Entrepreneurial Guide to Starting Up A Plastics Extrusion Business

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Abstract:

Due to the constant demand of extruded products on the market, this thesis is written to analyze guidelines prior to constructing an extrusion line. Entrepreneurs as clients are given an idea about which machineries are needed and the placement of every single one of them in the production line. The research was done in Finnish scale but dedicated to developing countries needing start-up in extrusion processes. The thesis is intended to give entrepreneurs an idea of how to set up various scales of extrusion line.

Literature reviews consisted of the core theory behind extrusion processing, different types of extruders with single screw being the most common, different sizes of extruders which serves different production capacity outputs generated, and general products of extrusion obtained in Finnish scale with the list of companies manufacturing them and the type of products manufactured. Excursions were held to a couple of big industries in order to get data samples of production line assembly and products generated.

As a methodology, the amount of plastic content of each extrusion products has been calculated to find the most suitable production capacity or size of the extrusion machine. Validation of extruder's production capacity formula done in the manufacturing laboratory. From the validated formula, the barrel diameter and power requirement of the suitable extruder were obtained. The key factors from the production capacity calculation using the energy formula are heat capacity of the plastic material and the temperature rise from feed to extrudate.

Result suggests that plastic film is the most generated product of the extrusion process. The most commonly manufactured products on the market are those with continous demand but simpler die design.
The hardest task of this thesis was to collect prices of extruders and extrusion lines. Order has to be made first in order to inquire prices.

Keywords:	Extruders, Single screw extruders, Extrusion line, Production capacity formula, Film blown extrusion, Distributing agent, Barrel diameter, Heat capacity
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Tiivistelmä:
Jatkuvan muovipursotettujen tuotteiden tarpeen takia tässä opinnäytetyössä analysoidaan ohjeita pursotuslinjaston perustamiseen. Muovipursotuslinjaston laitteet kuvataan ja niiden paikka linjastossa selvennetään. Selvitystyö tehtiin Suomen mittakaavassa, mutta on tarkoitettu auttamaan kehittyvien maiden pursotuslaitosten perustamista. Opinnäytetyön tavoitteena on opastaa yrittäjiä erilaisten muovipursotuslinjastojen perustamisessa.

Kirjallisuuskatsauksissa perehdyttiin pursotustekniikan teoriaan, erilaisiin pursotuslaitteisiin kuten yksiruuvipursottimeen, eri kokoisiin pursottimiin, sekä erilaisiin pursotustekniikalla tehtyihin tuotteisiin. Muutamaan suureen pursotustekniikkaa käyttävään yritykseen tehtiin yritysvierailut.

Erilaisten muovipursotustuotteiden muovimäärät laskettiin, jotta optimaalinen pursotuslaitteen koko saataisiin selville. Lisäksi pursotuslaitteen kapasiteettia kuvaava yhtälö validoitiin laboratoriossa. Validoidusta yhtälöstä saatiin sylinterin halkaisija sekä tehovaatimus. Olennaiset termit kapasiteetin laskemisessa ovat muovimateriaalin ominaislämpökapasiteetti, sekä lämpötilaero syötöstä loppumuotoon.

Tulokset viittaavat siihen, että muovikalvot ovat yleisin pursotettu tuote. Yleisimmät valmistetut tuotteet ovat niitä, joille on jatkuva tarve markkinoilla, sekä joiden pursotusmuotti on yksinkertainen.

Haastavin osa opinnäytetyön tekoa oli pursottimien sekä pursotuslinjastojen hintojen selvittäminen. Tilauksen on oltava tehty ennen kuin hintoja suostutaan kertomaan.

Avainsanat:	Pursottimet, Yksiruuvipursotin, Pursotuslinjasto, Tuotantokapasiteettiyhtälö, Kalvopuhalluspursotus, Maahantuoja-agentti, Sylinterin halkaisija, Lämpökapasiteetti
Sivumäärä:	70
Kieli:	Englanti
Hyväksymispäivämäärä:	

CONTENTS

Figures

Tables

List of Equations

List of Abbreviations

ABS:	Acrylonitrile butadiene styrene
CE-marked:	CE (Conformite Europeene or European Conformity) marking
E/VAL (EVOH):	Ethylene vinyl alcohol.
HDPE:	High-density polyethylene
LDPE:	Low-density polyethylene
L/D-ratio:	Screw length is referenced to its diameter
OEM:	Original equipment manufacturer (Ericsson, 2012)
OPP:	Oriented polypropylene
PA:	Polyamide
PE:	Polyethene/ Polyethylene
PE-LD:	Low-density polyethylene (also commonly called LDPE)
PE-X:	Cross-linked polyethylene
PERG:	Recycled PE temperature (Ruhonen, 2012)
PET:	Polyethylene terephthalate
PP:	Polypropylene/ Polypropene
PS:	Polystyrene
PTFE:	Polytetrafluoroethylene
PVC:	Polyvinyl chloride
RPM:	Revolutions per minute
TPE:	Thermoplastic Elastomer
UMHWPE:	Ultrahigh molecular weight polyethylene

List of Symbols

1 Btu: British thermal unit. 1 Btu = 1055 J

Cp: Heat capacity [$\frac{Btu}{lb \times Fahrenheit}$] or [J/Kg.K]

D: Diameter [mm]

ε: Error fraction [%]

1 Fahrenheit: 255.93 Kelvin

HP: Power [Horsepower]. 1 Hp = 735,5 W

1 inch: 25,40 mm

1 lb: 0,4526 kg

P: Power [Watt]

Qe: Extruder capacity. Imperial unit [lb/hour]. Metric unit [kg/h]

ΔT: Temperature rise from feed to extrudate [Fahrenheit or Kelvin]

w: Width [m]

xo: Initial width [m]

n: Increase within width [m]

FOREWORD

Special gratitude is expressed to my supervisor, Henry Clay Ericsson for recommending this thesis topic and for the support throughout my entire study time at Arcada. As well as other Arcada lecturers in Plastics Technology and International Business programme such as Mathew Vihtonen, Mariann Holmberg, Renee Herrmann, Marko Voho, Karis Badal Durbo and many more for the priceless enlightenment.

I would also like to have this opportunity to thank PET-Klubben especially Rasmus Pinomaa and Mikko Ketonen for the hard work arranging the unforgettable excursion to K-Messe plastics fair, Düsseldorf, 2010. Without my presence at the fair, creating compilation of companies providing extruders would have been much more challenging.

My sincere gratitude also goes to my parents for the endless amount of mental and financial support. My fellow plastics technology, plastteknik and industrial management programme friends for the companionship and support during my entire study time. Last but not least, to my dear husband Mikko Auvinen for the mentorship during the most challenging thesis completion.

1 INTRODUCTION

1.1 Background

The thesis is written to provide entrepreneurs with guidelines on building up an extrusion line. Observations were made to the Finnish market of extruders and the same methods can be furthermore implemented to developing countries. It would be considered useful as a read-on prior to starting up a business that is related to extrusion processing.

The thesis describes different types of extruders, production capacity generated by different sizes of extruders and different products generated out of the extrusion process. Depending on the entrepreneurs' desire, they can plan what to produce, the market size and how profitable the product might be, what is the suitable annual output of the production line, which suitable extruder to employ, where and how to obtain the extruder, the power requirement needed for the machinery and the work shift system of the extrusion line that can be further opted to estimate the total cost of an extrusion plant.

This thesis provides a guideline to minimize the costs of an extrusion plant by taking into account different companies providing the machines and their distance to location of manufacturing.

The thesis furthermore provides entrepreneurs with a database of extruders. The scope is to gather companies making single screw extruders as well as twin and multiple screw extruders to make the plant designing more accessible.

1.2 Objectives

- Types of extrusion processes and the right machinery required. Providing the entrepreneurs with know-how on different processes of extrusions depending on the form and amount of the end products in demand. The thesis concentrates on different production capacity of extruders in the market rather than different modes of operation in extrusion processes and the end products.

- Finding out extruded products in Finland that generates the most annual profit in order to take example on their business idea and implement it to new possible designs of an extrusion line.
- Finding out a method to link between the required production capacities of an extruder, the generic barrel size suitable for the operation and the total power consumption needed.

1.3 Method

This thesis provides entrepreneurs with chart of commonly extruded products in Finland along with the list of manufacturers, a chart of commonly extruded products in Finland, a graph of production capacity by machine manufacturers, annual production estimation of commonly extruded products, rough estimate of investment made for a plant and a chart comparing the annual production capacity to the barrel parameter throughout the formula that has been validated through an experiment done in Arcada’s manufacturing laboratory.

Calculations of production capacity depending on the barrel diameter and energy consumed are also being listed in the thesis. Furthermore, observation of the degree of precision that the formula gives is also assessed with a real-life example of extrusion machine in the manufacturing laboratory.

Total plant investment of an extrusion plant has been gathered by plant visit to the companies asking for production capacity of their machines and up-to-date prices whilst such information is not found on their webpage due to industry confidentiality. The main function of this method is giving entrepreneurs an idea how much it costs to prepare a production line.

2 LITERATURE REVIEW

Literature survey provides background information of each type and size of extruders and how their difference and design complexity of the components can affect the production capacity generated. Literature survey also provides entrepreneurs with general products that can be obtained from extrusion process, giving out ideas on which machinery should be chosen for each method of production.

The literature review contains general review of extrusion theory involving types of machinery presented in industrial scale extrusion lines. This chapter lists different modes of extrusion and general products of an extrusion process. This chapter provides entrepreneurs with know-how on different processes of extrusions depending on the form of the end products.

2.1 Extrusion Theory

The extruder can be considered as one of the core piece of machinery in the polymer processing industry. To extrude means to thrust out a polymer material in any kind of form with a desired cross section through a die. The shape of material will depend on the die opening, and it will change to some extent as it exits from the die. The extruded output is commonly referred to as the extrudate. (Rauwendaal, 2001, p. 1)

Some resins in a form of pellets, flake or powder need to be vacuum-dried before extruding to eliminate degradation of the polymeric bonds due to moisture. Other resins that don’t require drying normally may still need to be dried if they are stored in a cold temperature and brought into a warmer processing plant.

Once the resins or resins mixed with masterbatch and additives are already dried, the formula is fed to the hopper and undergo three ultimate zones of extruder such as melting, mixing and metering. After the extruder exists the die, the product is cooled in either water bath or vacuum cooler and pulled at a constant velocity to obtain constant cross sectional area.

After those pulling steps are done, comes the secondary operations such as flame treatment, printing, cutting and annealing. The logistics such as inspection, packing and shipping come ideally after the processing is done.
(Harold, 2005, p. 1)

Procurement flowchart of an extrusion process is an industrial logic that is used to describe the early steps of production, it as early as appointing the die designer and the person in charge of choosing the machines for extrusion processes. (Ericsson, 2012) Figure 1 gives a clear illustration to the movement of a possible extruded product or prototype in an industry from the early form of granules until the shipment of the extruded products.

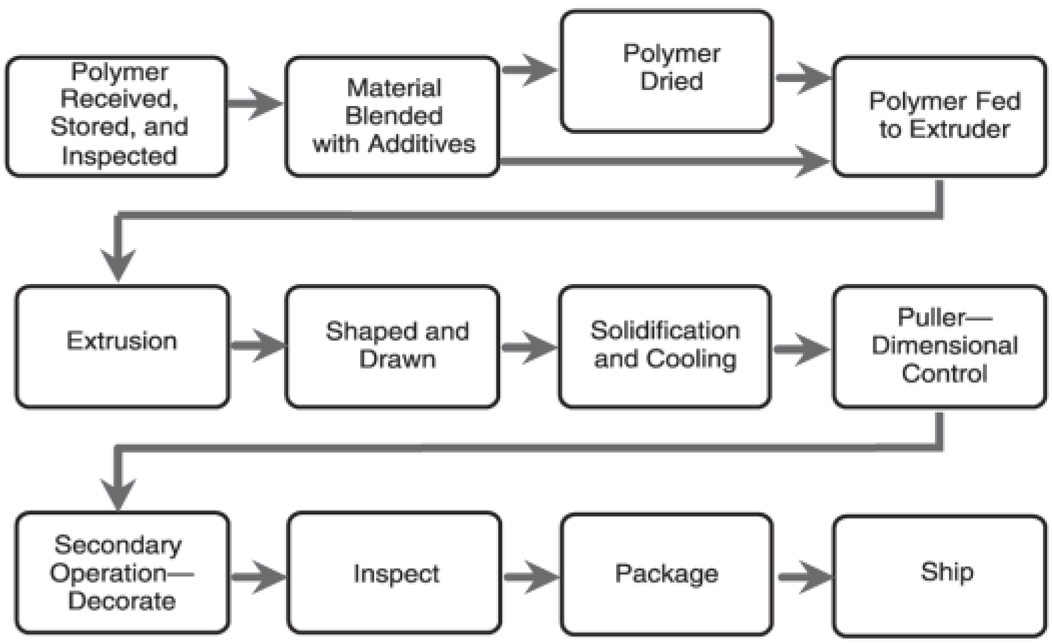

Figure 1 - Basic extrusion process schematic (Harold, 2005, p. 1)

Extrusion or extrusion molding is used in Finland more generally compared to injection molding. Extrusion systems normally use both single and twin screw extruders. Single screw extruders are used normally in common thermoplastic processing, whereas twin screw extruders are primarily used in PVC extrusion. Extrusion, similar to injection molding, has a rotating screw inside of the barrel which helps plasticizing process with the help of pressure, friction and heat resulting from the barrel's wall. The screw's rotating gap-volume is decreased towards the tip and it takes time for the plasticized raw material to rise its' pressure. The higher rotation speed that screw has, the higher friction there would be in the granules. Barrel temperature causing heat capacity can be controlled. The screws' most important parameters are its' diameter and its length-diameter ratio (L/D). (Järvinen, 2008, p. 175)

Commonly extruded materials are metals, plastics, clays, ceramics, food products, etc. In this thesis, we will concentrate on polymer extrusion. Polymers can be divided into three subgroups:

1) Thermoplastic materials soften when they are heated, and solidify when they are cooled. The material is thus considered to be price efficient, thermoplastics can be reground and recycled if the extrudate does not meet with specifications. The basic chemical structure of a thermoplastic does not change significantly as a result of extrusion process. Some of the most common thermoplastic materials are PE, PVC, PS, PP, PET and ABS.

2) Thermosets undergo a crosslinking reaction when the temperature is raised above a certain temperature. The crosslinking bonds the polymer molecules together to form a three-dimensional network that remains intact when the temperature is reduced again. Crosslinking causes an irreversible change to the materials which makes themosets impossible to recycle as thermoplastic materials. Some common examples of thermosets are bakelite, epoxy resins and polyimides.

3) Elastomers or generally known as rubbers are materials that are very much capable of large deformations with the material behaving in highly elastic manner, thus possessing high tensile and shear strength. When an elastomer's deformation force is removed, the material is completely recovered to its initial state. Some common examples of elastomers on the market are polyisoprene (both natural and synthetic), polybutadiene and neoprene.

(Crawford, 1998, pp. 3 - 6) (Rauwendaal, 2001, p. 1)

Polymers, unlike other materials are extruded in a molten state, however, some applications require solid-state extrusion of polymers. Methods of extrusion which includes different state of materials:

1) Plasticating extrusion is a method by which a polymer is fed into the extruder in a solid state and the material is melted as it is conveyed by the extruder screw from the feed port to the die.

2) Melt fed extrusion is a method by which a molten polymer is fed into the extruder. In a melt fed extrusion, the extruder acts purely as a pump, developing the pressure necessary to force the polymer melt through the die.

One can also divide types of extruders depending on the batch size desired:

1) Continuous extruders are capable of developing a steady, continuous flow of material. They utilize a rotating member for transporting the material.

2) Dicontinuous or batch type extruders operate in cyclic fashion. They generally have a reciprocating member to cause a transport of the material.

(Rauwendaal, 2001, p. 1)

A general production extrusion line consists of:

- Extruder
- Nozzle
- Calibration and cooling device
- Sawing unit

Extruder parts:

- Machine frame
- Drive:
  - Engine
  - Gearbox
  - Drive conservatory
- Plasticizing unit:
  - Screw or screws
  - Barrel

    - Temperature Control System
- Controller

(Pekkala, 2009, p. 34)

2.2 Different Types of Extruders

The main reason why extruders come in different models is their mode of operation, whether it is continuous or discontinuous. Design complexity also plays an important role in deciding the type of extruder used in a process. This chapter will focus on four types of extruders, including screw extruders that is divided into two kinds, the single screw extruders and the multiscrew extruders; the disk extruders and the ram extruders. Furthermore, we will also talk about what sort of products can be processed by those extruders and their core advantages in details. This thesis will focus mainly on the screw extruders due to limited amount of disk and ram extruders presented in the industry. (Rauwendaal, 2001, p. 11)
Extrusion is divided depending on which screw types used. There are single screws and twin screws, which again can be divided in the sub-categories, such as:

1) Single Screw with inlet zone and three zones (feeding zone, melting zone, metering zone).

