224  .431 .224  0.  1470.  1.6 0.150 410.4 0.1274  -7.8   410.
    57.35 400.0 .082  .197 .082  0.  1643.  1.9 0.150 413.3 0.1211  -1.3   413.
    62.35 408.2 .018  .057 .018  0.  1771.  2.3 0.150 416.3 0.1139   1.3   416.
```

```
         FILM THICKNESS IS 0 - TBAR=  0.4168E+03
         FILM THICKNESS IS 0 - TBAR=  0.4168E+03
 63.95 410.5 .005 .019 .005    0. 1800.  2.6 0.150 417.3 0.1124  11.4   417.
 ------------------------SECONDARY CHANNEL ENDS-------------------------
 64.83 411.9 .004 .004 .004    0. 1827.  2.6 0.269 417.9 0.1050   3.2   418.
 65.70 413.0 .003 .003 .003    0. 1844.  2.7 0.387 418.4 0.1172   2.9   418.
         FILM THICKNESS IS 0 - TBAR=  0.4188E+03
         FILM THICKNESS IS 0 - TBAR=  0.4188E+03
 70.65 417.6 .000 .000 .000    0. 1922.  2.8 0.412 421.1 0.1169   0.6   419.
 75.60 421.3 .000 .000 .000    0. 1991.  2.8 0.437 423.9 0.1155   0.6   419.
 77.16 422.6 .000 .000 .000    0. 2015.  2.9 0.338 425.0 0.1039   0.6   419.
 78.72 424.1 .000 .000 .000    0. 2047.  2.9 0.238 425.9 0.0952   0.8   419.
 -----------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
 95.32 424.1 .000 .000 .000    0. 2046.  2.9 0.213 430.6 0.0952   0.8   419.
 ----------------------------------------------------------------------
100.27 433.2 .000 .000 .000    0. 2178.  3.0 0.213 437.8 0.0967   0.8   419.


MINIMUM TEMPERATURE=   433.194 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.806
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.049503591 HRS


TORQUE  =         3790.5 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.000 HP
MELTING      =   1.858 HP
MIXING       =   0.444 HP
FLIGHT CLEAR =   0.638 HP
COMPRESSION  =   0.056 HP
MIXING DEVICE=   0.017 HP
PRESSURE FLUCTUATION=        73.69 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=   -103.7 TO     -67.4 BTU/MIN  OR
                                        -2.44 TO     -1.59 HP


MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:    3.0   4.5   6.0   7.5   9.0  10.5  12.0

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


!!!CAUTION!!!
MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.404 INCHES
YOUR FEED SECTION IS  0.437 INCHES DEEP
CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
OR MODIFY SCREW GEOMETRY!
POWER CONSUMPTION EXCEEDS PRUDENT STRENGTH OF SCREW BY   12.95 %


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE         TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     572.39        373.9        0.0542351
        0.82       390.1        0.1814330


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE         TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
      25.01        437.8        0.0937841
     286.19        329.0        0.0968691
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
```

```
4MBF10
    EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

    N= 50.0 RPM       OUTPUT=   63.50 LB/HR       SOAK TIME=  0.00 SECONDS


    SECTION  LENGTH    CH.DEPTH       WIDTH       LEAD   BAR.    FLT.   NO OF    HOLE
       #      (IN)   SOLID  MELT  SOLID MELT              DIAM   WIDTH  HOLES    AREA
                      (IN)  (IN)   (IN)  (IN)     (IN)   (IN)    (IN)           (SQIN)
       1     19.800  0.437  0.000 1.368 0.000   1.750  1.750   0.300
       2     27.550  0.150  0.000 1.368 0.000   1.750  1.750   0.300
       3     16.600  0.150  0.450 1.234 1.234   3.450  1.750   0.300
       4      1.750  0.387  0.000 1.368 0.000   1.750  1.750   0.300
       5      9.900  0.437  0.000 1.368 0.000   1.750  1.750   0.300
       6      3.125  0.237  0.000 2.417 0.000   3.125  1.750   0.300
       7     16.600  0.213  0.000 2.622 0.000   3.450  1.750   0.300   1.000   0.914
       8      4.950  0.213  0.000 1.368 0.000   1.750  1.750   0.300

                            HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.29 PSI
       INCREASE HEIGHT TO =   124.00 IN. MAXIMUM PRESSURE =      0.50 PSI


                      SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =     116.50 DEG.F      AND      SCREW =     135.50 DEG.F