2) Single Screw with longitudinal grooves

3) Double screw which screws rotate in the same direction

4) Double screw which screws rotate in opposite directions

(Pekkala, 2009), P. 33

Table 1 - Classification of polymer extruders (Rauwendaal, 2001, p. 12)

Screw Extruders (continuous)	Single screw extruders	Melt Fed Plasticating Single stage Multi stage Compounding

	Multi screw extruders	Twin screw extruders Gear pumps Planetary gear extruders Multi (>2) screw extruders
Disk or drum extruders (continuous)	Viscous drag extruders	Spiral disk extruder Drum extruder Diskpack extruder Stepped disk extruder
	Elastic melt extruders	Screwless extruder Screw or disk type melt extruder
Reciprocating extruders (discontinuous)	Ram extruders	Melt fed extruder Plasticating extruder Capillary rheometer
	Reciprocating single screw extruders	Plasticating unit in injection moulding machines Compounding extruders (e.g. the Kneader)

2.2.1 Single Screw Extruders

Single screw extruder is known as the most important type of extruder used in the polymer industry. Some core advantages of single screw extruders are including low cost, straightforward design, uneven surface, reliability and best performance/cost ratio. (Rauwendaal, 2001, pp. 11 - 12)

The basic operation of a single screw extruder is pretty much straightforward. Granules enter from the feed hopper, they flow down straight to the extruder barrel under normal circumstances, flooding method would not be a better feeding process than starving method, because some materials do not flow easily in dry form and bridging of the material will most likely to happen in the feed hopper when the granules are hung-up, more detailed extrusion process can be seen in Figure 2. (Rauwendaal, 2001, pp. 11 - 12)

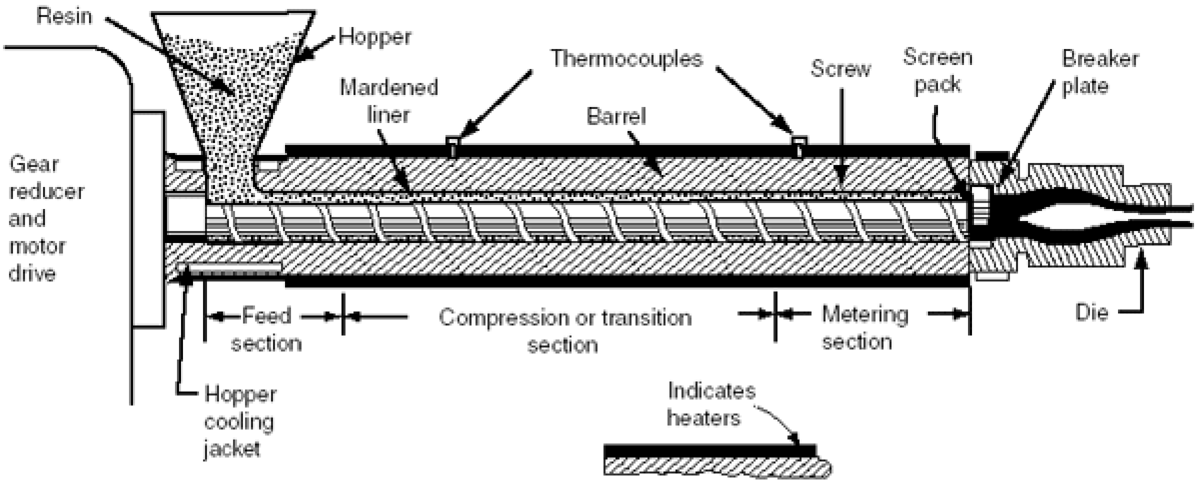

Figure 2 - Extrusion process using a single screw (Aipma, 2012)

2.2.2 Multiscrew Extruders

In a general description, a multiscrew extruder is an extruder consisting of more than one Archimedean screws. The early twin screw extruders, developed by Roberto Colombo and Carlo Pasquetti in the late 1930s had a number of mechanical problems. The most crucial limitation was the thrust bearing design. Due to limited space inside of the extruder, it is difficult to design a thrust bearing with good axial and radial load capacity. The early thrust bearings were not strong enough to give the twin screw extruders good mechanical reliability. In the late 1960s, special thrust bearings were developed specially for twin screw extruders. Since that, the mechanical reliability of twin screw extruders has been comparable to single screw extruders. However, twin screw extruders still do not possess as high a thrust bearing rate as single screw extruders. (Rauwendaal, 2001, pp. 18 - 576) The practical use of twin screw extruders is during the production of brittle PVC pipes. (Järvinen, 2008, p. 177)

Table 2 - Comparison of characteristics between single and twin screw extruders (Rauwendaal, 2001, p. 579)

Single screw extruder	Twin screw extruder
Used in simple profile extrusions and coextrusions.	Used in profile, compounding and reactive extrusion.

Modular design of screw and barrel is rarely used – less flexibility.	Often used with modular design of screw and barrel – great flexibility.
Easier prediction of extruder performance.	Difficult prediction of extruder performance.
Fair feeding, slippery additives tend to give problems.	Good feeding, can handle pellets, powder and liquids.
Fair melting, almost intact solids melting mechanism.	Good melting, dispersed solids melting mechanism.
Good distributive mixing with effective mixing elements.	Good distributive mixing with effective mixing elements.
Good dispersive mixing with effective mixing elements.	Good dispersive mixing with effective mixing elements.
Fair degassing.	Good degassing.
Not self-wiping, barrel is wiped but screw root and flight flanks are not.	Intermeshing ones can have completely self-wiping characteristics.
Relatively expensive.	Modular ones are very expensive.
Runs between 10 – 150 RPM, high screw speed is possible but rarely used.	Co-rotating ones can run at a very high screw speed, up to 1400 RPM.

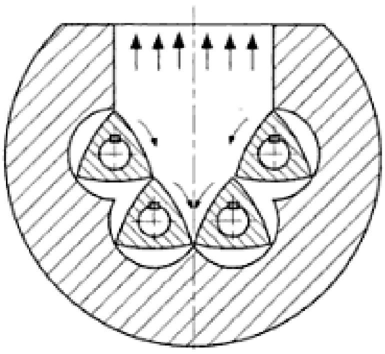

Figure 3 - Four screw extruder (Rauwendaal, 2001, p. 19)

2.2.3 Disk Extruders

Disk and Ram extruders are among the types of extruders that do not utilize an Archimedean screw for the transport of the material. These machines are referred to as screwless extruders. Disk extruders employ a disk or a drum to extrude the material. Most of disk extruders are based on viscous drag transport. One special disk extruder utilizes the elasticity of polymer melts to convey the material and to develop the necessary diehead pressure. Disk extruder was invented in 1950s. However, until nowadays the industrial significance of disk extruder is still relatively small compared to screw extruders. (Rauwendaal, 2001, pp. 21 - 27)

One of the first disk extruders was developed by Westover at Bell Telephone Laboratories. The heart of the machine is a stepped disk positioned by a small distance from a flat disk. A common disadvantage of the stepped disk extruder is the fact that the machine is difficult to clean because of the labyrinthine design of the flow channels in the stepped disk. A clear example of a stepped disk extruder can be seen in Figure 4. (Rauwendaal, 2001, pp. 21 - 27)

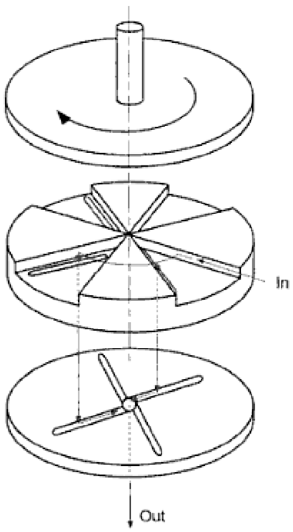

Figure 4 - The stepped disk extruder (Rauwendaal, 2001, pp. 21- 27)

A more advanced development in disk extruders is the diskpack extruder. Material drops in the axial gap between thin disks placed on a rotating shaft. The material moves with the disks almost a full turn and then it meets a channel block. The channel block closes off the space between the disks and transfer polymer flow to either an outlet channel or a transfer channel inside of the barrel. One can optimize the size of disks according to specific polymer processing operations such as solids conveying, melting, devolatilization, melt conveying and mixing. Thus, the diskpack competes mostly with the twin screw extruders. But in reality, twin screw extruders come as the first choice when it comes to specialty polymer processing operations. (Rauwendaal, 2001, pp. 21-27)

Although due to more complex machine geometry, the cost per unit throughput of the diskpack extruder is relatively higher than those of a conventional single screw extruder. Thus, the diskpack cannot compete directly to a single screw extruder. Schematic illustration of the diskpack extruder can be seen in Figure 5 (Rauwendaal, 2001, pp. 21- 27)

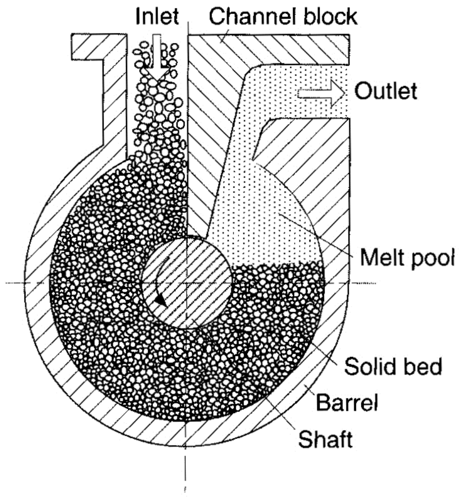

Figure 5 - Diskpack extruder (Rauwendaal, 2001, pp. 21 - 27)

2.2.4 Ram Extruders

Ram or plunger extruder possesses simple design, uneven surface and discontinuous mode of operation. Ram extruders are able to generate very high pressures. They are also ideal for cyclic process such as injection molding and blow molding. In fact, earlier molding machines were equipped with ram extruders to supply the polymer melt to the mold. Some limitations of ram extruder have caused a change to reciprocating screw extruders or combinations of both. The two main limitations are:

1. Limited melting capacity
2. Poor temperature uniformity of the polymer melt

Ram extruders can be divided into two categories: single ram extruders and multiple ram extruders. Single ram extruders are mainly used in special polymer processing operations. It is commonly used for extruding ultrahigh molecular weight polyethylene (UHMWPE) and polytetrafluoroethylene (PTFE). The reason why ram extrusion is used for these types of polymer is because they do not support melt processing on conventional equipments. (Rauwendaal, 2001, pp. 28 - 31)

The solid state extrusion is a technique that has been copied from the metal industry. In the process, polymer is forced through a die below its' Tm (melting point). This causes polymer deformation in the die followed by molecular orientation due to the solid state of the polymer. Compared to conventional melt processing, this is more effective and creates a better mechanical properties. (Rauwendaal, 2001, pp. 28 - 31) Schematic illustration of direct solid state extrusion or also broadly known as cold extrusion process can be seen in Figure 6.

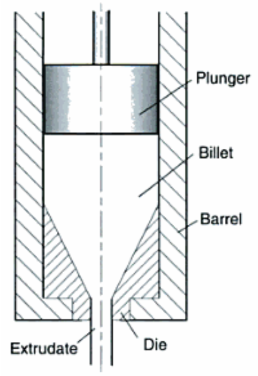

Figure 6 - Direct solid state extrusion process (Rauwendaal, 2001, pp. 28 - 31)

2.3 Different Sizes of Extruders

Extruder comes in three different types that employ different production capacities. Laboratories extruders for educational intended purpose with production capacity of 0.5 - 10 kg/h, the pilot screw extruders for small production lines with a capacity of 12 - 100 kg/h and production extruders for industries with greater production quantities. (Pekkala, 2009)

2.3.1 Laboratory extruder

Laboratory extruders are suitable for laboratory testing, research and development, training and quality testing. Their capacity is from 0.2 - 2.5 kg/h and 0.5 - 10 kg/h depending on the manufacturer. Their screws' sizes are ranging from 6.4 mm to 15.8 mm. (Pekkala, 2009)

Examples of laboratory extruders:

- Bantam Extruders ¼ "to 5/8" from Wayne Machine & Die Company is one kind of laboratory extruders. http://waynemachine.com
- Lab Ex series 10, 12, 15, 18, from KFM Machinery Ltd also has laboratory and educational extruders.
- Larger laboratory extruders are also available but their capacity does not exceed 16 kg / h.

(Pekkala, 2009), P. 36

2.3.2 Pilot extruder

The pilot screw extruders have been able to produce thinner profiles but the machine's heating power is not enough to melt large amounts of material quickly. (Pekkala, 2009, p. 37) Pilot extruder for small production lines is for example, Lab Ex series 18, 25, 35 from KFM Machine Ab. (KFM, 2009)

Figure 7 – Simple production line with extruder and cooling pool from KFM Machinery Ltd. (KFM, 2009)

2.3.3 Production extruder

The extruder Eco Ex 45HP 25 x D has a heating power of 18000 watts which is sufficient to guarantee a continuous outflow of the plastic material and the quality of the finished product. (Pekkala, 2009, p. 38)

Figure 8 – KFM's Eco EX production extruder (KFM, 2009)

Eco Ex series comes with a screw diameter of 18 - 75 mm in the standard program. The extruders are recommended for pilot plant or small production capacity from about 12 to 100 kg per hour. Eco Ex extruders come in standard equipments, but there is a model for film blowing purpose. Eco Ex extruders are available with water cooling attached to the barrel for extruding silicone and rubber. They also manufacture extruders for wheat-based food products. KFM manufactures material-specific screws for both their own machines and also other brands on request. They manufacture screws with 10 - 125 mm diameter with the geometry that is best for the intended material requested in relation to compression, mixing zones and ventilation. Silicone or rubber screws, screws for TPE materials and screws for wheat-based food products. (KFM, 2009)

Standard Options on Eco EX extruder:

- Fan-cooled heat zones for optimal barrel's temperature control.
- Corrugated material intake for higher production capacity.
- Ventilated design from 30 x D and above
- Pressure and temperature control of the melt
- Melt pump

All products are CE marked and tested to the present delivery.

Table 3 – Technical data of Eco EX production extruder by KFM (KFM, 2009)

	L/D förhållande	Värme effekt watt	Motor effekt Kw	Längd mm	Bredd mm	Höjd mm	Vikt ca. Kg
Eco Ex 45	20 x D	14000	30/38	2300/2910	750	*1700/**2000	825/960
Eco Ex 45 HP	25 x D	18000	30/38	2525/3140	750	*1700/**2000	850/995
	30 x D	21000	30/38	2750/3360	750	*1700/**2000	875/1020
	35 x D	24000	30/38	2975/3690	750	*1700/**2000	900/1045
	40 x D	27000	30/38	3200/3590	750	*1700/**2000	925/1070
Eco Ex 60	20 x D	17500	38/52	3270	900	*1700/**2000	825/960
Eco Ex 60 HP	25 x D	22500	38/52	3570	900	*1700/**2000	850/995
	30 x D	26500	38/52	2870	900	*1700/**2000	875/1020
	35 x D	30500	38/52	4170	900	*1700/**2000	900/1045
	40 x D	34500	38/52	4470	900	*1700/**2000	925/1070
Eco Ex 60	20 x D	21000	52/75	3630	1000	*1700/**2000	825/ 960
Eco Ex 60 HP	25 x D	27000	52/75	3930	1000	*1700/**2000	850/995
	30 x D	32000	52/75	4230	1000	*1700/**2000	875/1020
	35 x D	37000	52/75	4530	1000	*1700/**2000	900/1045
	40 x D	42000	52/75	4830	1000	*1700/**2000	925/1070

*Extruder height with entry

** Overall height inclusive operator interface and support arm.

Other L/D ratios are manufactured on request. The manufacturer reserves the right to make changes. (KFM, 2009)

2.4 General Products of Extrusion

The most common products of extrusion presented in Finland are simple profiles such as pipes, tubes, rails, seals, splatter, insulation cables, window frames, blown films, cast films, foils and coextrusion (such as tetrapak™ and presidenttikahvi packaging). (Lappalainen, 2012) (Pekkala, 2009) One of the objectives of this thesis work is to gather up information from Muoviyhdistys ry regarding the production volumes of each extruded product in Finland. Plant designers or entrepreneurs aiming to start a production line can concentrate on one single product of extrusion out of three that has been surveyed. From that chosen product, the individual can simulate the production line and estimate the cost of the extrusion line by providing the inquiries to the agent.

This thesis aim is to provide entrepreneurs with guidelines on choosing the most cost-effective machinery by giving out an idea of the production volumes that the machines are able to generate and sample budget quotation of one production line.

2.4.1 Pipes Extrusion

Plastic pipes are presented in different forms, they could be corrugated, water pipes, electricity pipes, high pressure pipes for many demanding applications and more pipes with special requirements.

Pipe and profile production line consists of an extruder which is equipped with a die depending on the end product and also a calibration device. After the extruder, the material is run through a cooling pool, nip rolls and a cutting saw. Biggest production of pipes is made out of PVC, PE and PP. Brittle PVC pipes are normally produced in a line with a twin screw extruder. During the manufacturing process of pipes, the molten plastic from extruder is led to a circle die towards the calibration device, where the final shape and size are determined. Pipe calibration can be carried out either in high or low pressure. Nip roll’s function is to pull the calibrated product towards the cooling pool, which is then cut into desired length. Flexible tubes, such as PE-LD are often wound into a roll. (Järvinen, 2008, p. 177)

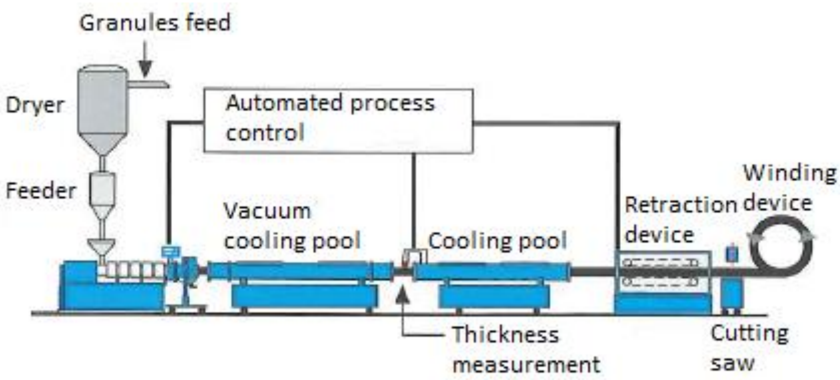

Figure 9 – Pipe manufacturing (Järvinen, 2008, p. 177)

Table 4 shows a list of companies providing pipes into the Finnish market, their pipe products and their sales revenue to get a rough estimation of their production capacity per year. The average pipe manufacturers in Finland makes revenue of 9 539 944 € per year, whereas the average Finnish companies providing extruded products have an average revenue of 18 425 556€ per year. In conclusion, sales revenue of pipe providers is less than the average extrusion companies by 8 885 611 €.

Total sales revenue of all Finnish pipe providers is 171 719 000€. Total sales revenue of extruded products providers companies altogether is 1 142 813 600€, therefore pipe providers contribute 15% of the total sales of extruded product providers.

Table 4 divides the size of the company into 3 standards, green ones are companies making the most sales, yellow ones are medium-sized revenues and the red ones are those making least sales.

Table 4 – Sales of extruded Pipes in Finland (Fonecta, 2009, pp. 95 - 201) (Talous Sanomat, 2013) (Kauppalehti, 2013) (Suomenyritykset, 2011) (compiled by author)

Manufacturers	**Products**	**Sales Revenue (M€)**
Aikolon Oy	PE-, POM- tubes	3,52
AS Nordplast Filial Finland	Ventilation pipes Pipes and fittings	0,2
Ekomuovi Oy	Pipes, process pipes Pipes and fittings	0,95
Etra Trading Oy	Material pipes PA-, POM-, PS-, PTFE- tubes	9,61
Foiltek Oy+B25	PMMA tubes	8,62
Irpola Oy	FEP-, PFA-, PTFE- tubings (hoses) Heat resistance cables PFA- pipes PTFE tubes	1,42
Maillefer Extrusions Oy	Pipes (koneet ja tuotantolinjat)	85,04
Muovityö Hiltunen Oy	Tube systems: pipes, pipe parts, valves, collars.	1,74
NCE Oy	Reinforced plastic-, process- pipes	11,44
Oy FL Pipe Ab	General- and sewage-, culvert- (rumpuputket), land drainage- pipes PP tubes PE-HD pipes and fittings	2,75
Oy Fluorplast Ab	Material-, FEP-, cable conduct-, pressure-, chemical- pipes. PFA- pipes and fittings. PA-, PE-, PET-, PFA-, pneumatic-, PP-, PTFE-, PUR-, PVC-, unplasticized PVC-, PVDF-, acid-proof- tubes. Tube systems: pipes, pipe parts, valves, collars.	2,38
Oy Plastex Ab	Multi-bore tubing Pipes and fittings, PE-HD pipes and fittings	5,25

Oy Primo Finland Ab	ABS-, PC-, PE-, PMMA-, POM-, PP-, PS-, PUR-, PVC-, unplasticized PVC- tubes (putki) Acryl-, cable conduct-, reinforced plastic-, PET-, process-pipes	12,05
Samplastic Oy	Tube systems: pipes, pipe parts, valves, collars.	0,61
SKM Composites Oy	Tube systems: pipes, pipe parts, valves, collars. Acid-proof tubes Chemical pipes Pipes and fittings	1,80
Soft Diamond Oy	Pressure pipes	1,64
Sulmu Oy	Reinforced plastics-, pressure-, process- pipes. Pipe systems Pipes and fittings	4,07
Vink Finland Oy	FEP-, PFA-, PTFE-, Industrial- tubings (hoses) ABS-, PA-, PC-, PE-, PMMA-, POM-, PP-, PTFE-, unplasticized PVC-, PVDF-, acid-proof- tubes Material-, acryl-, FEP-, pressure-, PFA-, process-, PVC-, land drainage-, sewage- (viemäri), chemical-, pressure air delivery- pipes Tube systems: pipes, pipe parts, valves, collars. Pipe systems Pipes and fittings, PFA-, ABS-, PE-HD-, PP-, PVC-, PVDC- pipes and fittings Rain water systems	18,65

An example of production line assembly of pipe manufacturer in Finland was obtained through plant excursion to Uponoy Oy in Nastola. The company review, machinery used and the dimensions of the corrugated irrigation pipes can be seen in Appendix B.

2.4.2 Profiles Extrusion

Profile extrusion has more or less similar principle and production line design as pipe extrusion. The extruder needs to be equipped with a die that suits the end profile and a calibration device. Afterwards comes the cooling pool, nip rolls and cutting saw. Profiles are mostly made out of PVC. Brittle PVC profiles are normally produced in a line with a twin screw extruder. During the manufacturing process of profiles, the molten plastic from extruder is led to a profile die towards the calibration device, where the final shape and size are determined. Profiles calibration is done in low pressure. Nip roll is pulling the calibrated product towards the cooling pool, which is then cut into desired length. (Järvinen, 2008, p. 177)

Table 5 shows a list of companies providing plastic profiles, their profile products and their sales revenue to get a rough estimation of their production capacity per year. The average profile providers in Finland makes revenue of 6 105 600 € per year, whereas the average Finnish companies providing extruded products own an average revenue of 18 425 556€ per year. In conclusion, sales revenue of profile providers is less than the average extrusion companies by 12 319 956 €.

Total sales revenue of all Finnish profile providers is 61 056 000€. Total sales revenue of extruded products providers altogether is 1 142 813 600€, therefore profile providers contribute 5% of the total sales of extruded products providers on the market.

Table 5 divides the size of the company into 3 standards, green ones are companies making the most sales, yellow ones are medium-sized revenues and the red ones are those making least sales.

Table 5 – Sales of extruded Profiles in Finland (Fonecta, 2009, pp. 95 - 201) (Talous Sanomat, 2013) (Kauppalehti, 2013) (Suomenyritykset, 2011) (compiled by author)

Manufacturers	**Types of profiles produced**	**Sales Revenue (M€)**
Etra Trading Oy	PA-, PE-, PET-, POM-, PP-, PTFE-, PUR-, PVC-, PVDF-, round profiles Insulating-, phenolic glass fibre- boards PE-, PP-, PTFE-, PVC- blocks PA-, PE-, POM-, PP-, PVC- bars	9,61
Irpola Oy	PTFE profiles	1,42
Kariplast Oy	Profiles, edging strips profiles	2,70
Muovix	Building profiles Traffic sound barrier walls	1,89
NMC Cellfoam Oy	PE Profiles Loudspeaker discs	7,95
Oy Fluorplast Ab	PE-, edging stips-, PVC-, extruded PVC-, plasticized PVC-, unplasticized PVC-, PP-, PS-, PTFE-, PUR-, PVDF-, round, TPE- Profiles Slide rails PTFE blocks	2,38
Oy Marino Ab	Profiles; reinforced plastics. Street furnitures Advertising pillars Reinforced plastic water slides	1,89

Oy Primo Finland Ab	Profiles, edging strips-, ABS-, acryl-, furniture-, reinforced plastic-, door-, PA-, PC-, PE-, PVC-, extruded PVC-, plasticized PVC-, unplasticized PVC-, foamed PVC-, PMMA-, POM-, PP-, PS-, PTFE-, PUR-, PVDF-, round-, building-, TPE-, electrical installation- profiles Slide rails PVC wall panels	12,05
Rinotop Oy	ABS-, Edging strips-, PVC-, plasticized PVC-, unplasticized PVC-, building- profiles Pullers	2,54
Vink Finland Oy	PC-, HDPEX-, PE-, PVC-, round- profiles Phenolic glass fiber-, damp proof-, laminate-, corrugated GRP- boards Slide rails Traffic sound barrier-, shower- walls PA-, PE-, PMMA-, POM-, PP-, PVC- bars	18,65

An example of production line assembly of profile manufacturer in Finland was obtained through Kaj-Mikael Pekkala's degree thesis. Where the production line was designed for manufacturing an annual total of 5 – 10 km of plastic profiles of roadscreen marker. The line assembly consisted machineries from feed to storage can be seen in Appendix C.

2.4.3 Foams

Table 6 shows a list of companies providing plastic foams, their foam products and their sales revenue to get a rough estimation of their production capacity per year. The average foam providers in Finland makes revenue of 10 383 200 € per year, whereas the average Finnish extruded products providers own an average revenue of 18 425 556€ per year. In conclusion, sales revenue of foam providers is less than the average extruded products providers by 8 042 356 €.

Total sales revenue of all Finnish foam providers is 51 916 000€. Total sales revenue of companies providing extruded products to the market altogether is 1 142 813 600€, therefore foam providers contribute 5% of the total sales of extruded products providers.

Table 6 divides the size of the company into 3 standards, green ones are companies making the most sales, yellow ones are medium-sized revenues and the red ones are those making least sales.

Table 6 – Sales of extruded foams in Finland (Fonecta, 2009, pp. 95 - 201) (Kauppalehti, 2013) (Talous Sanomat, 2013) (Suomenyritykset, 2011) (compiled by author)

Manufacturers	**Types of foams produced**	Sales Revenue (M€)
Fibrocom Oy	Sandwich panel elements	1,15
NMC Cellfoam Oy	Paddings Nomalen™ windowstrips	7,95
NMC Termonova Oy	Cellular plastic sheets Sports mats (karate, wrestling, gymnastics, judo) Camping mattresses PE-E-, sport- Paddings	12,13
Oy Primo Finland Ab	Foamed PVC profile	12,05
Vink Finland Oy	Sandwich panels, Foamed and expanded PVC sheets	18,65

An example of foam manufacturer in Finland was acquired through Jonne Hakkarainen's degree thesis, which assessed the production line of NMC Termonova Oy in Inkoo. The production line consisting machineries used from the early process of cross-linking of PE in order to expand the structure, until the unwinding of PE-X into rolls. The common use of foams in Finland is also explained in Appendix D.

2.4.4 Plastic Films

Films are produced by blowing and calendering. (Järvinen, 2008, p. 175) The post-processed plastic films can be compressed together as plastic bags, film laminations.

In blowing method, extruder is melting granules and they are pushed through the die into a form of a plastic tube. Filming machine automated rollers will close the tube, and then the tube existing in between the orifice and rollers' gap will be extended to a desired level by the help of air pressure building inside. The gap diameter between the die and the blown film is often called as blow ratio. The thickness of the film can be decided by the speed of the pulling device as well as blow ratio. A large blow ratio (around 1:4) produces for example two-way shrinkable shrink film. PE and PP are the most common materials used in blown film manufacturing. (Järvinen, 2008, p. 176)

In calendering, melted granules are pushed through a sheet die towards cooling rollers. The speed of resin exiting the die and rollers' RPM are the factors of film thickness. Calendering is a common manufacturing method for PVC, PP and PS both films and sheets. The method is also used for manufacturing various combination of film, which PE is often acting as one of the raw materials. (Järvinen, 2008, p. 176)

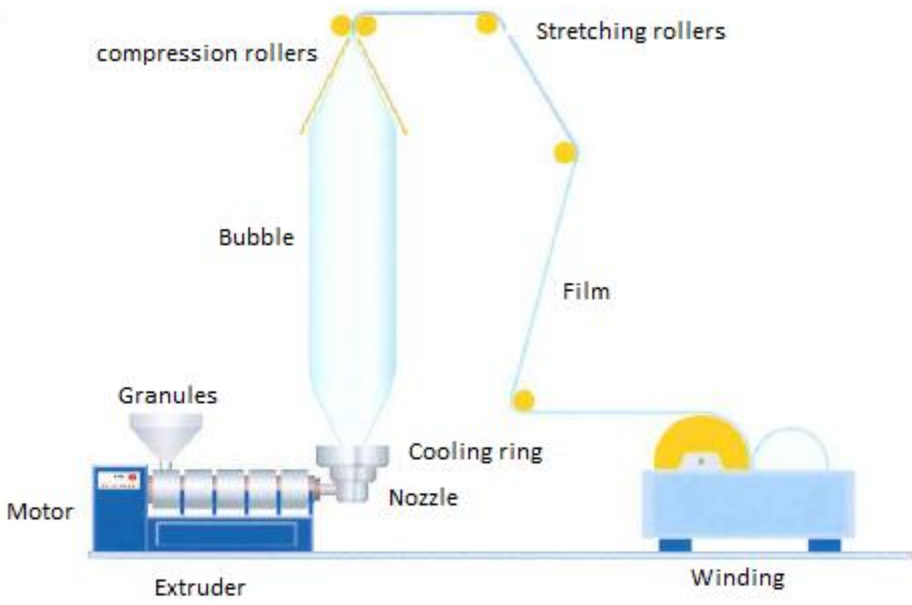

Figure 10 – Film manufacturing (Järvinen, 2008, p. 176)

Table 7 shows a list of companies providing plastic films to the market, their film products and their sales revenue to get a rough estimation of their production capacity per year. The average film providers in Finland makes revenue of 47 673 478 € per year, whereas the average Finnish extruded products providers has an average revenue of 18 425 556€ per year. In conclusion, sales revenue of film providers is more than the average extruded products providers by 29 247 922 €.

Total sales revenue of all Finnish film providers is 858 122 600€. Total sales revenue of extruded products providers altogether is 1 142 813 600€, therefore film providers contribute 75% of the total sales of extrusion companies. From these figures, one can conclude that plastic film providers contribute to the most output of extruded products providers.

Table 7 divides the size of the company into 3 standards, green ones are companies making the most sales, yellow ones are medium-sized revenues and the red ones are those making least sales.

Table 7 – Sales of extruded plastic films in Finland (Fonecta, 2009, pp. 95 - 201) (Talous Sanomat, 2013) (Kauppalehti, 2013) (Suomenyritykset, 2011) (compiled by author)

Manufacturers	**Type of films produced**	**Sales Revenue (M€)**
Bayer Oy	PC films	509,31
Etra Trading Oy	PTFE Films Epoxy-, impact resistant plastic-, PA-, PC-, PE-HD-, PE-HMW-, PE-LD-, PET-, PMMA-, POM-, PP-, PTFE-, PUR-, PVC-, foamed and expanded PVC-, PVDF-, cellular plastic- sheets Woven fabric sheet bakelites Streamline- (profiilinauhat), PTFE-, PVC-, sealing- tapes PTFE graphite-, PTFE carbon-, PTFE fiberglass-, PTFE bronze-, PTFE profile-, PTFE joint blushings- (tiivisteholkit) sealings	9,61
Foiltek Oy	Coextruded-, hot stamping films, thermal transfer ribbons, packaging-, PET-, polyester-, PP-, PS-, PVC-, deep drawing-, electrically conductive- films ABS-, CP-, PC-, PC Cell-, PET-, PMMA-, multiwall PP-, PS-, patterned PS-, metallized PS-, foamed and expanded PVC-, conductivity-, acryl mirror- sheets Sheet light carton (Paper+ foamed PS + paper)	8 ,62
Oy Fluorplast Ab	PTFE-, FEP-, release films, PFA Bladders (PFA kalvot), PVDF- films. PTFE-, PVDF- sheets Streamline- (profiilinauhat), PTFE-, PVC-, sealing-, adhesive electrical insulation- tapes Profile-, PTFE graphite-, PTFE carbon-, PTFE fiberglass-, PTFE bronze-, PTFE profile-, PTFE joint blushings- (tiivisteholkit) sealings	2,38
Innobit Oy	Films, biodegradable-, food-, stretch-, book-, coextruded-, photocopy-, (PP, PVC) shrink-, bakery products-, biaxially oriented (BOPP)-, metal coated-, microwave-, orientated-, packaging-, PET-, transparent-, polyester-, PP-, PS-, PP-C (cast)-, PVC/PVDC-, PVDC/ varnished cellulose-, coated cellulose-, recovered cellulose-, sticker-, self-adhesive transparent- films Coated carboards/ papers, plastic coated papers Stretch film packages Packaging films	1,69
Irpola Oy	PTFE-, FPE films. PTFE sheets PTFE carbon-, PTFE fiberglass-, PTFE bronze-, PTFE profile-, PTFE joint blushings- (tiivisteholkit) sealings	1,42
Kalliomuovi Oy	Films, furniture covers, vapor barrier-, shrink-, soil improvement-, agricultural-, strawberry-, packaging-, PE-LD-, cover-, garden-, building-, industrial- films	5,48

	PE bags Sacks	
KG Enterprise Oy	Release-, silicone bagging-, vacuum bagging- films	0,91
Lapin Muovi Oy	Vapor barrier-, shrink-, strawberry-, layflat tubing PE (PE-letku)-, building- films Plastic bags	4,27
Pelloplast Oy	Surface treatment-, self-adhesive PVC-, surface protection-, self-adhesive protection-, sticker-, self-adhesive transparent- films	4,86
Perel Oy	Metal coated films Packaging bags	11,75
Ab Rani Plast Oy	Vapor barrier-, stretch films, (stretch, cover hood, tube)-, shrink-, agricultural-, multi-layer-, packaging-, PE-HD-, PE-LLD- films. Sacks	168,69
Rosenlew RKW Finland Oy	Films, stretch-, shrink films	56,97
Sataplast Oy	Packaging films. Carrier-, packaging-, PE-, PP- bags Wrapping papers PC sheets	3,41
Structor Oy	Biodegradable-, bakery products-, cellulose acetate-, water sollluble- films	0,97
Suominen Joustopakkaukset Oy	Films, food-, coextruded-, laminated-, bakery products-, multi-layer-, thin-, packaging-, PE-, PE-HD-, PE-LD-, PE-LLD-, PET/PE-, PP- films Tamper evident- (arvokuljetus), carrier- (kantopussit), bakery-, plastic-, freezer-, packaging-, PE-, PE-HD, PP-, garbage-, on the roll- (rullapussit), self-adhesive-, tape bags Refuse sacks (jätesakit) Hygiene products packaging Packaging films	46,28
Thermoplast Oy	Films, antistatic- , COC-, release-, coextruded-, adhesive-, and biaxially oriented (BOPP)-, orientated-, PC-, PET-, PET/PE-, PI-, polyester-, PP-, embossed plastic-, PUR-, (unplasticized) PVC-, adhesive PVC-, deep drawing-, dielectric- films PP-, unplasticized PVC-, cellular plastic- sheets	2,86

Vink Finland Oy	PTFE-, FPE-, geo-, adhesive-, packaging-, PC-, PE-, PE-HD-, PE-HMW-, PET-, polyester-, PP-, (plasticized and unplasticized) PVC-, self-adhesive, adhesive- PVC-, self-adhesive protection-, deep drawing-, dielectric-, sticker-, technical-, industrial- films Acrylic-, PC-, PS-, corrugated-, cellular-, ABS-, epoxy-, impact resistant plastic-, MF-, PA-, PC-, electrically conductive PC-, PC cell-, PE-HD-, PE-HMW-, PE-LD-, PET-, PMMA-, PMMA multiwall-, corrugated PMMA-, POM-, PP-, fabric laminated PP-, multiwall PP-, PS-, patterned PS-, PTFE-, PUR-, PVC-, corrugated PVC-, laminated PVC-, plasticized PVC-, unplasticized PVC-, foamed and expanded PVC-, PVDF-, plastics coated wallboard-, decorating board-, cellular plastic-, conductivity-, acryl mirror-, PS mirror- sheets. Cell-, PC Cell- sheets (kennolevy) Window-, marking-, PTFE-, PVC-, adhesive decorative- (somistamoteippi) tapes Sealings	18,65

An example of film manufacturer is acquired through a plant excursion to Kalliomuovi Oy in Kalliola. The company review includes their mode of operation (batch size, work shift method and material processed and the daily width increase method of manufacturing). Figures of their machineries from the feeding hopper until the reeling in done by the guiding rolls were also shown in Appendix E.