    LOCATION PHI    ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT               BARREL   SCREW     HP        PSI
   FRICTION COEFFICIENT ON BARREL SURFACE MUST BE HIGHER THAN ON SCREW SURFACE
   FRIS=     0.110451E+00 FRIB=     0.110404E+00
       1.00   32.9   21.08  0.107 0.110     126.7    135.5     0.00        0.26
       2.00   32.5   21.08  0.105 0.110     130.2    135.5     0.00        0.22
       3.00   32.2   21.08  0.104 0.110     131.5    135.5     0.00        0.19
       4.00   32.2   21.06  0.102 0.108     132.2    135.5     0.00        0.17
       5.00   32.2   21.06  0.111 0.108     105.1    135.5     0.00        0.15
       6.00   32.2   21.06  0.076 0.108      70.0    135.5     0.00        0.12
       7.00   32.3   21.03  0.073 0.107      70.0    135.5     0.00        0.09
       7.50   32.3   21.03  0.070 0.107      70.0    135.5     0.00        0.08
       7.69   32.3   21.03  0.071 0.107      70.0    135.5     0.00        0.07
       7.92   32.3   21.03  0.071 0.107      70.0    135.5     0.00        0.07
       8.17   32.3   21.03  0.071 0.107      70.0    135.5     0.00        0.06
       8.35   32.3   21.03  0.071 0.107     330.0    135.5     0.00        0.06
   ATTENTION - SOLIDS CONVEYING CONTROLS OPERATION
   REQUESTED OUTPUT IS UNATTAINABLE


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F      SOLID          PSI      HP    IN   DEG F LB.SEC BTU/IN TEMP
                                REAL  FULL                   /SQ.IN  .MIN  DEG F
    10.70 342.5                   0.   376.       0.437 349.0 0.0870
    12.70 342.5                   0.   778.       0.437 349.0 0.0985
    14.20 333.3 .951 .951 .827    0.   875. 0.08 0.437 349.0 0.2867 -17.8   349.
    18.80 345.6 .851 .851 .729    0.   919. 0.38 0.437 391.0 0.2581  -2.3   390.
    19.80 349.3 .823 .823 .706    0.   928. 0.43 0.437 391.5 0.2470  -2.4   391.
    24.80 370.0 .753 .753 .682    0.   975. 0.68 0.385 394.6 0.1628   1.0   394.
    29.80 383.6 .686 .686 .652    0. 1098. 0.92 0.333 397.7 0.1424   0.6   397.
    34.80 391.8 .618 .618 .616    0. 1237.  1.2 0.281 400.6 0.1309   0.1   400.
    39.80 394.7 .546 .546 .546    0. 1390.  1.4 0.229 403.5 0.1257  -1.4   403.
    44.80 397.2 .464 .464 .464    0. 1532.  1.6 0.177 406.3 0.1220  -2.1   406.
    47.35 398.4 .416 .416 .416    0. 1568.  1.7 0.150 407.9 0.1204  -2.8   407.
    ------------------------SECONDARY CHANNEL BEGINS-------------------------
    52.35 393.7 .199 .383 .199    0. 1694.  1.8 0.150 410.4 0.1265  -7.3   410.
    57.35 401.3 .068 .163 .068    0. 1866.  2.2 0.150 413.3 0.1199  -0.9   413.
    62.35 409.1 .012 .038 .012    0. 1994.  2.6 0.150 416.3 0.1132   1.6   416.
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         FILM THICKNESS IS 0 - TBAR=  0.4163E+03
         FILM THICKNESS IS 0 - TBAR=  0.4163E+03
  63.95 411.2 .001 .005 .001     0. 2024.  2.9 0.150 417.3 0.1118  -0.5   417.
  -----------------------SECONDARY CHANNEL ENDS--------------------------
  64.83 412.7 .000 .000 .000     0. 2050.  2.9 0.269 418.0 0.1044   0.7   418.
  65.70 413.8 .000 .000 .000     0. 2067.  2.9 0.387 418.5 0.1166   0.6   418.
  70.65 418.1 .000 .000 .000     0. 2145.  3.0 0.412 421.1 0.1165   0.6   418.
  75.60 421.6 .000 .000 .000     0. 2214.  3.1 0.437 423.9 0.1153   0.6   418.
  77.16 422.8 .000 .000 .000     0. 2237.  3.1 0.338 425.0 0.1038   0.6   418.
  78.72 424.3 .000 .000 .000     0. 2270.  3.1 0.238 425.9 0.0951   0.8   418.
  -----------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.32 424.3 .000 .000 .000     0. 2268.  3.1 0.213 430.6 0.0951   0.8   418.
  ----------------------------------------------------------------------
 100.27 433.3 .000 .000 .000     0. 2400.  3.2 0.213 437.8 0.0967   0.8   418.