2.4.5 Extrusion Coating and Laminating

Extrusion coating is a method in which a rail of material is coated with plastic, typically PE. Extrusion coating is considered as common, especially in Finland and Sweden. Most of the products coated are paper and cardboard, but the rail could also be of different plastic films, for example PA, PET and OPP. Other materials such as aluminum foil, steel and fabric can also be coated by extrusion. The term extrusion lamination is used when the molten plastic is laminated between two separated tracks, thus the polymer is acting as the “lamination glue”. The coating gives sealants to fiber-based materials, and acts as heat-treated plastic when it comes to liquid packaging. PE-LD has an excellent vapor sealant, but if we want it can be treated for better gas sealant properties, we can use special plastics such as E/VAL (EVOH). The coating line is formed by open winding machinery, extruder, pressure roll, chilling roll and close winding machinery. In addition, the line consists of pre- and post-corona devices to improve the adhesion and printability. The coating line also consists of outer-line trimmers. The molten plastic with the temperature as high as 320 ° C is pressed through a flat die towards the corona treated coated track located in between the extrusion roll and cooling roll. The plastic is then cooled down, it is corona treated and the coated track is wound up into a roll. (Järvinen, 2008, p. 176) Schematic process of extrusion coating and laminating can be seen in Figure 11.

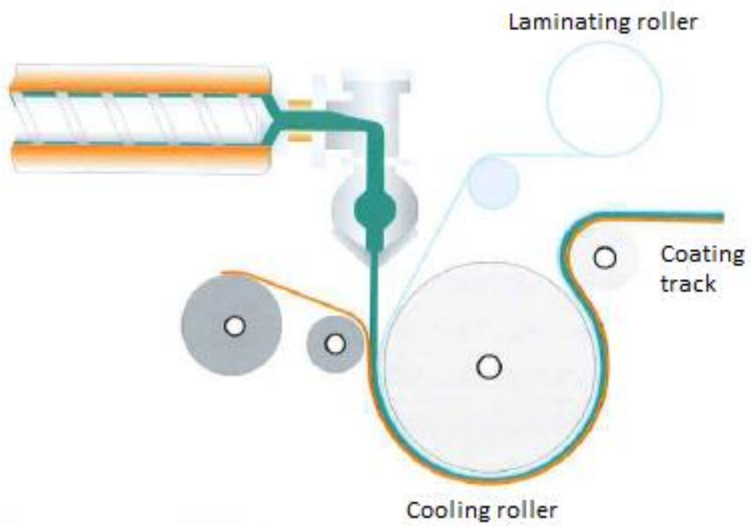

Figure 11 – Extrusion coating and laminating (Järvinen, 2008, p. 176)

An example of extrusion coating and lamination line is acquired through a plant excursion to Kalliomuovi Oy in Kalliola. The company review includes the manufacturing processes done with the Finnish design extruder by Plastex. The lamination film blowing process can be seen in Appendix F.

2.4.6 Cable Coating

Cable insulation and coating is also done by extruder. The extrusion line comprises an extruder which is equipped with crossed head, cooling pool and retraction and winding device. Coated wire or a partly coated cable is pulled in a certain angle towards a cross-headed extruder. The cross head will cover the wire or cable with molten plastic. After exiting the cooling pool, the solidified plastic and cable are rolled. Plastic materials that are most common for cable coating are PVC and PE. (Järvinen, 2008, p. 176)

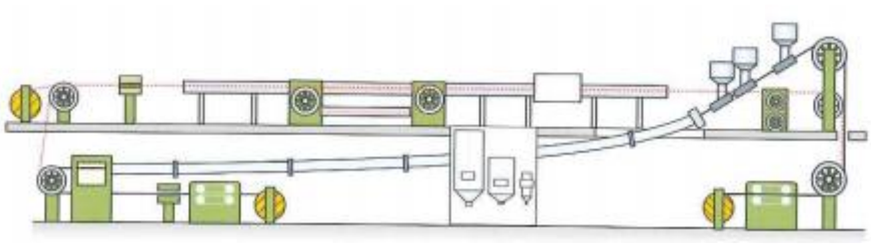

Figure 12 – Cable manufacturing (Järvinen, 2008, p. 177)

2.4.7 Extrusion Blow Molding

Extrusion blow molding produces bottles, jugs and container up to 100 liters. It also produces pipes, pipe fittings and tanks. Larger containers are manufactured by rotational molding of plastic powder. By far the most commonly used in extrusion-blow molding of plastic is HDPE. (Järvinen, 2008, p. 177)

In extrusion blow molding process, thick and extruded plastic hose preform is extruded into a plastic, which closes its other end. Air pressure is released into the preform hose from the open end, where the hose preform is expanded and the products gets its final shape from the mold's chilled surfaces. (Järvinen, 2008, p. 177)

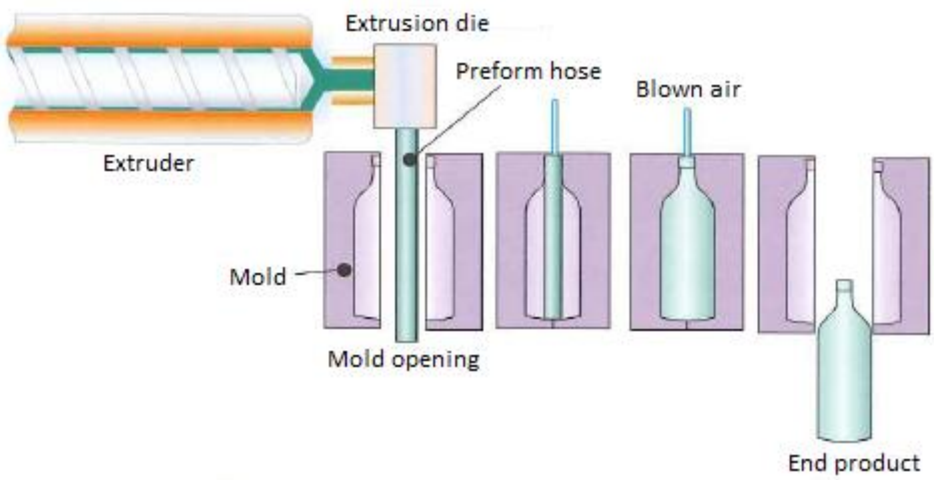

Figure 13 – Mold blowing (Järvinen, 2008, p. 177)

An example of extrusion blow molded bottles manufacturer was acquired through a literature review of Uusi Muovitieto book by Pasi Järvinen. The company review of Oy Plastex Ab can be found in Appendix G.

3 METHODOLOGY

Methodology parts conducted for this thesis were including:

- A conversion chart of plastic content from each plastic products in order to generate annual production volume of each product.
- Validation of the extruder capacity formulae conducted with the help of Arcada's manufacturing lab using the barrel's diameter, materials' heat capacities and the raise of temperature within extrudate.
- Plotting graph of the extruders' capacity range. Allocating extruders into low, medium and high production capacity level.
- From the production capacity calculation, the optimum barrel size for production is chosen according to low-, mid- and high range capacity demand.
- Company visits to plants involving extrusion process.
- Database of extruders' manufacturers

3.1 Conversion Chart

In this subchapter, the amount of plastic content (kg/m or kg/m^2) of each type of extrusion products is calculated to find the suitable size of extruder that serves the purpose of manufacturing products the most effective and efficient way.

3.1.1 Pipes

The example of pipe product for the conversion chart calculation is rain water drainage pipe by Uponor. The rain water drainage pipes are corrugated and it has 3 layers of laminations as observed in Appendix B.

The material used for water drainage pipe is PP, which has density of ρ = 946.00 kg/m^3 (Wikipedia, 2013). Such type of pipe has an average outside diameter of 180mm and 3.5 mm of wall thickness. (Uponor, 2008, p. 51)

Equation 1 - Conversion chart of Uponor water drainage pipe (author)

$$Plastic\_content = \frac{[m]kg}{1m\_pipe\_length}$$

$$= [\rho]kg/m^3 x[Vcross\_\sec tion]m^3 /1m$$

$$= 946kg/m^3 x\left[\pi x(0{,}09m)^3 x1m - \pi x(0{,}08825m)^3 x1m\right]/1m$$

$$= 946kg/m^3 x1{,}31\text{x}10^{-4} m^3 /1m$$

$$= 0{,}12\text{kg/m}$$

3.1.2 Profiles

The example of profile product for the conversion chart calculation is roadside marker (Fin: Litteä sukupylväs) by Trafino Oy as seen in Figure 20 of Appendix C. The roadside marker is 1m long, 30 cm wide and 3 cm thick. The material used for roadside marker is ABS, which has density of 1.04 g/cm^3. (Wikipedia, 2013) The holes presented in Figure 21 of Appendix C are punctured after the profile exits the extruder, therefore plastic content calculation is done as a slab profile. (Trafino Oy, 2008)

Equation 2 - Conversion chart of roadside marker profile by Trafino Oy (author)

$$Plastic\_content = \frac{[m]kg}{m}$$

$$= \frac{[\rho]kg/m^3 x[V]m^3}{m}$$

$$= \frac{1{,}04g/cm^3 x[100cmx30cmx3cm]}{m}$$

$$= \frac{1{,}04g/cm^3 x9000cm^3}{m}$$

$$= 9360g/m$$

$$= 9{,}36kg/m$$

3.1.3 Foams

The example of foam product for the conversion chart calculation is nomalen™ foam by Termonova. The most common nomalen™ products have density of 28kg/m^3. The average nomalen™ foams are 30mm in thickness. (Hakkarainen, 2007, p. 34)

Equation 3 – Conversion chart of nomalen™ plastic foam by Termonova (author)

$$Plastic\_content = \frac{[\rho]kg/m3x[V]m3}{m^2}$$

$$= \frac{28kg/m^3 x1mx1mx0{,}03m}{m^2}$$

$$= \frac{0{,}84kg}{m^2}$$

3.1.4 Films

Example of plastic films covered in plastic content calculation for plastic films is by Kalliomuovi Oy. The average thickness of the end product is 70 µm. Material used is LDPE. (Koljonen, 2012) Average thickness of LDPE is 0,925 g/cm^3. (Wikipedia, 2013)

Equation 4 - Conversion chart of LDPE plastic film by Kalliomuovi Oy (author)

$$Plastic\_content = \frac{[\rho]kg/m^3 x[V]m^3}{m2}$$

$$= \frac{0{,}925g/cm3x1mx1mx70\mu m}{m2}$$

$$= \frac{9{,}25x10^{-4}kg/m^3 x1m^2 x70x10^{-6}m}{m^2}$$

$$= \frac{6{,}48x10^{-12}kg}{m^2}$$

3.2 Introduction to The Extruder Capacity Calculation

3.2.1 Aims and Objectives

The 2-hours experiment was done under full supervision of Simo-Pekka Toivonen to validate a couple of equations regarding the production capacity of an extruder. The first equation that the author needs to assess is triggered by the barrel diameter of the extruder, the second equation involves the heat capacity of materials extruded, power of the extruder and temperature change presented in the barrel.

3.2.2 Equations Needing Validation

The extruder is normally designated by the inside diameter of the extruder barrel. In European Union, standard extruder sizes are 20, 25, 30, 35, 40, 45, 50, 60, 90, 120, 150, 200, 250, 300, 350, 400, 450, 500 and 600 millimeters. Most extruders are ranged from 25 to 150 millimeters. An additional designation that is often used is the length of the extruder, generally expressed in length to diameter ratio (L/D ratio). Typical L/D ratios range from 20 to 30, with 24 being the most common. Vented extrudes possess the highest L/D ratio that starts from 35. (Rauwendaal, 2001), P.11

Extruder capacity is normally calculated from the inside barrel diameter. Equation 5 best illustrates simplified way of calculating the production capacity. In the list of symbols, one can observe what each symbol used in Equation 5 to Equation 19 stand for.

Equation 5 - Simplified production capacity calculator in imperial unit (Aipma, 2009)

$$Qe = 16 \times Db^{2,2}$$

Qe: Extruder capacity [lb/hour]

Db: Barrel’s inside diameter [inch]

Conversion calculation from Equation 5 into metric unit can be seen in Equation 16 section in Appendix A.

Equation 6 - Simplified production capacity formula in metric unit (author)

$$Qe = 4{,}35 \times 10^4\, Db^{2,2}$$

Qe: Extruder capacity [kg/hour]

Db: Barrel's inside diameter [mm]

Another formula that can be applied to estimate the extruder capacity can be calculated by the amount of energy needed to melt the granules from the mechanical work and barrel heaters function mainly as material insulators.

Equation 7 - Production capacity formula with energy, in imperial unit (Aipma, 2009)

$$Qe = 1{,}9 \times 10^3 \times \frac{Hp}{Cp \times \Delta T}$$

Qe: Extruder capacity [lb/hour]

Hp: Power [Horsepower]

Cp: Heat capacity [$\frac{Btu}{lb \times Fahrenheit}$]

ΔT: Temperature rise from feed to extrudate [Fahrenheit]

Conversion calculation from Equation 7 into metric unit can be seen in Equation 17 section in Appendix A.

Equation 8 - Production capacity formula with energy in metric unit (author)

$$Qe = 1{,}32 \times 10^3 \times \frac{P}{Cp \times \Delta T}$$

Qe: Production capacity [Kg/h]

P: Power [Watt]

Cp: Heat capacity [J/Kg.K]

ΔT: Temperature rise from feed to extrudate [Kelvin]

3.2.3 Guide for Extrusion Molding Machine Settings

Table 8 illustrates the guidelines for suitable extrusion temperature settings, by taking into account the materials' T_m (melting temperature) and T_g (glass transition temperature).

Table 8 – Extrusion temperatures and heat capacities of most common materials (Rosato, 1998), P. 170 - 172

Resin data	Extrusion temperature [F]	Specific heat [Btu/lb.F]
ABS	435	0,34
Acrylic	375	0,35
Nylon-6	520	0,4
Nylon-6,6	510	0,4
Nylon-6,12	475	0,4
Nylon-11	460	0,47
Polycarbonate	550	0,3
Polyester	480	0,4
HDPE	410	0,55
LDPE film	410	0,55
LDPE wire	400	0,55
LDPE extrusion coating	600	0,55
PP	450	0,5
PS impact sheet	450	0,34
PS gp crystal	410	0,32
Polysulfone	650	0,28
Polyurethane	400	0,4
PVC rigid profiles	365	0,25
PVC pipe	380	0,25
SAN	420	0,31
Urethane elastomers	390	0,46

3.3 Methods Used for Capacity Calculation

3.3.1 ECO EX 18

A test run was made in Arcada's manufacturing laboratory. The extruder that the author was operating is the ECO EX 18 from KFM Machine Ab. The pilot screw extruders have been able to produce thinner profiles but the machine’s heating power is not enough to melt large amounts of material quickly. The production capacity of this sort of extruder is from 12 up to 100 kg per hour.

Figure 14 – Simple production line with extruder and cooling pool from KFM Machinery Ltd. (KFM, 2009)

ECO EX 18 is a single screw extruder as seen on Figure 14. The number 18 simply comes from the barrel’s inside diameter which is 18.4 mm. Power of the extruder is 5.2 kW. There are 6 zones presented in the extruder, although each one has the similar method of transporting which is feeding, melting and metering.

3.3.2 Materials tested

First polymer tested was 148,5 g of PS with 1,5g of blue masterbatch from Kauko – Telko Oy to define the travel time of the material in the extruder. The material was extruded under constant flow, it was not starved, neither was it entirely flooded. Materials were run at initial temperature of 22°C which is the ideal room temperature of the manufacturing laboratory in winter time.

Second polymer was recycled PP as well as virgin violet PP from Sabic. The last polymer tested was recycled LDPE. Some recycled granules were chosen due to the assumption that the heat capacity does not differ drastically compared to virgin materials, thus realistic values will still be achieved. All materials were extruded at 50 RPM screw speed and the process was occasionally stopped whenever each color change were present.

Result of laboratory experimentation can be seen in Subchapter 5.2.1. Whereas the calculation result is seen in Subchapter 5.2.2. Discussion and conclusion of the experimentation and calculation can be seen in Subchapter 6.1.

4 EXTRUSION COMPANIES

This chapter includes a database list of local big companies providing extruders as well as their agents, extrusion dies, barrels, screws, simulation softwares and other necessities in extrusion plant. Some of the local companies operating on extruders can be found in Figure 15.

4. Levyjä, profiileja, kierrätystä, kalvoja ja muoviputkia

Yritys	Nettiosoite
Aikolon Oy	www.aikolon.fi
Apollo Materials Oy	www.apollomaterials.fi
Ares Oy	www.ares.fi
Duuri Oy	www.duuri.fi
Etra Trading Oy	www.etratrading.fi
Exel Oyj	www.exel.fi
FL Pipe Ab	www.flpipe.fi
Oy Fluorotech Ltd	www.fluorotech.fi
Foiltek Oy	www.foiltek.fi
Irpola Oy	www.irpola.fi
Jita Oy	www.jita.fi
Kalliomuovi Oy	www.kalliomuovi.fi
Kalustemuovi Virtala Oy	www.kalustemuovi.fi
Keraplast Oy	www.keraplast.fi
KG Enterprise Oy	www.kgenterprise.fi
Kumiapu Oy	www.kumiapu.fi
KWH Pipe	www.kwhpipe.fi
Muoviura Oy	www.muoviura.fi
Muovix Oy	www.muovix.fi
NCE Oy, Nordpipe Composite Engineering	www.nce.fi
NMC Termonova Oy	www.termonova.fi
AS Nordplast Filial Finland	www.nordplast.fi
Oy Parlok Ab	www.parlok.com
Pema Import Oy	www.bruggpema.fi
Pipelife Finland Oy	www.pipelife.fi
Plastilon Oy	www.plastilon.fi
Polyno Oy	www.kolumbus.fi/polyno
Oy Primo Finland Ab	www.primo.com
Propipe Oy	www.propipe.com
Ab Rani Plast Oy	www.raniplast.com
Rosenlew RKW Finland Oy	www.rosenlewrkw.com
Röchling Rimitoplast Oy	www.rimitoplast.fi
SKM Composites Oy	www.skmcomposites.com
Sulmu Oy	www.sulmu.fi
Suominen Joustopakkaukset Oy	www.suominen.fi
ThermiSol Oy	www.thermisol.fi
Oy Toppi Ab	www.toppi.fi
Uponor Oy	www.uponor.fi
Uusiomateriaalit Recycling Osakeyhtiö Ltd	www.uusiomateriaalit.com
Vink Finland Oy	www.vink.fi

Figure 15 - Finnish companies dealing with sheets, profiles, recycling, films and pipes (Järvinen, 2008)

4.1 Distributing Agents

The role of agents is replacing the role of distributors in Finland when it comes to extruders market. A couple examples of agents for extruders have been contacted by Henry Ericsson to provide us with a more in-depth knowledge on their business strategies in providing customers with solutions for extrusion lines depending on the end products that they are manufacturing.

There are quite many benefits for being an agent rather than a distributor, for the company making the extruder, the end customer and the agents themselves. Agents generally take commission out of the sales conducted from the extruder manufacturer that they represent. They have broad amount of contacts both from the extruder manufacturers side as well as the companies that are in need of extruders. Unlike distributors, agents are not required to inquire a space to store the machineries, thus, the cost is minimized because it is not their responsibility to own a warehouse to store the products, no maintenance cost and free of delivery cost as well. The risk of loss due to trend is also minimized because they do not need to purchase the machine before selling them forward.
(Ericsson, 2012)

Table 9 - Common differences between distributors and agents (Difference between, 2012)

Distributors / Importers	Agents
Direct salesmen of the products	Not direct sales persons
They buy the product directly from the company and distribute it in the market.	Are only responsible for selling the products
	Not involved in the delivery
Providing after sales services	Do not provide after sales services
Cannot be called the company’s representative, as they buy the product and then resells it.	Can be called the company’s representative
They do not have any role in negotiating with the customers; they only perform the role of distributing the product in the market.	Responsible for finding the target people and negotiating with them to buy the product

Available distributing agents in Finland, the companies that they are representing and the range of production volumes that their machines can handle can be seen in the Table 10.

Table 10 – Collection of extruder importers in Finland (Fonecta, 2009, pp. 80 - 94) (compiled by author)

Name of company	Country of Origin	Smallest machine (kg/h)	Biggest machine (kg/h)	Agents
AXON AB PLASTICS MACHINERY	Sweden	0,30	25,00	Aspokem, telkogroup
Extrusion Dies Industries, LLC	USA			EKOFORM
Gloucester engineering extrusion line	UK			EKOFORM
Hosokawa Alpine Ag	Germany	105,00	600,00	Helge Jansson & Co Oy Ab
KFM	Sweden	0,50	100,00	Oy Bowtec Ab
Macro Engineering & Technology Inc.	Canada	16,00	1552,00	Helge Jansson & Co Oy Ab
Optical control systems GmbH	Germany	4,32	10,45	Ky C-E Fuhrmann & Co Kb
Oy Scanex Ab	Finland			EKOFORM
Reifenhäuser Kiefel Extrusion GmbH	Germany	32,35	679,10	Ollila & Co. Oy
Tecnova	Italy	90,00	1100,00	Cupton Oy

4.1.1 Cupton Oy

The first query was conducted with Tomi Lappalainen, the managing director of Cupton Oy in Arcada building, Tuesday, 13th of March at 14:15. Cupton Oy is an agent representative of extrusion lines providers such as Gruppo Colines and Tecnova. The company has been working in the industry for 20 years. (Cupton Oy, 2012)

4.2 Extruders

This subchapter is written in order to get a closer look at the companies operating with extruders.

Table 11 - Companies manufacturing single screw extruders, their countries of origin and their range of production capacity. (K Trade Fair, 2010) (compiled by author)

Company	Country of origin	Production capacity (kg/h)

		Min	Max
AXON AB PLASTICS MACHINERY	Sweden	0,30	25,00
Battenfeld-Cincinnati	Germany	30,00	2200,00
Cincinnati Milacron Extrusion Systems	USA		3628,00
Extron	Finland	500,00	1500,00
Extrusion Technik	India	60,00	500,00
High Tech Extrusion	Austria	10,00	1400,00
HMG Extrusions GmbH	Austria	25,00	262,00
Hosokawa Alpine Ag	Germany	105,00	600,00
Japan Steel Works	Japan	500,00	100000,00
Jwell Extrusion Machinery (Shanghai) Co., Ltd.	China	15,00	1100,00
KFM	Sweden	0,50	100,00
Leader Extrusion Machinery Ind., Co., Ltd.	Taiwan	150,00	1000,00
Leistritz Extrusionstechnik GmbH	Germany	2,62	286,94
Macro Engineering & Technology Inc.	Canada	16,00	1552,00
Nanjing Useon Extrusion Equipment Co., Ltd.	China	5,00	4500,00
Optical control systems GmbH	Germany	4,32	10,45
Qingdao Friend Plastic Extrusion Technology Co., Ltd.	China	4,00	1600,00
R.R. Plast Extrusions Pvt. Ltd.	India	30,00	1200,00
Reifenhäuser Kiefel Extrusion GmbH	Germany	32,25	679,10
STC Extrusion Machinery	Taiwan	10,58	600,00
THEYSOHN Extrusionstechnik GmbH	Austria	10,00	1400,00
Tecnova	Italy	90	1100,00

Among the list seen on Table 11, it is concluded that the three biggest companies producing extruders (judged by the range of production capacity) are Japan Steel Works, Nanjing Useon Extrusion Equipment Co., Ltd. And Battenfeld-Cincinatti.

4.2.1 Capacity Graph of Extruder Manufacturers

Low, medium and high capacity in production capacity charts of Figure 16 and 17 do not necessarily mean that they have to follow the production capacity parameters of pilot, laboratory and production extruders as mentioned is Subchapter 2.3.

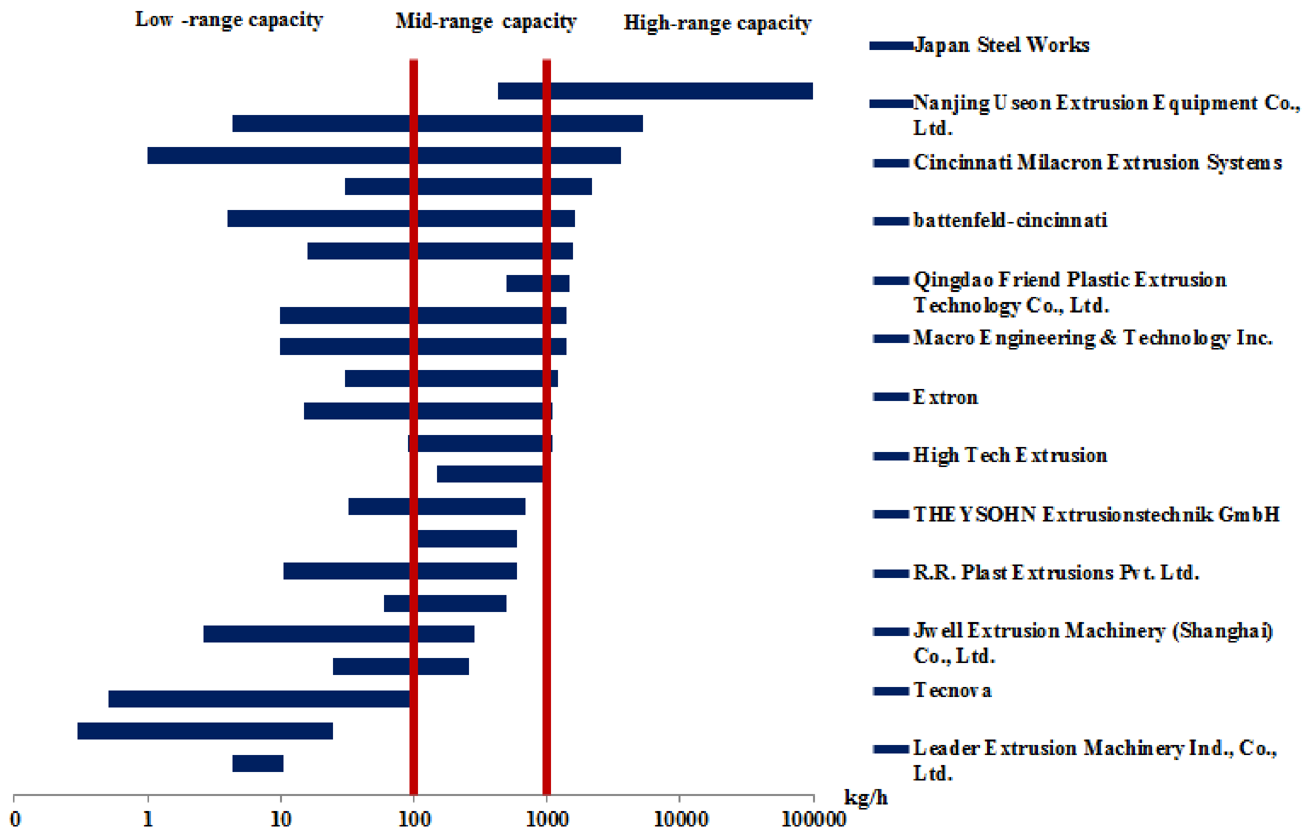

Figure 16 - Production capacity chart of single-screw extruders (compiled by author)

Middle range capacity (100- 1000 kg/h) is the numbers surrounding the median area of the chart. The median that the author has acquired from the given statistics was 585 kg/h. The average production capacity of the extruders that these companies produce is 2882,84 kg/h. The number is more on the high-range due to the fact that Japan Steel Works produce machines that are far bigger than the rest of the world standard. The names of companies seen in Figure 16 represent only half of what is shown in Table 11.

Compared to single screw extruders, there are not that many companies producing twin screw extruders due to the factors mentioned in section 2.2.2. In Table 12, the author has listed the twin screw extruder manufacturers based on the production capacity range that they produce.

Table 12 - Companies manufacturing twin screw extruders, their countries of origin and their range of production capacity. (K Trade Fair, 2010) (compiled by author)

Company	Country of Origin	Production capacity (kg/h)	
		Min	Max

Cincinnati Milacron Extrusion Systems	USA	11	3636
Extricom GmbH, Blach Extruder & Components	Germany	3,4	416,23
Japan steel works	Japan	25	100000
HMG Extrusions GmbH	Austria	150	1200
Qingdao Friend Plastic Extrusion Technology Co., Ltd.	China	20	1200

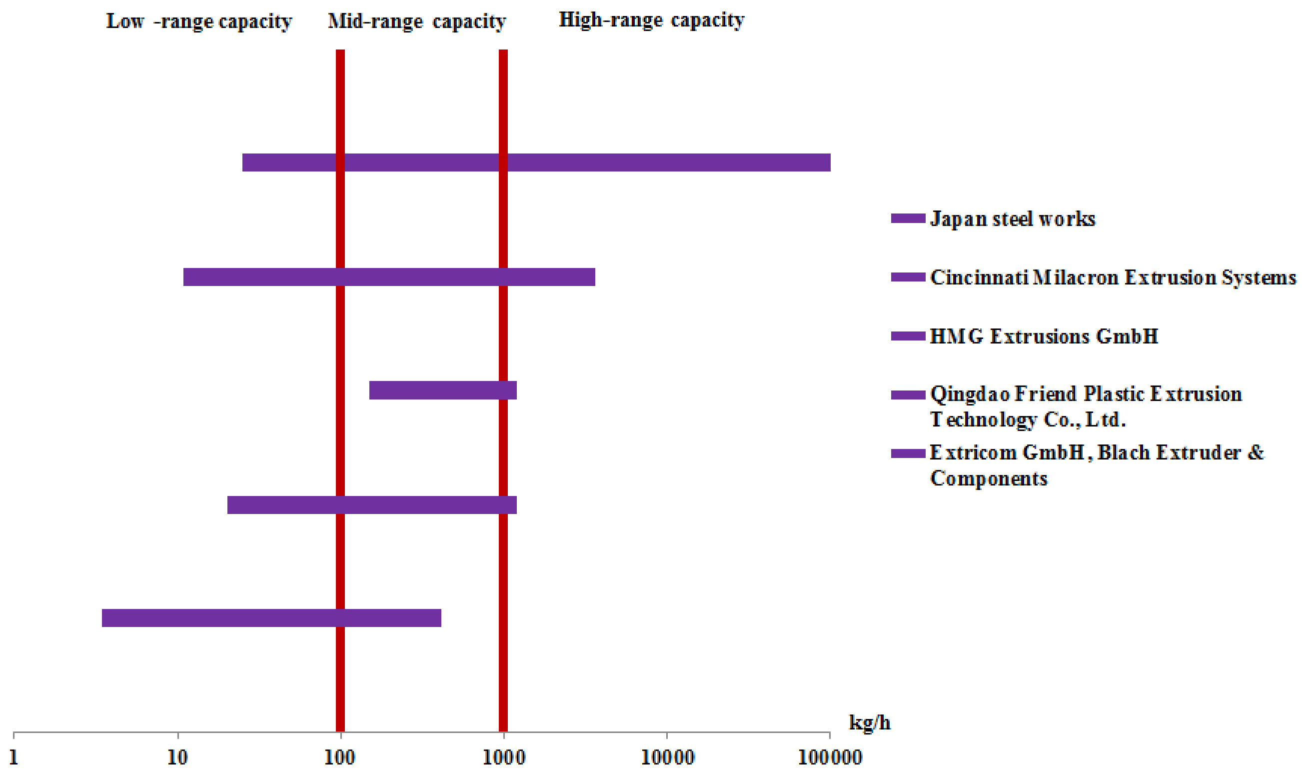

Figure 17 - Production capacity chart of twin screw extruders (compiled by author)

4.2.2 Tecnova S.r.l.

The reason why the author chose to write about this company is because she had the chance to meet with the agent (refer to subchapter 4.1.1.) and was given the opportunity to look closer at the insight of the production line design. Tecnova extruders come in different sizes, purposes and ability to handle different materials (refer to Appendix H). They are generally easier to acquire in Finland due to existence of a local agent located in Espoo, Uusimaa.

Tecnova s.r.l. is an industry leader in plastic recycling equipment and extrusion lines' manufacturer. Tecnoviti is a daughter company of Tecnova S.r.l., they manufacture screws and cylinders. It is possible for Tecnoviti to also supply screws for extruders that are not made by Tecnova S.r.l.

Tecnova S.R.L. was established in 1982 by Mr. Antonio Massaro, nowadays still their President and Director. Their presence in Italian as well as worldwide market has been possible by their top-standard of technology plant, best quality of materials and components used for their machines, they also offer their customers with reliable technical assistance. (Tecnova s.r.l., 2012) They offer big range of extruders that serve different purposes, production capacity outputs and material processing abilities. Such can be seen in Table 24 of Appendix H.

Figure 18- Recycling line and extrusion line of Tecnova s.r.l. (Cupton Oy, 2012)

4.3 Extrusion Dies Providers

In many cases, a die could actually be more expensive than the extruder by 3:2 of the price. Dies are manufactured by some certain die providers. Extruder manufacturers normally have a contact with die manufacturers, the die manufacturers then will provide them a die that is compatible with the machine production capacity output. (Lappalainen, 2012) Die manufacturers are generally B2B operating companies.

Table 13 represents companies that design and manufacture extruder dies depending on the customers' preference.

Table 13 - Die providers (K Trade Fair, 2010)(compiled by author)

Name of company	Country of Origin
AES GmbH Allianz Extrusion Service	Germany

Alpha Marathon Film Extrusion Technologies Inc.	Canada
EMO Extrusion Molding GmbH	Austria
Extrusion Dies Industries, LLC	USA
Precision Dies & Tools Mnfg. Co. LLC	United Arab Emirates
Profile Dies S.r.l.	Italy

4.4 Barrels Providers

Barrel diameter is a common reference of production capacity for chosen extruders. In the olden days, the screw size was much bigger than they are nowadays. Common difference within the northern American extruders and European extruders are the L:D ratio and RPM presented. The Americans tend to employ extruders with small L:D ratio and high revolution. Whereas the Europeans tend to employ extruders with larger L:D ratio but low revolution to save power in the long run. The chemical company Exxon Mobile is employing the European standard of extrusion. (Lappalainen, 2012)

Table 14 represents companies that design and manufacture barrels depending on the customers' preference.

Table 14 - Barrel providers (K Trade Fair, 2010)(compiled by author)

Name of company	Country of Origin
ERE Kunststoff RAM-Extrusion GmbH & Co. KG Kelberg	Germany
Extruder-Komponenten Salzgitter GmbH	Germany
Shree Radhekrishna Extrusions Pvt. Ltd.	India

4.5 Screw Providers

As well as barrels, some screws are also manufactured according to the customers' order. Table 15 shows some big companies that specialize in screw manufacturing for extruders.

Table 15 - Screw providers (K Trade Fair, 2010) (compiled by author)

Name of company	Country of Origin
ERE Kunststoff RAM-Extrusion GmbH & Co. KG Kelberg	Germany
Extruder-Komponenten Salzgitter GmbH	Germany
Shree Radhekrishna Extrusions Pvt. Ltd.	India
Xinxing Twin Screw Machinery Co., Ltd, of Shanghai	China
Zhoushan Zhongyang Screw Manufacturing Co., Ltd.	China

4.6 Simulation Software

In order to simulate the extrusion process to make sure that the flow is precise (not exceeded and enough to push the material along the barrel) and the whole line is compatible with the extruded product, simulation software is often required to check whether the material and tool designs are compatible for the operation. One of the most common simulation software is provided by a German company called AgfISS - Agentur für Industrie-Software und Services, Extrusion – Simulation. (AgfiSS, 2012)

4.7 Other necessities

Gear pumps can be ordered according to preference from a Swiss company called Eprotec Extrusion Technology AG. Pelletizers that can convert plastic products to cutom sized granules can be ordered from a German company called Extruder Experts GmbH & Co. KG. (K Trade Fair, 2010)

5 RESULTS

- Extrusion machine providers can be found in EU and various countries.
- Agents are available in most countries. Contact the manufacturer of the machine and find the agent closest to your extrusion plant. There might not be any agent in the same country as the manufacturing plant.

- The extruder is only the beginning of the manufacturing process. Afterwards comes post-processing such as reshaping, cooling, sawing, packaging and delivery. It is therefore advisable to contact the agent for further assistance.
- Post-processing is the most essential part of an extrusion flow. What matters the most is what happens after the extruded product exits the machine.
- Simple design products such as plastic films have the highest demand and biggest market; they can be very profitable even when done in a small scale of dimension range.