 MINIMUM TEMPERATURE=   433.268 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.806
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=    0.052056838 HRS


 TORQUE  =        4052.7 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.000 HP
 MELTING      =   2.005 HP
 MIXING       =   0.461 HP
 FLIGHT CLEAR =   0.678 HP
 COMPRESSION  =   0.059 HP
 MIXING DEVICE=   0.017 HP
 PRESSURE FLUCTUATION=        73.66 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -94.9 TO      -58.8 BTU/MIN  OR
                                         -2.24 TO      -1.39 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    3.2   4.8   6.4   8.0   9.6  11.3  12.9

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 !!!CAUTION!!!
 MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.393 INCHES
 YOUR FEED SECTION IS  0.437 INCHES DEEP
 CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
 OR MODIFY SCREW GEOMETRY!
 POWER CONSUMPTION EXCEEDS PRUDENT STRENGTH OF SCREW BY   18.45 %


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
     533.99         372.6        0.0562162
       0.50         349.0        0.2586268


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
    1/SEC          DEG.F       LB.SEC/SQ.IN
      25.01         437.8        0.0937818
     150.90         329.0        0.1218715
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
 :
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4MBF15
    EXPERIMENT NUMBER     1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


    N= 50.0 RPM      OUTPUT=   63.50 LB/HR      SOAK TIME=  0.00 SECONDS



    SECTION  LENGTH    CH.DEPTH      WIDTH      LEAD   BAR.   FLT.   NO OF   HOLE
       #      (IN)   SOLID  MELT  SOLID MELT           DIAM   WIDTH  HOLES   AREA
                     (IN)   (IN)   (IN)  (IN)   (IN)   (IN)   (IN)          (SQIN)
       1     19.800  0.437  0.000 1.368 0.000  1.750  1.750  0.300
       2     27.550  0.150  0.000 1.368 0.000  1.750  1.750  0.300
       3     16.600  0.150  0.450 1.234 1.234  3.450  1.750  0.300
       4      1.750  0.387  0.000 1.368 0.000  1.750  1.750  0.300
       5      9.900  0.437  0.000 1.368 0.000  1.750  1.750  0.300
       6      3.125  0.237  0.000 2.417 0.000  3.125  1.750  0.300
       7     16.600  0.213  0.000 2.622 0.000  3.450  1.750  0.300  1.000  0.914
       8      4.950  0.213  0.000 1.368 0.000  1.750  1.750  0.300

                             HOPPER ANALYSIS

       ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

       SOLIDS HEIGHT =    36.00 IN. BASE PRESSURE =     0.21 PSI
       INCREASE HEIGHT TO =    64.55 IN. MAXIMUM PRESSURE =     0.26 PSI


                        SOLIDS CONVEYING ZONE ANALYSIS


    OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
    BARREL =      72.00 DEG.F      AND      SCREW =     229.00 DEG.F


     LOCATION PHI   ROBP   FRIB  FRIS TEMPERATURE,DEG F  POWER   PRESSURE
        IN    DEG LB/CU.FT                BARREL   SCREW     HP       PSI
        1.00  32.9  21.09  0.170 0.076     72.5    229.0    0.00      0.35
        2.00  32.3  21.15  0.174 0.079     72.7    229.0    0.00      0.57
        3.00  31.6  21.25  0.180 0.085     73.1    229.0    0.00      0.94
        4.00  30.9  21.44  0.192 0.094     73.0    229.0    0.00      1.57
        5.00  29.9  21.73  0.206 0.109     76.9    229.0    0.00      2.63
        6.00  29.0  22.01  0.184 0.123     70.0    229.0    0.00      3.57
        7.00  28.1  22.33  0.198 0.138     70.0    229.0    0.01      4.73
        8.00  27.0  22.73  0.213 0.155     70.0    229.0    0.01      6.16
        9.00  25.7  23.21  0.231 0.174     70.0    229.0    0.01      7.91
       10.00  24.4  23.79  0.251 0.194     70.0    229.0    0.02     10.03
       11.00  23.0  24.49  0.270 0.215     70.0    229.0    0.03     12.61
       11.70  21.9  25.07  0.284 0.228    330.0    229.0    0.04     14.79