5.1 Rank of Finnish Commonly Extruded products

Table 16 illustrates the main extruded products of Finland in a nutshell. The products are listed from the average of companies with the highest sales revenues to the lowest. One can see the result that plastic film is the most common produced product in Finland, with average sales revenue being 29 247 922€ higher than the average of companies using extruders as their main method of manufacturing.
Plastic films also contribute to 75% of the total sales of extruded products. This might be caused by the non-demanding die design and the non-stop output of the extrusion line. It also ensures continuous orders from subcontractors.

Table 16 - Extruded products of Finland(compiled by author)

Type of extruded products	Average sales revenue (M€)	Difference (M€)	Total (M€)	Contribution to total sales
Plastic Films	47,67	29,25	858,12	75 %
Foams	10,38	-8,04	51,92	5 %
Pipes	9,54	-8,89	171,72	15 %
Profiles	6,11	-12,32	61,06	5 %
Average	18,43	Sum	1142813600	

5.2 Results of The Capacity Calculation

5.2.1 Experiment result

Table 17 – Result of experimentation, temperature change of the material within the barrel and the travel time. (compiled by author)

Sample	Polymer	Cp [Btu/lb.F)	T1(°C)	T2(°C)	T2(F)	ΔT(°C)	ΔT(F)	Δt(s)
1	PS	0,34	22	181	357,8	159	318,2	100
2	PS	0,34	22	181	357,8	159	318,2	150
3	PS	0,34	22	180	356,0	158	316,4	98
1	PP	0,50	22	182	359,6	160	320,0	210
2	PP	0,50	22	184	363,2	162	323,6	120
3	PP	0,50	22	183	361,4	161	321,8	96
4	PP	0,50	22	184	363,2	162	323,6	46
5	PP	0,50	22	184	363,2	162	323,6	98
1	LDPE	0,55	22	181	357,8	159	318,2	152
2	LDPE	0,55	22	184	363,2	162	323,6	76

From Table 17, it is summarized that the higher heat capacity that a material has, the higher temperature it requires to melt the material within the barrel. Thus, higher power is required to operate the machine, which results in higher production costs.

The time it takes for the material from the hopper to the die does not really seem to differ that much in materials, the flow is supposedly constant.

The average ΔT that the author has obtained from the experiment are 158,67°C for PS, 161.40°C for PP and 160.50°C for LDPE. Average time it takes for the material to exit the die after it was being fed from the hopper is 116 s for PS and 114 s for both PP and LDPE.

5.2.2 Calculation result

The calculation was done in imperial unit because the formulas were in imperial, thus more accurate to validate. Extruder's power and barrel's inside diameter were converted into imperial units.

The change of temperature from the feed to the barrel can be compared with the result of equations, the value presented in the laboratory extruder and the value obtained from the literature.

Imperial form of ΔT can be calculated by solving the production capacity of Equation 5, and plugging in that formula into Equation 7.

Equation 9 – ΔT calculation. Fusion of Equation 5 and Equation 7. (author)

$$\Delta T = \frac{190 \times Hp}{Cp \times Qe}$$

$$\Delta T(°F) = \frac{190 \times 6{,}97Hp}{Cp \times 7{,}53lb / h}$$

$$\Delta T(°F) = \frac{175{,}87}{Cp}$$

The constant of 1900 was achieved from Equation 7. But by running the machine and calculation, the value was way too large, the result was in thousands due to numerical error in the original literature. Lowering the constant to tenth of the original was considered necessary.

The power of the extruder is 6.97 Hp, Inside diameter of the barrel is 0,71 inch. From Equation 5, the extruder capacity is calculated to be 7.53 lb/h or 3,42 kg/h. From the manufacturer's site, the production capacity of this sort of extruder is from 12 up to 100 kg per hour. Therefore we can assume that the size of this type of extruder is actually smaller than those of pilot extruder, it should be classified as laboratory extruder.

Ideal capacity of laboratory extruders is from 0.2 - 2.5 kg/h and 0.5 - 10 kg/h depending on the manufacturer. Although the screw diameter which is 18 mm would be too big for laboratory extruder which screws' sizes are ranging from 6.4 mm to 15.8 mm.

(Pekkala, 2009), P. 36

Table 18 – Comparisons of ΔT within the equation, experiment and literature (compiled by author)

Sample	Polymer	Cp [Btu/lb	ΔT(F) - equation	ΔT(F) - labresult	ΔT(F) - literature	ε - EqVSLab	ε – EqVSLit	ε - LabVSLit

		.F)						
1	PS	0,34	517,40	357,80	450,00	30,85 %	13,03 %	20,49 %
2	PS	0,34	517,40	357,80	450,00	30,85 %	13,03 %	20,49 %
3	PS	0,34	517,40	356,00	450,00	31,19 %	13,03 %	20,89 %
1	PP	0,50	351,83	359,60	450,00	2,21 %	27,90 %	20,09 %
2	PP	0,50	351,83	363,20	450,00	3,23 %	27,90 %	19,29 %
3	PP	0,50	351,83	361,40	450,00	2,72 %	27,90 %	19,69 %
4	PP	0,50	351,83	363,20	450,00	3,23 %	27,90 %	19,29 %
5	PP	0,50	351,83	363,20	450,00	3,23 %	27,90 %	19,29 %
1	LDPE	0,55	319,85	357,80	400,00	11,87 %	25,06 %	10,55 %
2	LDPE	0,55	319,85	363,20	400,00	13,55 %	25,06 %	9,20 %
					Average	13,29 %	22,87 %	17,93 %

From Table 18, one can compare the result of Equation 9, the result of experimentation as well as the ideal temperature change given in the literature. To be more precise, the error fraction comparing the three different results was also calculated for all samples. From the error fraction point of view, the value generated from Equation 9 and the ideal value in the literature present quite a big gap (more than 20% of ε). Thus, the constant of Equation 7 is changed according to the literature in order to give out a more precise value of extruder's capacity calculation.

The optimized formulae are presented in Subchapter 6.2. The implementation of the formula was used to calculate the production capacity of the extruder in relations to barrel diameter and power requirement in order to produce commonly extruded products such as pipes, profiles, foams and films. The implementation can be seen in Subchapter 5.5.

Table 19 – Average ΔT for different materials in Celsius (compiled by author)

Polymer	ΔT(C) - equation	ΔT(C) - labresult	ΔT(C) - literature
PS	269,67	180,67	232,22

PP	177,68	183,40	232,22
LDPE	159,91	182,50	204,44

5.3 Annual Production of Plastic Products with Extruder

Taking into account the conversion chart in subchapter 3.1., it is concluded that Uponor's corrugated drainage pipe has product content of 0,12 kg/m. Our example of Trafino Oy's roadside marker has product content of 9,36kg/m. Average nomalen™ foam by Termonova has product content of 0,84 kg/m^2. And our last example of average plastic film by Kalliomuovi Oy has a product content of 6,84*10^{-12}kg/m^2.

As observed in Figure 16 of subchapter 4.2.1., lower capacity single screw extruders have a production capacity of under 100kg/h. The medium range single screw extruders have production capacity rate between 100 – 1000 kg/h. And high range single screw extruders have a production capacity of higher than 1000kg/h.

The annual production was calculated using Figure 16 or the single screw extruders due to the fact that twin screw extruders are normally used for processing brittle PVC pipes. (Järvinen, 2008, p. 177)

Taking the example from Kalliomuovi Oy in Appendix E, extrusion companies normally work 8 hours per shift for 5 working days per week. They were employing the 3-shift system in the company to minimize the downtime of the extruder. Therefore, the number of working hours per year in average extrusion companies is 5760.

Equation 10 - Annual production calculation of plastic products (author)

$$Annual\_production(m/year) = \frac{Production\_capacity(kg/h)}{Plastic\_content(kg/m)} * 24h * 5d * 4w * 12m$$

$$= 5760 * \frac{Production\_capacity}{Plastic\_content} * (m/year)$$

Table 20 - Result of Annual production calculation of plastic products(compiled by author)

	Annual production (km/year) or (hectare/year)

Product (plastic content)	Low capacity (<100 kg/h)	Mid capacity (100-1000 kg/h)	High capacity (>1000 kg/h)
Pipe (0,12kg/m)	4800 km	4800 – 48000 km	48000 km
Profile (9,36 kg/m)	61,54 km	61,54 – 615,39 km	615, 39 km
Foam (0,84kg/m^2)	68,57 ha	68,57 – 685,71 ha	685,71 ha
Film ($8,84*10^{-12}$ kg/m2)	$6,51*10^{10}$ ha	$6,52*10^{10}$ - $6,52*10^{11}$ ha	$6,52*10^{11}$ ha

Production line of Trafino Oy in Appendix C was designed for manufacturing 5 - 10 km profile length / year. To conclude, Trafino Oy's sidemarker screen production is on the lower level of annual production.

5.4 Rough Estimate of Investment for Total Plant

As seen in Appendix E, The biggest extruder that Kalliomuovi Oy owns comes from Extron. The production capacity is 300 kg/h which is mid-range machine. The whole line costs them 1.5 million euros. The barrel diameter is 120 mm. (Koljonen, 2012)

5.5 Production capacity VS Barrel Parameter

As seen in Section 3.2.2, in European Union, standard extruder sizes are 20, 25, 30, 35, 40, 45, 50, 60, 90, 120, 150, 200, 250, 300, 350, 400, 450, 500 and 600 millimeters. Most extruders are ranged from 25 to 150 millimeters. (Rauwendaal, 2001, p. 11) In order to obtain the typical barrel size in low capacity, medium capacity and high capacity extruders produced, a calculation was made using Equation 6.

$$Qe = 4{,}35 \times 10^4 Db^{2{,}2}$$

Qe: Extruder capacity [kg/hour]

Db: Barrel's inside diameter [mm]

Equation 11 - Barrel size formula from the simplied production capacity formula (author)

$$Db = \sqrt[2{,}2]{\frac{Qe}{4{,}35 * 10^4}}$$

The power of Eco EX 18 laboratory extruder in Arcada is 5,2 kW. In order to find out typical power requirement for low, medium and high capacity extruders, a calculation was made using Equation 8.

$$Qe = 1{,}32 \times 10^3 \times \frac{P}{Cp \times \Delta T}$$

Qe: Production capacity [Kg/h]

P: Power [Watt]

Cp: Heat capacity [J/Kg.K]

ΔT: Temperature rise from feed to extrudate [Kelvin]

Equation 12 - Power formula using the energy calculation (author)

$$P = \frac{QexCpx\Delta T}{1{,}32 * 10^3}$$

In order to calculate the power used for the machine, experimentation sample from Table 17 of section 5.2.1 was used to obtain temperature rise within the barrel and heat capacity of the material. Material used is PP which has been tested 5 times. Average temperature rise within all 5 experimentations using PP is 161.4°C, which is 434.15 Kelvin. Heat capacity of PP is 1925 J/Kg.K. (Iben, 2011)

Table 21 - Production capacity VS barrel parameter(compiled by author)

	Low capacity		Mid capacity		High capacity	
	Low point	High point	Low point	High point	Low point	High point
Capacity (kg/h)	32	100	100	1000	1000	56 289
Capacity (tonne/year)	182,46	576	576	5 760	5 760	324 223
Typical barrel diameter (mm)	20	63	60	200	180	600

Power requirement (kW)	20	63	60	650	633	35 638

In order to validate the result of Capacity VS barrel parameter Table 21, a comparison was made to a technical data of an actual extruder provider.

Table 22 - Production capacity VS barrel parameter from an actual extruder provider (Qichang Plastic Machinery, 2008)

Parameter / Type / Item	SJ-35	SJ-45	SJ-55	SJ-65	SJ-80	SJ-90	SJ-100	SJ-120
Screw Diameter	Ø35mm	Ø45mm	Ø55mm	Ø65mm	Ø80mm	Ø90mm	Ø100mm	Ø120mm
Screw L/D ratio	25: 1	25: 1	25: 1	25: 1	25: 1	25: 1	25: 1	25: 1
Centre Height	1000mm	1000mm	1000mm	1000mm	1000mm	1000mm	1000mm	1000mm
Production Capacity(PE)	15kg /h	45kg /h	70kg /h	100kg /h	150kg /h	180kg /h	220kg /h	300kg /h
Production Capacity(PVC)	10kg /h	30kg /h	42kg /h	60kg /h	90kg /h	110kg /h	130kg /h	180kg /h
Screw Revolution(PE)	90Turn/min	90Turn/min	90Turn/min	90Turn/min	90Turn/min	90Turn/min	90Turn/min	90Turn/min
Screw Revolution(PVC)	30Turn/min	30Turn/min	30Turn/min	30Turn/min	30Turn/min	30Turn/min	30Turn/min	30Turn/min
Power(PE)	4kw	11kw	15kw	22kw	30kw	45kw	55kw	75kw
Power(PVC)	2.2kw	7.5kw	11kw	15kw	22kw	30kw	37kw	45kw
Heater zone	2+2	3+2	3+2	4+2	4+2	4+4	6+4	6+4
total power(PE)	7kw	18kw	25kw	38kw	50kw	70kw	85kw	110kw
total power(PE)	5kw	12kw	20kw	20kw	30kw	42kw	55kw	68kw
Weight	0.3t	1t	1.2t	1.5t	1.8t	2.2t	2.5t	4t

The difference calculation within the values was made with SJ-65, an extruder with 100 kg/h production capacity rate. Barrel diameter of Table 21 was calculated to be 63 mm, whereas the barrel diameter of the example of an actual extruder in Table 22 is 65 mm. There was only a 2mm difference within the values.

The power requirement calculated in Table 21 is 63 kW. Whereas in the actual machine shown in Table 22, the total power for the production is ranging between 20 – 38 kW. The power requirement seems to have a significant difference with the actual machine due three factors:

1) PP was used during the experimentation, instead of PE like the SJ-65 suggests
2) The temperature rise value from feed to extrudate is definitely smaller when done with a smaller laboratory extruder.

3) As seen in section 3.3.1, ECO EX 18's heating power is not capable to melt large amounts of material quickly.

6 DISCUSSION

6.1 The Most Commonly Extruded Products in Finland

Result of general products of extrusion of subchapter 2.4 is seen on Table 16. According to the result of the calculation, plastic film has the biggest demand in the market, afterwards comes plastic pipes, plastic foams and then plastic profiles. Plastic film contributes to 75% of the sales of extruded products. The factors of this result are due to the simplicity of the die design and the continuous output of the extrusion line. Being an OEM (original equipment manufacturer) also ensures continuous batch orders from subcontractors. As seen in Kalliomuovi Oy in Appendix E, there normally is 1 worker running 1 production line for each shift, which makes plastic film manufacturing less demanding and cheaper in terms of labor force compared to other products.

Surprisingly, foam manufacturers own bigger sales revenue compared to profile manufacturers although the number of foam manufacturers presented in Table 6 of section 2.4.3 is noticeably less by half of those of profile manufacturers presented in Table 5 of section 2.4.2.

6.2 Optimization of Capacity Calculation

Equation 8 of Section 3.2.2 is not very precise since we are neglecting the existence of melting heat and other thermal effects. (Aipma, 2012)

In order to optimize Equation 8, the error fraction between the equation and literature results needs to be minimized, firstly by finding the average difference between those values, and bring the result of the equation closer to the literature.

Table 23 – Optimizing Equation 4. (compiled by author)

Sample	Polymer	ΔT(F) - equation	ΔT(F) - literature	ε - EqVSLit

1	PS	595,01	450,00	24,37 %
2	PS	595,01	450,00	24,37 %
3	PS	595,01	450,00	24,37 %
1	PP	404,61	450,00	11,22 %
2	PP	404,61	450,00	11,22 %
3	PP	404,61	450,00	11,22 %
4	PP	404,61	450,00	11,22 %
5	PP	404,61	450,00	11,22 %
1	LDPE	367,82	400,00	8,75 %
2	LDPE	367,82	400,00	8,75 %
			Average	14,67 %

The least average error fraction was achieved when the initial ΔT(F) was multiplied by 1,15. We can observe that the result of the calculation is much closer now to the literature. The fraction of error has been reduced to 14.67%, from 22.87% presented in Table 23.

Equation 13 – Optimized formula for ΔT (imperial) suitable with Arcada's laboratory extruder (author)

$$\Delta T = \frac{1{,}15 \times 190 \times Hp}{Cp \times Qe}$$

$$\Delta T(°F) = \frac{218{,}5 \times 6{,}97 Hp}{Cp \times 7{,}53 lb / h}$$

$$\Delta T(°F) = \frac{202{,}25}{Cp}$$

Equation 14 – Optimized production capacity with energy formula (imperial) (author)

$$Qe = 218{,}5 \times \frac{Hp}{Cp \times \Delta T}$$

Conversion calculation from Equation 14 into metric unit along with the conversion factors can be seen in Equation 19 in Appendix A.

Equation 15 - Optimized production capacity calculation with energy formula (metric) (author)

$$Qe = 0{,}31 \frac{P}{Cp \Delta T}$$

6.3 Considerations Prior to Purchasing Extruder

In order to maximize the performance of the extruder, it is important to pay attention to the design of the screw according to its intended function. For each resin, screw parameters such as: grooved or smooth feed, screw pitch, compression ratio, flight depth, screw diameter and length, single flight or barrier, through put are adjusted to suit the screw to the material. (Alpha Marathon, 2012)

Due to the nature of an extruder, surfaces of the screw and barrel gradually wear. Screw and barrel reconditioning is one of the most cost-effective methods to restore the equipment to achieve its original performance. (Alpha Marathon, 2012)

7 CONCLUSION

The biggest problem within this thesis topic is to get the cost for the machinery of extrusion, whether it is the extruder alone or the entire extrusion line of a plant. It is still a big secret in the plastics industry over the cost of machinery and that manufacturers do not want to give out publicly until an order inquiry is officially made by the company or the entrepreneur.

Looking at the sizes of extruders presented in the thesis, we can conclude that the biggest extruders for mass production come from Asia and America. European companies tend to employ extruders with smaller capacity for household equipment. Many European companies, especially Nordic countries, make more laboratory and pilot size extruders compared to production size. Entrepreneur needs to look up to the amount of output that they want to generate annually prior to choosing the size of extruder suitable for the manufacturing line.

Some literatures suggested the existence and definitions of disk- and ram-extruders. But the author did not find the need to include them in the literature survey area because they are not commonly used in real production sites due to their enhanced method of caretaking (lubricants and disassembly).

8 SUGGESTIONS FOR FURTHER WORK

Due to confidentiality of the extruder manufacturers, the author did not manage to get prices of extruders sold in the market. A business deal needs to be made prior to information collection.