     L    TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
     IN   DEG F     SOLID           PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                               REAL  FULL                    /SQ.IN  .MIN  DEG F
     14.28 349.9                428.  428.       0.437 359.9 0.0855
     16.28 370.9                704.  704.       0.437 390.1 0.0923
     17.28 350.2 .929 .929 .787  707.  707. 0.09 0.437 390.1 0.2329 -23.3    390.
     19.80 354.2 .858 .858 .726  715.  715. 0.22 0.437 391.7 0.2396  -2.5    390.
     23.88 367.7 .801 .801 .707  726.  726. 0.43 0.395 394.1 0.1665   1.2    393.
     28.88 381.8 .732 .732 .681  846.  846. 0.68 0.343 397.1 0.1450   0.8    397.
     33.88 390.7 .664 .664 .648  982.  982. 0.91 0.291 400.1 0.1324   0.4    400.
     38.88 394.8 .594 .594 .594 1134. 1134.  1.1 0.238 403.0 0.1259  -1.2    402.
     43.88 396.9 .516 .516 .516 1284. 1284.  1.4 0.186 405.8 0.1225  -1.9    405.
     47.35 398.3 .452 .452 .452 1342. 1342.  1.5 0.150 407.9 0.1204  -2.7    407.
     -------------------------SECONDARY CHANNEL BEGINS-------------------------
     52.35 392.8 .224 .431 .224 1471. 1471.  1.7 0.150 410.4 0.1274  -7.8    410.
     57.35 400.0 .082 .197 .082 1644. 1644.  2.0 0.150 413.3 0.1211  -1.3    413.
     62.35 408.2 .018 .057 .018 1772. 1772.  2.3 0.150 416.3 0.1139   1.3    416.
              FILM THICKNESS IS 0 - TBAR=  0.4168E+03
              FILM THICKNESS IS 0 - TBAR=  0.4168E+03
     63.95 410.5 .005 .019 .005 1801. 1801.  2.6 0.150 417.3 0.1124  11.4    417.
     --------------------------SECONDARY CHANNEL ENDS-------------------------
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  64.83 411.9 .004 .004 .004 1827. 1827.  2.7 0.269 417.9 0.1050   3.2   418.
  65.70 413.0 .003 .003 .003 1845. 1845.  2.7 0.387 418.4 0.1172   2.9   418.
        FILM THICKNESS IS 0 - TBAR=  0.4188E+03
        FILM THICKNESS IS 0 - TBAR=  0.4188E+03 .
  70.65 417.6 .000 .000 .000 1923. 1923.  2.8 0.412 421.1 0.1169   0.6   419.
  75.60 421.3 .000 .000 .000 1992. 1992.  2.9 0.437 423.9 0.1155   0.6   419.
  77.16 422.6 .000 .000 .000 2016. 2016.  2.9 0.338 425.0 0.1039   0.6   419.
  78.72 424.1 .000 .000 .000 2048. 2048.  2.9 0.238 425.9 0.0952   0.8   419.
  ---------------------------------------------------------------------------
              FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.32 424.1 .000 .000 .000 2047. 2047.  2.9 0.213 430.6 0.0952   0.8   419.
  --------------------------------------------------------------------------
 100.27 433.2 .000 .000 .000 2179. 2179.  3.0 0.213 437.8 0.0967   0.8   419.


 MINIMUM TEMPERATURE=   433.194 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.806
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.049503591 HRS


 TORQUE  =        3834.8 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.035 HP
 MELTING      =   1.858 HP
 MIXING       =   0.444 HP
 FLIGHT CLEAR =   0.638 HP
 COMPRESSION  =   0.056 HP
 MIXING DEVICE=   0.017 HP
 PRESSURE FLUCTUATION=          73.69 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=   -102.2 TO      -67.4 BTU/MIN  OR
                                         -2.41 TO      -1.59 HP


 MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:    3.0   4.6   6.1   7.6   9.1  10.6  12.2

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 !!!CAUTION!!!
 MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.402 INCHES
 YOUR FEED SECTION IS  0.437 INCHES DEEP
 CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
 OF MODIFY SCREW GEOMETRY!
 POWER CONSUMPTION EXCEEDS PRUDENT STRENGTH OF SCREW BY   13.89 %


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
      572.39       373.9       0.0542351
        0.82       390.1       0.1814330


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE       TEMP.       VISCOSITY
     1/SEC         DEG.F      LB.SEC/SQ.IN
       25.01       437.8       0.0937841
      286.19       329.0       0.0968691
AT  50.00 RPM &   63.50 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  2179. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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4MBF20
   EXPERIMENT NUMBER    1.00       SCIENTIFIC PROCESS & RESEARCH, INC.