From the list of companies given in chapter 4, entrepreneur can plan to start an extrusion line way ahead by contacting their local distributing agents and talk about the plant assembly. Figure 16 and 17 of subchapter 4.2.1 is considered useful as a reference prior to ordering a production size extruder.

While the agent is presenting the customers with a list of barrel prices, the customer can bargain with a help of the list of barrel manufacturers on the market. The customer will do the calculations and decide if they will take the agents' offer and agree on the recommended spare parts or if they can buy a spare part that is worth a fraction of what the agent is offering.

Future thesis topics that can be related to this thesis:

- Estimating cost of an injection molding plant
- Production capacity calculations for typical barrel sizes in European Union
- Starting up a distributing agency to extruder manufacturers that are not yet available in your country.
- Regression analysis to find the formula for prices of extruders in the market. The formula can be used for forecasting the price of the upcoming extruders on the market. Furthermore the risk of error will be reduced to find the optimum formula.

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Appendix A

Equation 16 - Conversion of simplified production capacity to metric unit

1lb = 0.4536 kg

1 inch = 25.40 mm

$$[lb/h]Qe = 16 \times ([inch]Db)^{2,2}$$

$$[lb/h] \times [0.45kg/lb]Qe = 16 \times ([inch] * [25.40mm/inch]Db)^{2,2}$$

$$0,45Qe = 16 \times (25,4Db)^{2,2}$$

$$Qe = \frac{16 \times 25,4^{2,2} \times Db^{2,2}}{0,45}$$

Equation 17 - Conversion of production capacity formula with energy to metric unit

1lb = 0.4536 kg

1Hp = 735.5 W

1 Btu = 1055 J

1 Fahrenheit = 255.93 Kelvin

$$Qe[lb/hour] = 1{,}9 \times 10^3 \times \frac{Hp}{Cp\left[\frac{Btu}{lb \times Fahrenheit}\right] \times \Delta T[Fahrenheit]}$$

$$Qe[lb/hour] \times 0{,}45[kg/lb] = 1{,}9 \times 10^3 \times$$

$$\frac{Power[Hp] \times 735.5[W/Hp]}{Cp\left[\frac{Btu \times 1055[J/Btu]}{lb \times [0{,}45kg/lb] \times Fahrenheit \times 255{,}93[K/F]}\right] \times \Delta T[Fahrenheit] \times 255{,}93[K/F]}$$

$$0{,}45Qe[kg/hour] = 1{,}9 \times 10^3 \times \frac{735.5P[W]}{Cp\left[\frac{1055J}{0{,}45kg \times 255{,}93K}\right] \times 255{,}93K \times \Delta T}$$

$$Qe[kg/h] = \frac{1{,}9 \times 10^3 \times 735.5W \times 0{,}45kg \times 255{,}93K}{0{,}45 \times 1055J \times 255{,}93K} \times \frac{P}{Cp \times \Delta T}$$

Equation 18 - Conversion factors of heat capacity equation

$$1hp = 735{,}5W \leftrightarrow 1W = 0{,}00136HP$$

$$1\frac{Btu}{lb°F} = 4{,}186\frac{kJ}{kg.K} \leftrightarrow 1\frac{kJ}{kg.K} = 0{,}2389\frac{Btu}{lb°F}$$

$$1°F = 0{,}555K \leftrightarrow 1K = 1{,}8°F$$

$$1lb = 0{,}45kg \leftrightarrow 1kg = 2{,}2lb$$

$$1Btu = 1055J$$

Equation 19 - Conversion of Equation 9 into metric unit

$$Qe = 218{,}5\left[\frac{\frac{Btu}{h}}{HP}\right]\frac{P[HP]}{Cp\left[\frac{Btu}{lb°F}\right]\Delta T[°F]}$$

$$= 218{,}5\left[\frac{\frac{Btu}{h}}{HP}\right]x0{,}45\left[\frac{\frac{kJ/h}{W}}{\frac{\frac{Btu}{h}}{HP}}\right]\frac{P[W]x0{,}00136\left[\frac{HP}{W}\right]}{Cp\left[\frac{kJ}{kgK}\right]x0{,}2389\left[\frac{\frac{Btu}{lb°F}}{\frac{kJ}{kgK}}\right]x\Delta T[K]x1{,}8\left[\frac{°F}{K}\right]}$$

$$= \frac{218{,}5x0{,}45x0{,}00136}{0{,}2389x1{,}8}\frac{P[W]}{Cp\left[\frac{kJ}{kgK}\right]\Delta T[K]}$$

$$= 0{,}31\frac{P}{Cp\Delta T}$$

Appendix B

Example of Pipes: Uponor

During Production economics class visit to the Uponor headquarter in Nastola, we were greeted by the training manager, Mr. Tommi Ruhonen. In 1964, they started the first plastic production in Lahti, which was followed by many other companies afterwards. When the company was first built, they used to employ 1000 workers and own housing and medical facilities intended for their workers. Nowadays they employ 270 workers, they have cut down 30 in the recent year due to automation development. They have consultants working in the main headquarter, and they outsource designers from their subcontractors. So far they have had a total of 30000 of product variations, the variations can be measured by the length or diameter of the product and material composition.

They have sale offices all over the world all the way to China. They do not have so many production plants, many of them have been sold due to competition. They only headquarter is in Nastola, Finland. They have a net sale of 720 million euros. Uponor Oyj is a listed company, they have to inform their place in the stock market to the shareholders every once in 3 months.

Their products are ranging from pipes, pipe fittings and chambers. Their pipes have special properties such as for clean water provider and in infrastructure such as for grey and black water safety transport. Uponor spotted some problems while using the PVC materials for pipe fittings, later on they were changed to PP. The problems were diagnosed in apartment buildings in Czech Republic, people used to install PVC-based pipes and pipe fittings in the olden days, later on they realized that PVC evaporates into toxic gas when the buildings catch fire.

The use of PP-based pipes and pipe fittings has replaced PVC since then because in practice, PP can be burnt down for energy recovery. The replacement of PVC has nothing to do with its granulate price.

Uponor’s house drainage system is already patented. They produce drainage system pipes in Germany where they reinforce a pipe out of a double layer of PP and aluminium in the middle. The function of aluminium is to provide strength within the pipe, and the function of double PP layer is to protect the quality of the water and to avoid metal corrosion within the aluminium. In the manufacturing process, they used the PERG which is the recycled PE temperature.

Uponor’s contribution in infrastructure sector includes the manufacturing of pressure withstanding pipes for sewage, storm water and gas properties. Those pipes are normally PE or PP based. PE neutralizes the taste, therefore it is generally used for drinking water. The plastic in pipes are welded together with electric fusion in order to close the loops. They also manufacture chambers for waste water treatments such as sauna chambers and grey water filter. Their rotation molded products are manufactured in Sweden.

We observed the production of corrugated pipes. The function of corrugated pipes is basically to utilize less material while employing maximum strength. The corrugation pattern can be seen widely at the range of cardboard boxes available on the market.

The longest corrugated pipe extrusion line that we observed in the plant hails the length of 70 m. More detailed steps of corrugated pipes production can be seen in Figure 19.

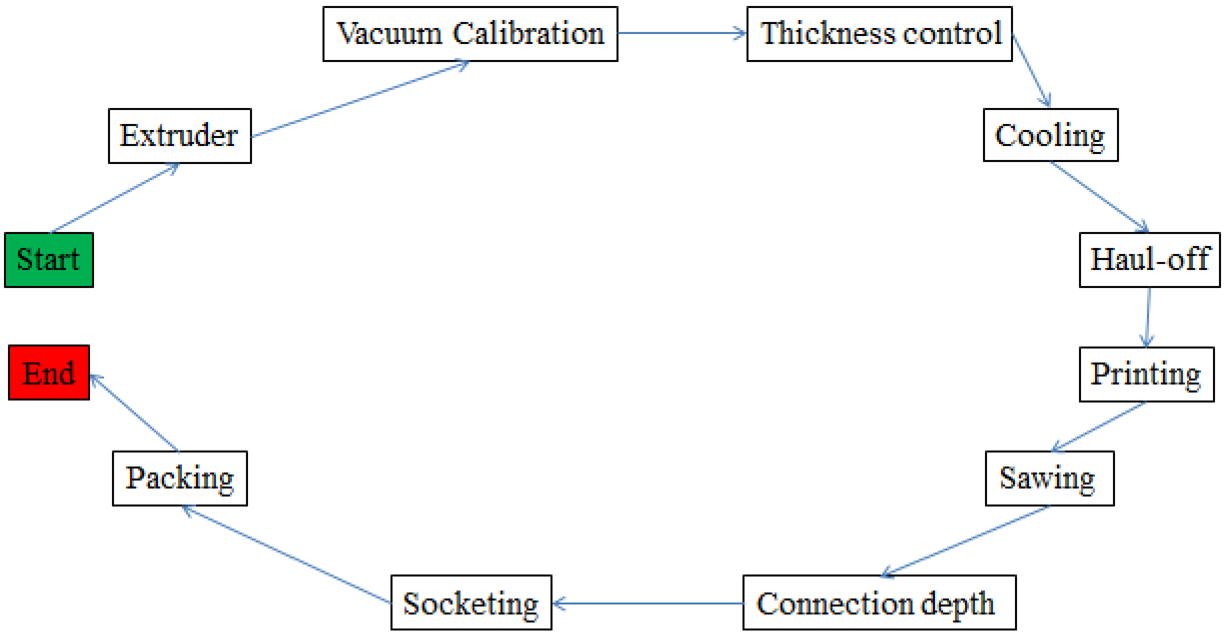

Figure 19 – Corrugated pipe extrusion process in Uponor Oyj.(compiled by author)

Feeding of extruders is done by silos, they are transported by pneumatic carriage, and furthermore blended with additives to a special section called the mixing road (fin.

Sekoitustie). The granules stored in silos are normally PVC, for PE they have bags that consist of 2 tons of granules per bag. Their products are normally made from maximum 20% of recycled materials.

Uponor uses Clariant's masterbatches for their rain water pipes, it is a stream flow process that never stops throughout the year. The workers are working on 3 shifts, there are 30 workers on each shift. The production site is running the whole year around, except for mid-summer when it is only up for maintenance operations. The rain water drainage pipes are corrugated, has a cross sectional diameter of 10 cm, it has 3 layers of laminations, and the production line is 70 m long as observed in Figure 12. The 3 layers of laminations are done by 3 different extruders, one of them by Cinpres am EX3000. The production capacity of the extrusion line is 5 meters per minute, there is a minimum amount of 840 g materials in each meter. The machine produces a maximum capacity of 250 kg/h, two single screw extruders are put on top of one single screw extruder in order to smoothly reinforce the plastics and reduce the gap between the machines. Their biggest extruders comes from Extron. Measurement and calibration are done by battenfeld extrusion technik device. The cooling is done by rollerpool RHO 20-6T chamber. The extrusion line employs automated cutting and conveying.

(Ruhonen, 2012)

Appendix C

Example of Profiles: Trafino Oy

Trafino Oy specializes in selling products for road safety. Trafino Ltd is headquartered in Espoo and is also available in Raisio. Trafino is a subsidiary of Putkiyhtymä Oy and is also a family business founded in 1986. The company has both purchased and own produced products and were interested to start manufacturing their own road mark signs. (Pekkala, 2009, p. 8)

Roadside marker screens for road works of this type are used as temporary help to direct and facilitate motorists to drive right on road work sites and other hazardous locations requiring temporary marking needs. They are normally used with other brands to improve security further. It is safer in traffic and easier for drivers to notice their existence since the reflecting surface of the plate is larger than the round tower models. The red safety color is standardized and there are two different grades of reflectors to choose from. (Pekkala, 2009, pp. 10 - 11)

Figure 20 – Snapshot of the roadside-marker screen and bottom (Pekkala, 2009, p. 11)

Production line designed for manufacturing 5 - 10 km profile length / year of roadside-marker screens including:

1) Filling of plastic granules

   Filling is done by hand or by machine with a suction device. Plastic granules are available in bulk or in sacks of 25 kg.

2) The extruder

   Choose the right size of the screw for the production of roadside-marker screens. Screw should be able to process plastic materials PP and PVC. Suitable extruder for producing the roadside-marker screen profiles is Extruder Eco 45HP EX 25 x D

3) Die and conveyor belt

   Conveyor belt DBT 3, dual-band conveyor belt

   The appropriate die manufactured by Axon Plastics Machinery AB

4) Cooling pool for the profile

   Adapted so that the profiles are cooled down long enough and the profile does not become deformed. Suitable cooling tunnel V2/225 10, Vacuum calibrator equipped cooling tunnel.

5) Cutting of profiles

   Sawing is done by machine or by hand depending on the final costs. Suitable mechanical saw for cutting MS 3, saw working dimension is 1.5 m. Saw will be synchronized with the conveyor belt placement.

6) Drying

   No separate drying, the profiles are cut and stored vertically; water is automatically run down by gravity.

7) Sticking reflectors

   Done by hand, because there are no reflectors of this kind in ready rolls. The client was questioned and he confirmed that they were glued on by hand.

8) Punching holes and recycling symbols.

   There are four different kinds of holes on the product, as seen on Figure 21. The large hole 1, is designed to facilitate transportation of the roadside-marker screen as it is attached to the rubber bottom, the hole is used as a handle. Hole number 2 is used to attach the roadside marker screen in rubber bottom, see Figure 22. Holes 3 and 4 are for attaching the roadside-marker screen with screws if the bottom is not used.

Stamping of the recycling symbol, see Figure 23. Recycling Symbol was seen on the old roadside-marker screen.

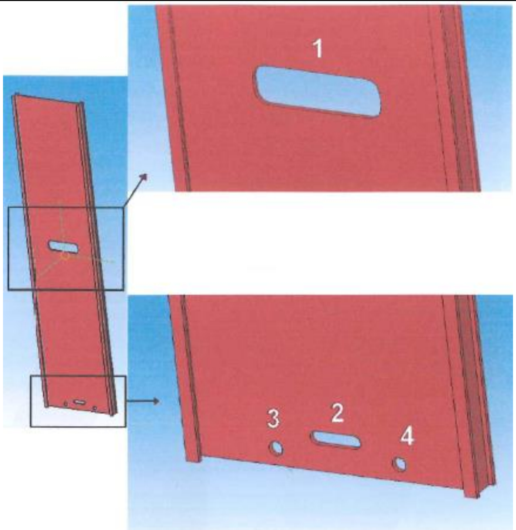

Figure 21 - Roadside-marker screen and the holes to be punched out zoomed in (Pekkala, 2009), P. 42

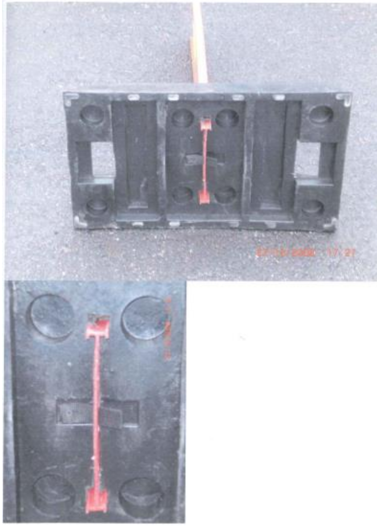

Figure 22 - Roadside marker screen's bottom zoomed in. The screen is attached to the bottom and sealed with a rubber band. (Pekkala, 2009), P. 43

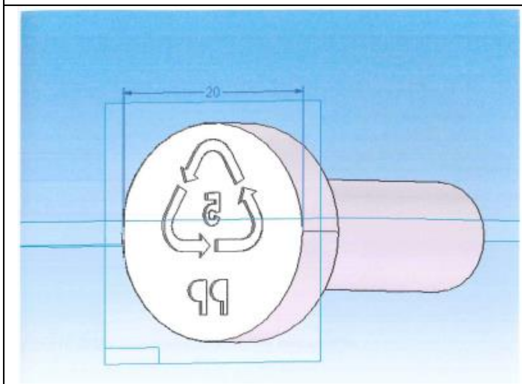

Figure 23 - Stamp with PP symbol. The stamp is 20 mm in diameter. (Pekkala, 2009), P. 44

9) Storage

Side-marker screen can be stored horizontally or vertically for reflectors attachment.

(Pekkala, 2009), P. 40 - 44

Appendix D

Example of Foams: NMC Termonova Oy

NMC Termonova Oy is a subsidiary of NMC Group. NMC has been operating in many European countries. The Group is headquartered in Belgium. Development, production, sales and marketing of plastics are the areas that the Group is mainly specializing in. The product sale includes various technical insulation, decorative profiles for indoor and outdoor use, packaging, products for sports and recreation and various solutions for industry.

NMC Termonova Oy's Finnish headquarter is located in Inkoo, about 50 km west of Helsinki. The factory is the only Nordic manufacturer of cross-linked polyethylene foam. Some portion of the output sold as intermediate goods, mainly rolls and sheets. The rest is processed into finished products including carpets, floor coverings, sports- and leisure gear. A large part of the production is exported.
(Hakkarainen, 2007, p. 16)

Crosslinked Polyethylene Foam

Foams occur with both of open and closed cells. Materials that have a closed cell structure are characterized in that the liquid does not permeate in the uncompressed state and releases air when compressed under liquid. Open cell structure makes it possible to release air from the cells and the material both absorb and emit liquid. Nomalen™ is cross-linked polyethylene foam with closed cell structure. (Hakkarainen, 2007, p. 19)

One can alter the properties of polyethylene, by three dimensional crosslinking. Crosslinked polyethylene is broadly known as PE-X, where X is the symbol of the cross.
Polyethylene containing cross-linking additives may be plasticized in an extruder in the usual manner at 160 ° C and are crosslinked at temperatures up to 230 ° C.