   N= 50.0 RPM      OUTPUT=   63.50 LB/HR      SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH    CH.DEPTH       WIDTH      LEAD   BAR.    FLT.   NO OF   HOLE
      #      (IN)    SOLID  MELT  SOLID MELT           DIAM   WIDTH   HOLES   AREA
                     (IN)   (IN)   (IN)  (IN)   (IN)   (IN)    (IN)          (SQIN)
     1      19.800  0.437   0.000 1.368 0.000  1.750  1.750  0.300
     2      27.550  0.150   0.000 1.368 0.000  1.750  1.750  0.300
     3      16.600  0.150   0.450 1.234 1.234  3.450  1.750  0.300
     4       1.750  0.387   0.000 1.368 0.000  1.750  1.750  0.300
     5       9.900  0.437   0.000 1.368 0.000  1.750  1.750  0.300
     6       3.125  0.237   0.000 2.417 0.000  3.125  1.750  0.300
     7      16.600  0.213   0.000 2.622 0.000  3.450  1.750  0.300  1.000  0.914
     8       4.950  0.213   0.000 1.368 0.000  1.750  1.750  0.300

                          HOPPER ANALYSIS

      ATTENTION - SOLIDS HEIGHT IN HOPPER IS LOW !

      SOLIDS HEIGHT =     36.00 IN. BASE PRESSURE =      0.14 PSI
      INCREASE HEIGHT TO =     37.27 IN. MAXIMUM PRESSURE =      0.15 PSI

                    SOLIDS CONVEYING ZONE ANALYSIS


   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      72.50 DEG.F      AND     SCREW =     229.00 DEG.F


    LOCATION PHI    ROBP    FRIB   FRIS TEMPERATURE,DEG F  POWER    PRESSURE
       IN    DEG LB/CU.FT               BARREL    SCREW     HP        PSI
      1.00   32.9   21.07   0.218 0.075    72.7    229.0    0.00       0.31
      2.00   32.2   21.17   0.225 0.081    73.1    229.0    0.00       0.69
      3.00   31.1   21.42   0.241 0.094    73.3    229.0    0.00       1.53
      4.00   29.2   21.95   0.272 0.120    73.2    229.0    0.00       3.46
      5.00   25.8   23.19   0.327 0.173    77.7    229.0    0.01       8.05
      6.00   21.9   25.06   0.347 0.228    70.0    229.0    0.02      15.04
      6.60   18.8   27.05   0.369 0.250    70.0    229.0    0.03      22.47
      7.10   15.8   29.75   0.365 0.245    70.0    229.0    0.04      33.36
      7.60   12.2   34.48   0.365 0.242    70.0    229.0    0.07      53.79
      8.10    8.8   42.76   0.366 0.240    70.0    229.0    0.11      94.45
      8.60    6.1   55.94   0.366 0.237    70.0    229.0    0.18     178.26
      9.10    4.4   72.23   0.365 0.235    70.0    229.0    0.32     352.85
      9.35    3.9   79.23   0.366 0.234   330.0    229.0    0.43     501.10