The crosslinking of PE results in distinct property improvements. Cross-linked PE, PE-X, has a higher heat distortion temperature, higher resistance to stress corrosion and abrasion than ordinary PE. The cross-linking leads to further improved creep resistance and impact strength at low temperatures and better aging resistance in comparison with thermoplastic polyethylene. The stiffness and impact strength will slightly be lower at room temperature. (Hakkarainen, 2007, p. 25)

Polyethylene Cross-linking Method

The crosslinking of the polyethylene is done by physical or chemical means. The physical methods is irradiating polyethylene with an electron gun or isotopes, while the chemical is based on:

- Radical Formation of azo compounds
- Graft polymerization of vinylsilanes
- Radical Formation of peroxides

At Termonova they use the peroxide process. The crosslinking is created by mixing polyethylene with a relatively stable peroxide. The peroxides are stable at normal processing temperatures but decomposes at elevated temperature and crosslink polyethylene.
(Hakkarainen, 2007, pp. 25 - 26)

Production of PE-X at NMC Termonova Oy

The plant in Inkoo manufactures cross-linked polyethylene by continuous extrusion of two separated production lines. The process starts by feeding LDPE by negative pressure from the three silos with volume of 50 m^3 (Figure 24) into a dosing unit (Figure 25). (Hakkarainen, 2007), P. 27

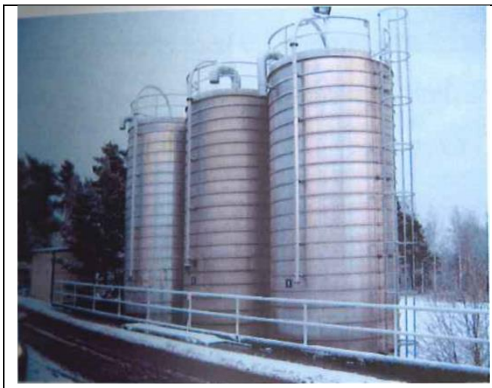

Figure 24 - Storage silos for polyethylene (Hakkarainen, 2007), P. 27

Figure 25 - - Dosing unit (Hakkarainen, 2007), P. 27

Dosing unit (Figure 25) adds the right amount of raw material into the extruder barrel (Figure 26), depending on the type of material fed. Granules flow through the metering funnels down to the twin-screw extruder, where they are melted and blended. Afterwards, the plasticizing screws presses out the resin through the nozzle. The plastic mass is then rolled out into an oven where cross-linking takes place by the foretold peroxide process. (Hakkarainen, 2007), P. 28

Figure 26 - Extruder's barrel (Hakkarainen, 2007), P. 28

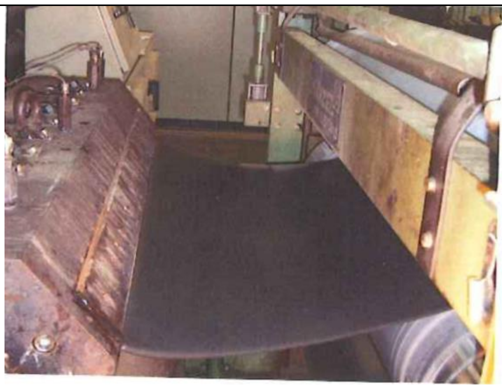

Figure 27 - Extruder's die and backwards rolling (Hakkarainen, 2007), P. 28

After the cross-linked polyethylene is carried through the furnace (Figure 29), it is cooled down in a water bath. The length of material is measured with a measuring wheel, as shown in Figure 31, while the rough edges are removed. The semi-finished result is wound into rolls; the dimensions shall then be specified by the customer

(Figure 32). At NMC Termonova Oy, this product is known as the nomalen™. (Hakkarainen, 2007), P. 28

Figure 28 - Extruded resin is wound into rolls (Hakkarainen, 2007), P. 28

Figure 29 - The rolled resin is carried onto the furnace (Hakkarainen, 2007), P. 28

Figure 30 - After the peroxide process, cross-linked polyethylene is coming out of the oven, (Hakkarainen, 2007) P. 29

Figure 31 - Measurement wheel measures the length of the production batch, (Hakkarainen, 2007) P. 29

Figure 32 - Unwinding PE-X into rolls (Hakkarainen, 2007), P .29

Uses for nomalen™ Foam

Nomalen ™ is used mainly in the following areas:

1) Semi-fabricated:
   - As rollers
   - As discs

2) Building Products:
   - Thermal insulating materials
   - Sound Insulators

3) Sports and camping:
   - Archery target boards
   - Gymnastics mats
   - Mats of martial arts
   - Swimming aids
   - Sleeping and sitting mats
   - Golf mats

4) Boats:
   - Boat cushions
   - Fender

5) Home:
   - Carpets covered by textile surfaces
   - Mats

(Hakkarainen, 2007, p. 35)

Appendix E

Example of films: Kalliomuovi Oy

Kalliomuovi is a family inherited company located in Kalliola. The company was founded in 1971. It is a comparatively small company, they are not a part of the stock exchange, and neither do they operate abroad. They operate in blown-film manufacturing, their product varieties solely depending on the thickness and width of the film, number of layers of the film, colorants and material type. Kalliomuovi uses in total 4 to 5 virgin plastic materials. (Koljonen, 2012)

The workers use normally 1 type of material per week, or 1 variation that includes that core material. This is a pretty wise system that can downsize the amount of scraps presented in random mixtures of materials. The extruder is automatically heated up 3 hours prior to Monday morning early shifts to eliminate downtime. The width of the film produced within an operational week depends on the day of the week, its width either increase or decrease day by day. The theory is best illustrated in Figure 33.

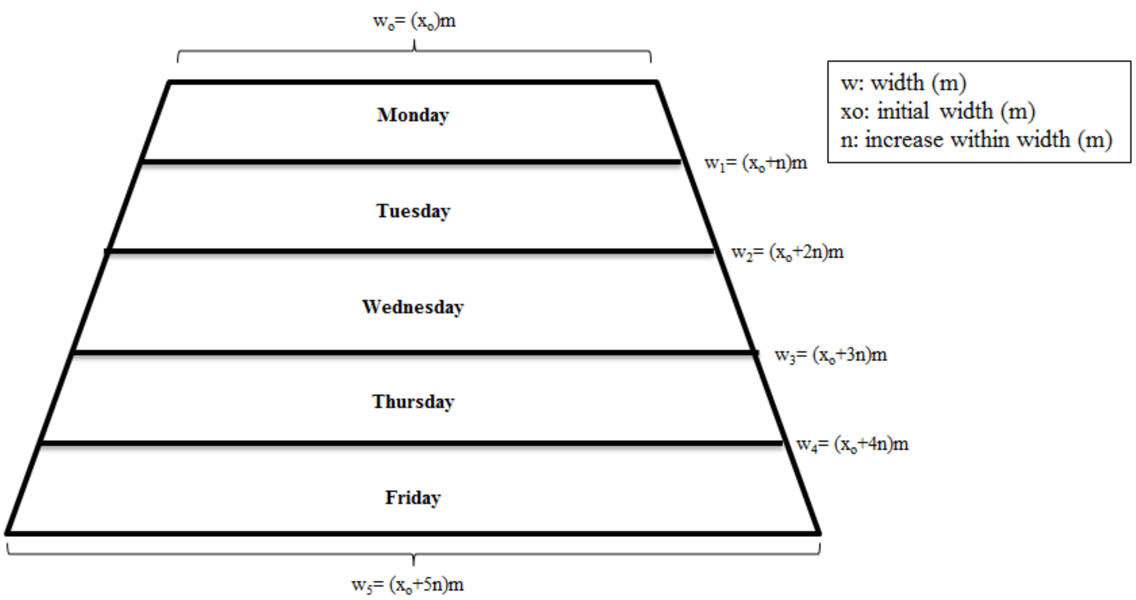

Figure 33 – Daily increase of width in film production plant in Kalliomuovi Oy (Koljonen, 2012) (compiled by author)

They are implementing OEM (original equipment manufacturer). It is considered as a safe method of doing business, they need to be friendly with the other suppliers, but they do not decide upon the brand names. They produce plastic films depending on the order to contractors such as K-rauta, Findomo, Sini-pii Ky, Mercamer Oy (packaging film depot). Those companies are the ones who get to decide on the brand name for the plastic films that Kalliomuovi Oy has produced. The type of plastic film that they provide for Findomo during that particular week has a density of 828 g/m and there is 41 m in every roll.

The only standardize vapor barrier from their products. Inspectors from their contractors are the ones deciding whether the film is good enough not let any humidity passes to ensure that the product is freshly kept inside the film.

The harder the PE granules are, the thicker quality of film is produced. They have a vacuum hose that transports the PE granules that can also select the size for the end product. The granules are fed into the middle hopper presented in Figure 34. While the side hoppers are used for additives such as UV-stabilizers, colorants and antistatic. The colder the temperature is, the more antistatic additives are added to the film production.

Figure 34 – Feeding hoppers in Kalliomuovi Oy.(image taken by author)

The biggest extruder that they have comes from Extron. The production capacity is 300 kg/h. The whole line costs them 1.5 million euros. The barrel diameter is 120 cm. The extruder possesses a reciprocal Archimedean screw system; the material is transported back and forth within the barrel.

The blower die presented in Figure 36 is manufactured by Alpha Marathon. It possesses constant cooling and warm air is blown inside to expand the diameter of the blown film. The die is rotating in order to homogenize the fluctuations or in other words to even out the thickness. Thickness of the end product is ranging from 40 µm to 100 µm. The faster the die rotates, the thinner and larger foils are achieved. There is a sensor inside of the die that can control the expansion; air flow is adjusted depending on the value that the sensor gives. The temperature of the film exiting the die is 220°C; it reaches a minimum of room temperature of 22°C when it is at the peak before it is rolled into sheet. The height of the cooling tower is 12.5 m. The process is clearly illustrated in Figure 35.

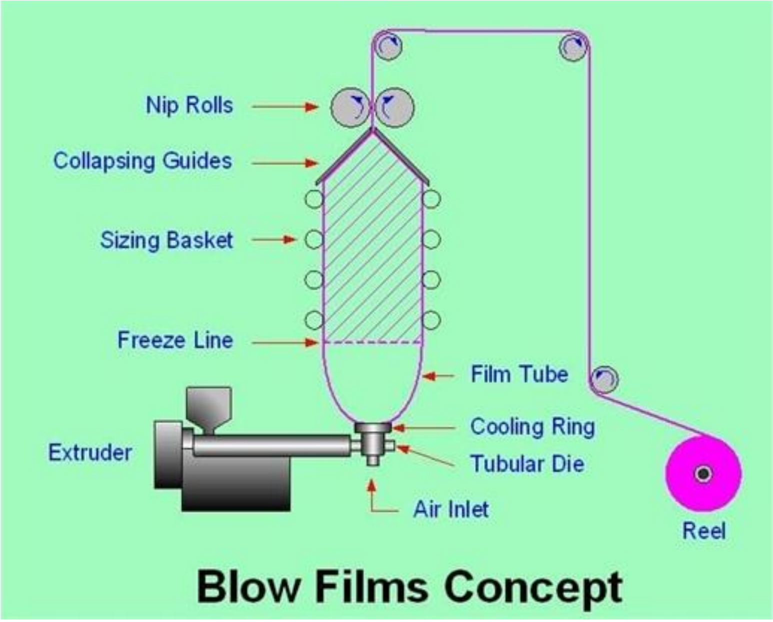

Figure 35 – Illustration of blown film process (plastic, 2012)

Figure 36 – Rotating blown film die (image taken by author)

Figure 37 – Blown film is collected into sheet at the very top by the nip roll (image taken by author)

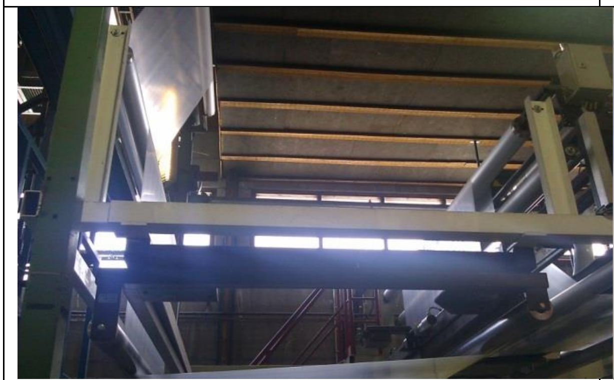

Figure 38 – Guiding rolls retracting the sheet from nip roll (image taken by author)

Figure 39 – The guiding rolls are operated by this calibration machine (image taken by author)

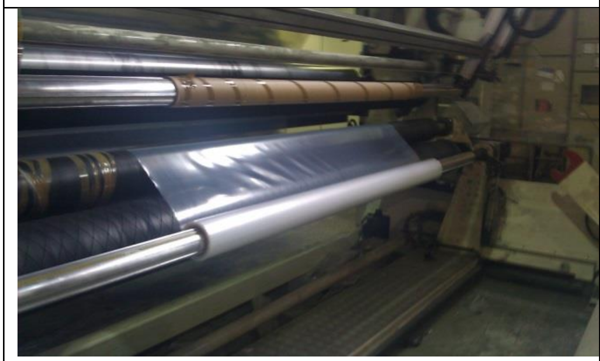

Figure 40 - Plastic film reeled in (image taken by author)

Appendix F

Example of extrusion coating and laminating: Kalliomuovi Oy

The second film blowing line presented in Kalliomuovi Oy was the lamination film blowing line. It comprises 3 different single screw extruders that are combined into 1 same die. The extruders are manufactured by Plastex. The extruder has production capacity of 250 kg/h. (Koljonen, 2012)

In Figure 41, the plastic film is already hardened. Even though the method of production is fully automated, but they apparently still use manual workforce for replacing the old stocking and setting up a new stocking assembly.

Figure 41 – Lamination film blowing process (image taken by author)

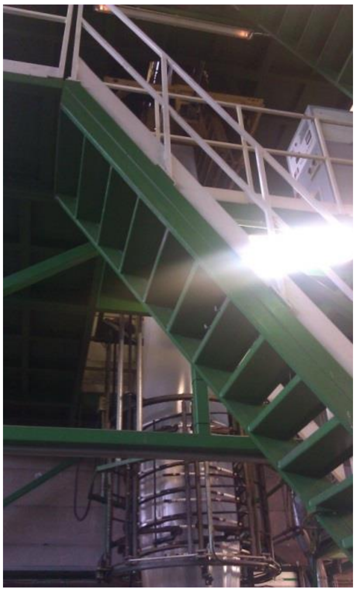

Figure 42 - Tower of lamination film blowing(image taken by author)

Appendix G

Example of extrusion blow molding: Oy Plastex Ab

Oy Plastex Ab is specialized in blow molding, where it produces products of different sizes up to 100 liters up to the entire class. Plastex manufactures own and contract manufacturing of products. 15 per cent of their turnover comes from injection molded products. Injection molded products manufacturing is outsourced to North Karelia’s Plasthill Oy.

Plastex is Finland's largest wholesale supplier of retail stores. The company manufactures all the well-known specialty goods such as Watering Cans, petrol canisters, Juice package bottles, big mouthed cans and water containers. In addition, Plastex manufactures products such as the expansion tank, and tanks to the automotive industry's connection pipes, and storm water systems. Packaging of the major products are different from the bottles and cans, in addition to selection takes packaging buckets for example, sprayer pistols, metering pumps, cans and PET.

Exports of the company's products are about 13 percent. The main export countries are Sweden, Norway and Estonia.

Plastex is a family business of third generation. Operations began in Helsinki in 1936 as Company Jewelry Box and Carton Plant. The company produced hand-made machines, buttons, and other small plastic products. Activity increased and diversified at a steady pace. In 1942, they moved to larger facilities in Lohja. At the same time, the name was changed to Plastex Oy Ab.

Plastex became the first Finnish company to the domestic plastic bottle blow molding. Some of the company's products have been in production since 1940-50s. Long-standing favorites include: Hay rake, baler and dustpan. New custom and contract manufactured products are constantly being developed in cooperation with leading Finnish designers. Plastex product development has long been focused on high-quality design.

Plastex is a certified quality system ISO 9001 and go by the significant level of automation and information systems modernization. Plastex’s vision is to become the Nordic region's leading consumer goods manufacturer of blow and separate segment.

(Järvinen, 2008, p. 179)

Figure 43 – Plastex specializes in plastic blow molding (Järvinen, 2008, p. 179)

Oy Plastex Ab
Venteläntie 12, 08500 Lohja | puhelin: 019 357 601 | info@plastex.fi | www.plastex.fi
Henkilöstö: noin 34 | Liikevaihto: 4,7 miljoonaa euroa vuonna 2007
Päätuotteet: käyttötavaroista vesiastiat, autotarvikkeet, keittiötarvikkeet sekä marjastus- ja säilöntätuotteet, sopimusvalmistustuotteista putkiteollisuudelle ja ajoneuvoteollisuudelle valmistettavat tuotteet sekä pakkauksista erilaiset pullot, purkit ja kanisterit.

Figure 44 - Plastex's contact information (Järvinen, 2008, p. 179)

Appendix H

Table 24- Tecnova extruders with the processable materials and production capacity range (Tecnova s.r.l., 2012)

Product	Material	Production capacity Range [kg/h]	
Complete plant E60 FTTA	Film LDPE / HDPE	90	120
Complete plant E60 FTTC	Film LDPE / HDPE /PP	120	150
Complete plant E75 FTTC	Film LDPE / HDPE	170	190
Complete plant MINI 90 FTTC	Film LDPE / HDPE /PP	90	120
Complete plant E90 TTC	Film LDPE / HDPE / PP / PS / ABS	220	280
Complete plant E90	Polyamide	160	230
Complete plant MINI 90 FTTA	Film LDPE / HDPE	90	120
Complete plant E105 TTC	Film LDPE / HDPE / PP / PS / ABS	300	380
Complete plant E105 FTTC	LDPE / HDPE /PP	270	350
Complete plant E105 - PET	PET	350	
Complete plant E130 TTC	LDPE / HDPE / PP / PS / ABS	500	600
Complete plant E130 FTTC	Film LDPE / HDPE /PP	450	580
Complete plant E130/54D – TTC DOUBLE VENT	LDPE / HDPE / PP / PS / ABS	500	600
Complete plant E130/54D – FTTC DOUBLE VENT	Film LDPE / HDPE /PP	450	580
Complete plant E160 TTC	LDPE / HDPE / PP / PS / ABS	900	1100
Complete plant E160 FTTC	LDPE / HDPE /PP	900	1100
Complete plant E160/54D – TTC DOUBLE VENT	LDPE / HDPE / PP / PS / ABS	900	1100
Complete plant E160/54D – FTTC DOUBLE VENT	Film LDPE / HDPE /PP	900	1100
Complete plant E160/54D – FTTC DOUBLE VENT - INOX	Film LDPE / HDPE /PP	900	1100
TWIN SCREW 128/42D with 3 vents complete plant	Film LDPE / HDPE /PP	900	1100