   L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
   IN    DEG F     SOLID          PSI      HP    IN  DEG F LB.SEC BTU/IN TEMP
                              REAL  FULL                   /SQ.IN  .MIN  DEG F
   11.93 342.5                1106. 1106.       0.437 349.0 0.0871
   13.93 343.7                1493. 1493.       0.437 350.9 0.0986
   14.93 333.9 .951 .951 .827 1503. 1503.  0.5 0.437 350.9 0.2842 -18.0   351.
   19.53 346.1 .850 .850 .729 1550. 1550.  0.8 0.437 391.4 0.2566  -2.4   391.
   19.80 347.2 .842 .842 .722 1552. 1552.  0.8 0.437 391.7 0.2508  -2.5   391.
   24.80 368.8 .773 .773 .699 1603. 1603.  1.1 0.385 394.6 0.1645   1.1   394.
   29.80 383.1 .705 .705 .671 1726. 1726.  1.3 0.333 397.7 0.1429   0.7   397.
   34.80 391.7 .638 .638 .636 1866. 1866.  1.6 0.281 400.6 0.1310   0.2   400.
   39.80 394.5 .566 .566 .566 2020. 2020.  1.8 0.229 403.5 0.1258  -1.4   403.
   44.80 397.1 .485 .485 .485 2162. 2162.  2.0 0.177 406.3 0.1221  -2.1   406.
   47.35 398.2 .437 .437 .437 2198. 2198.  2.1 0.150 407.9 0.1205  -2.7   407.
   ------------------------SECONDARY CHANNEL BEGINS-------------------------
   52.35 393.2 .213 .411 .213 2326. 2326.  2.3 0.150 410.4 0.1270  -7.6   410.
   57.35 400.3 .076 .184 .076 2499. 2499.  2.6 0.150 413.3 0.1208  -1.1   413.
   62.35 408.5 .016 .049 .016 2627. 2627.  2.9 0.150 416.3 0.1137   1.4   416.
           FILM THICKNESS IS 0 - TBAR=  0.4168E+03
           FILM THICKNESS IS 0 - TBAR=  0.4168E+03
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  63.95 410.7 .004 .014 .004 2656. 2656.  3.2 0.150 417.3 0.1122  11.5   417.
  --------------------------SECONDARY CHANNEL ENDS--------------------------
  64.83 412.1 .003 .003 .003 2683. 2683.  3.3 0.269 417.9 0.1048   3.2   418.
  65.70 413.2 .002 .002 .002 2700. 2700.  3.3 0.387 418.5 0.1171   0.3   418.
  70.65 417.8 .000 .000 .000 2778. 2778.  3.4 0.412 421.1 0.1168   0.6   419.
  75.60 421.4 .000 .000 .000 2847. 2847.  3.4 0.437 423.9 0.1154   0.6   419.
  77.16 422.6 .000 .000 .000 2871. 2871.  3.5 0.338 425.0 0.1039   0.6   419.
  78.72 424.2 .000 .000 .000 2903. 2903.  3.5 0.238 425.9 0.0951   0.8   419.
  --------------------------------------------------------------------------
             FLUTED SECTION WITH  1. PAIRS OF FLUTES
  95.32 424.2 .000 .000 .000 2902. 2902.  3.5 0.213 430.6 0.0951   0.8   419.
  -------------------------------------------------------------------------
 100.27 433.2 .000 .000 .000 3034. 3034.  3.6 0.213 437.8 0.0967   0.8   419.


 MINIMUM TEMPERATURE=   433.214 DEG F
 TEMP FLUCTUATION=        0.000 DEG F
 FLOW INDEX (N)=          0.806
 GRATIO INJ.=             0.000
 RESIDENCE TIME:
      MELT POOL=   0.051591475 HRS


 TORQUE  =          4548.9 INCH.POUNDS
 POWER BREAK-DOWN:
 SOLIDS CONV. =   0.434 HP
 MELTING      =   1.977 HP
 MIXING       =   0.458 HP
 FLIGHT CLEAR =   0.670 HP
 COMPRESSION  =   0.058 HP
 MIXING DEVICE=   0.017 HP
 PRESSURE FLUCTUATION=         73.68 PSI/CYCLE
 TOTAL CONDUCTED HEAT THROUGH BARREL=    -78.2 TO      -60.9 BTU/MIN  OR
                                         -1.84 TO      -1.44 HP


 MAXIMUM SCREW SPEED,RPM:              50.0  75.0 100.0 125.0 150.0 175.0 200.0
 POWER CONSUMPTION, % OF AVAILABLE:     3.6   5.4   7.2   9.0  10.8  12.6  14.4

 STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


 !!!CAUTION!!!
 MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.375 INCHES
 YOUR FEED SECTION IS  0.437 INCHES DEEP
 CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
 OR MODIFY SCREW GEOMETRY!
 POWER CONSUMPTION EXCEEDS PRUDENT STRENGTH OF SCREW BY   28.30 %


  VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
      863.73        342.5        0.0559446
        0.49        350.9        0.2542148


  VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
  SHEAR RATE        TEMP.        VISCOSITY
     1/SEC          DEG.F       LB.SEC/SQ.IN
       25.01        437.8        0.0937835
      150.73        329.0        0.1219206
 AT  50.00 RPM &    63.50 LB/HR PRODUCTION RATE
 HEAD PRESSURE IS  3034. PSI.

 FOR MORE DETAIL
 SELECT ONE OF THE FOLLOWING:

 1 - Data Analysis
 2 - Run New Simulation
 3 - EXIT
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4MBF25
   EXPERIMENT NUMBER     1.00        SCIENTIFIC PROCESS & RESEARCH, INC.

   N= 50.0 RPM       OUTPUT=   63.50 LB/HR       SOAK TIME=  0.00 SECONDS


   SECTION  LENGTH     CH.DEPTH        WIDTH      LEAD    BAR.    FLT.    NO OF    HOLE
      #      (IN)    SOLID  MELT   SOLID MELT             DIAM    WIDTH   HOLES    AREA
                     (IN)   (IN)    (IN)  (IN)    (IN)    (IN)     (IN)           (SQIN)
      1     19.800  0.437  0.000 1.368 0.000   1.750   1.750   0.300
      2     27.550  0.150  0.000 1.368 0.000   1.750   1.750   0.300
      3     16.600  0.150  0.450 1.234 1.234   3.450   1.750   0.300
      4      1.750  0.387  0.000 1.368 0.000   1.750   1.750   0.300
      5      9.900  0.437  0.000 1.368 0.000   1.750   1.750   0.300
      6      3.125  0.237  0.000 2.417 0.000   3.125   1.750   0.300
      7     16.600  0.213  0.000 2.622 0.000   3.450   1.750   0.300   1.000   0.914
      8      4.950  0.213  0.000 1.368 0.000   1.750   1.750   0.300

                             HOPPER ANALYSIS

      ATTENTION - KEEP SOLIDS  LEVEL IN HOPPER ABOVE    24.47 IN.
      BASE PRESSURE =       0.10 PSI

                      SOLIDS CONVEYING ZONE ANALYSIS

   OPTIMUM SURFACE TEMPERATURES FOR SOLIDS CONVEYING:
   BARREL =      72.50 DEG.F      AND      SCREW =     229.00 DEG.F

    LOCATION PHI    ROBP   FRIB   FRIS TEMPERATURE,DEG F  POWER     PRESSURE
       IN    DEG LB/CU.FT                 BARREL    SCREW     HP         PSI
      1.00   33.0  21.06  0.268 0.074      72.7    229.0     0.00        0.29
      2.00   32.0  21.23  0.279 0.084      73.1    229.0     0.00        0.86
      3.00   30.1  21.70  0.307 0.108      73.3    229.0     0.00        2.58
      4.00   25.9  23.16  0.383 0.172      74.2    229.0     0.01        8.08
      4.55   21.5  25.26  0.455 0.232      74.6    229.0     0.01       15.81
      5.05   16.8  28.76  0.422 0.245     265.5    229.0     0.03       29.54
      5.55   11.8  35.27  0.421 0.242     276.5    229.0     0.05       57.90
      6.05    7.3  48.55  0.422 0.238     286.7    229.0     0.11      129.05
      6.55    4.6  69.37  0.419 0.235     300.5    229.0     0.24      314.71
      7.05    3.6  84.89  0.414 0.234     326.6    229.0     0.56      791.44
      7.15    3.5  86.10  0.414 0.234     330.0    229.0     0.67      950.84


    L     TOUT  X/W  X/W GRATIO PRESSURE  POWER  HOUT  TBAR  TVISC D.HEAT  FILM
    IN    DEG F    SOLID             PSI       HP    IN  DEG F LB.SEC BTU/IN TEMP
                                  REAL  FULL                   /SQ.IN  .MIN  DEG F
     9.73 342.5                   1554. 1554.       0.437 349.0 0.0870
    11.70 342.5                   1931. 1931.       0.437 349.0 0.0992
    12.70 333.2 .952 .952 .829 1929. 1929.  0.7 0.437 349.0 0.2868 -17.7    349.
    17.30 345.4 .852 .852 .731 1921. 1921.  1.0 0.437 390.1 0.2587  -2.3    390.
    19.80 353.8 .784 .784 .673 1916. 1916.  1.2 0.437 391.7 0.2284  -2.6    391.
    24.80 372.7 .714 .714 .647 2023. 2023.  1.4 0.385 394.7 0.1593   0.8    394.
    29.80 384.8 .646 .646 .616 2144. 2144.  1.6 0.333 397.7 0.1410   0.4    397.
    34.80 392.2 .578 .578 .577 2283. 2283.  1.9 0.281 400.6 0.1305   0.0    400.
    39.80 395.0 .505 .505 .505 2435. 2435.  2.1 0.229 403.5 0.1255  -1.5    403.
    44.80 397.5 .423 .423 .423 2575. 2575.  2.3 0.177 406.3 0.1219  -2.2    406.
    47.35 398.5 .372 .372 .372 2610. 2610.  2.4 0.150 407.9 0.1204  -3.1    407.
    ------------------------SECONDARY CHANNEL BEGINS------------------------
    52.35 394.6 .169 .326 .169 2734. 2734.  2.5 0.150 410.5 0.1255  -6.6    410.
    57.35 402.7 .052 .124 .052 2905. 2905.  2.9 0.150 413.4 0.1185  -0.4    413.
            FILM THICKNESS IS 0 - TBAR=  0.4157E+03
            FILM THICKNESS IS 0 - TBAR=  0.4157E+03
    62.35 410.0 .002 .007 .002 3033. 3033.  3.5 0.150 416.3 0.1124  11.3    416.
    63.95 412.2 .000 .000 .000 3062. 3062.  3.6 0.150 417.3 0.1110   0.7    417.
    -------------------------SECONDARY CHANNEL ENDS-------------------------
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 64.83 413.7 .000 .000 .000 3088. 3088.  3.6 0.269 418.0 0.1038   0.8   417.
 65.70 414.7 .000 .000 .000 3105. 3105.  3.6 0.387 418.5 0.1159   0.6   417.
 70.65 418.6 .000 .000 .000 3183. 3183.  3.7 0.412 421.1 0.1161   0.6   417.
 75.60 421.8 .000 .000 .000 3251. 3251.  3.7 0.437 423.9 0.1151   0.6   417.
 77.16 423.0 .000 .000 .000 3275. 3275.  3.8 0.338 425.0 0.1037   0.6   417.
 78.72 424.4 .000 .000 .000 3307. 3307.  3.8 0.238 425.9 0.0950   0.8   417.
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             FLUTED SECTION WITH  1. PAIRS OF FLUTES
 95.32 424.4 .000 .000 .000 3306. 3306.  3.8 0.213 430.7 0.0950   0.8   417.
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100.27 433.3 .000 .000 .000 3438. 3438.  3.9 0.213 437.8 0.0966   0.8   417.


MINIMUM TEMPERATURE=   433.345 DEG F
TEMP FLUCTUATION=        0.000 DEG F
FLOW INDEX (N)=          0.806
GRATIO INJ.=             0.000
RESIDENCE TIME:
     MELT POOL=   0.053090241 HRS


TORQUE  =        4915.9 INCH.POUNDS
POWER BREAK-DOWN:
SOLIDS CONV. =   0.667 HP
MELTING      =   2.001 HP
MIXING       =   0.467 HP
FLIGHT CLEAR =   0.694 HP
COMPRESSION  =   0.060 HP
MIXING DEVICE=   0.017 HP
PRESSURE FLUCTUATION=        73.64 PSI/CYCLE
TOTAL CONDUCTED HEAT THROUGH BARREL=    -65.9 TO     -57.5 BTU/MIN  OR
                                        -1.55 TO     -1.35 HP


MAXIMUM SCREW SPEED,RPM:             50.0  75.0 100.0 125.0 150.0 175.0 200.0
POWER CONSUMPTION, % OF AVAILABLE:    3.9   5.8   7.8   9.7  11.7  13.6  15.6

STRENGTH ANALYSIS OF YOUR SCREW (4140STEE):


!!!CAUTION!!!
MAXIMUM PERMISSIBLE CHANNEL DEPTH FOR SAFE SCREW IS: 0.362 INCHES
YOUR FEED SECTION IS  0.437 INCHES DEEP
CHECK RESIN VISCOSITY, SOURCE OF POWER CONSUMPTION
OR MODIFY SCREW GEOMETRY!
POWER CONSUMPTION EXCEEDS PRUDENT STRENGTH OF SCREW BY   35.15 %


 VISCOSITY WAS CALCULATED IN THE FOLLOWING SHEAR RATE RANGE
 SHEAR RATE       TEMP.       VISCOSITY
    1/SEC         DEG.F      LB.SEC/SQ.IN
    877.20        342.5       0.0555635
      0.48        349.0       0.2586268


 VISCOSITY WAS CALCULATED IN THE FOLLOWING TEMPERATURE RANGE
 SHEAR RATE       TEMP.       VISCOSITY
    1/SEC         DEG.F      LB.SEC/SQ.IN
     25.02        437.8       0.0937795
    154.31        329.0       0.1209496
AT  50.00 RPM &   63.50 LB/HR PRODUCTION RATE
HEAD PRESSURE IS  3438. PSI.

FOR MORE DETAIL
SELECT ONE OF THE FOLLOWING:

1 - Data Analysis
2 - Run New Simulation
3 - EXIT
:
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