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Sunil K. Agrawal
University of Windsor

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OPTIMUM VELOCITY REQUIREMENTS IN GRIT CHAMBERS AND AERATION TANKS BASED ON CRITICAL SHEAR STRESS

by

SUNIL K. AGRAWAL, B.E., M.E.

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TO MY PARENTS, SUSHMA AND SHIVANI

ABSTRACT

A modified approach to design various treatment units handling particles in suspension or in settled form in water and wastewater treatment is proposed. The recommended method of design is based on the concept of critical shear stress. It is shown that the design of different treatment units based on critical shear stress is more rational and can be used to optimize the performance of the units.

This study was conducted in four parts. The first part consisted of the experiments on different sizes of grit and gravel particles in a laboratory flume to obtain the critical bed shear stress necessary to initiate the motion. Grit samples, collected from the West Windsor Pollution Control Plant were washed and sieved. Some larger gravel particles were included also in the study. The information gathered through these experiments have been used to determine the minimum bed shear stresses required in various water and wastewater treatment units, where the deposition of inert particles is undesirable. These critical bed shear stress values can also be used to design treatment units, where the deposition of inert particles is desired.

In the second part critical bed shear stresses, necessary to initiate the motion of different types of sludge particles in the laboratory flume, were obtained. Sludge samples were collected from water and wastewater treatment plants in Windsor, Amherstburg and Chatham. Five different types of sludge samples were analyzed; biological wastewater sludge, physico-chemical wastewater sludge, alum sludge from water treatment plant, secondary digested sludge and a mixture of primary and secondary biological sludge. These experiments allowed a determination of the minimum shear stress required in various water and wastewater treatment units where the deposition of these sludge particles is undesirable.

The third part was concerned with the rheological properties of all five types of sludges, both before and after settling. The yield stress values obtained in the laboratory using viscosity meters are recommended for use in the design of treatment units where the settling and shearing of sludge particles or flocs is not permitted. The value of yield stress is the maximum shear that can be allowed in a treatment unit or in a mixing chamber without breaking the flocs or particles and also keeping them in suspension.

In the fourth part an empirical model of an aeration tank was formulated based on the actual experimental velocity distribution data. The horizontal velocities at different depths in an aeration tank were measured under a range of different operating conditions. The developed model is based

on the horizontal velocity, 25 mm above the tank bottom, under different operating conditions such as air flow rate, diffuser submergence, liquid depth and tank width. The information on horizontal velocites close to the tank bottom is important in the design of an aeration tank in which the settling of floc particles is not allowed.

Typical applications of the proposed design methods are presented. These methods can be used in the design of grit chambers, both conventional and aerated, storm and sanitary sewers, flocculation chambers, settling tanks, aeration tanks and mixing chambers.

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Chapter I

INTRODUCTION

1.1 General

Both raw water and wastewaters contain settleable and suspended particles with different settling characteristics. In certain treatment units, these particles are removed by gravity, with or without the use of chemical coagulants, whereas in some other units, it becomes necessary to keep these particles in suspension. For example, the grit chambers are designed to remove only the inert grit particles from the wastewater while keeping the decomposable organic solids in suspension, whereas the sedimentation tanks are designed to remove all the settleable particles. On the other hand, mixing chambers, flocculators and aeration tanks are designed to keep such particles and flocs in suspension all the time.

Air agitated tanks and channels are among the most power consuming units in water and wastewaters treatment plants. The diffused air in these treatment units serves one or more of the following functions:

1. Mix the contents of the tank
2. Provide dissolved oxygen to satisfy biological and/or chemical oxygen demands

3. Provide sufficient circulating velocities to keep the settleable flocs or particles in suspension
4. Allow heavier inert particles to settle while keeping the lighter organic particles in suspension

Although a great deal of field and laboratory data are available on the design of mechanically agitated tanks, the information available on the design of air agitated tanks and channels is limited. Most of the research work with air agitated tanks has been directed towards mass transfer of oxygen and air requirement to satisfy biological and/or chemical oxygen demand. Only a limited amount of information is available on the air requirement to keep the particles in suspension under specified conditions or to allow heavier particles to settle while keeping lighter particles in suspension.

It has been reported [103] that, in aeration tanks for conventional domestic wastewater treatment plants, the amount of air required to keep the floc in suspension is higher than that needed to satisfy biochemical oxygen demand, BOD. Thus, if the aeration tank is designed to keep the flocs in suspension all the time, then the oxygen demand would also be satisfied. However, most of designs have been based mainly on oxygen requirement. It should be recognized that while keeping the floc in suspension in an aeration tank, it should not be sheared to an extent that it would not settle efficiently in the settling tank.

1.2 Objectives

The purpose of this research was to develop a better approach for the design of various treatment units which handle particles in suspension or in settled form in water and wastewater treatment practices. The modified method for the design is based on the concept of critical shear stresses required to initiate particle motion and on yield stresses. This research was divided into four parts:

1. Determine the scouring velocities for different sizes of grit particles in a flume in order to calculate the shear stress required to initiate the motion of particles and use this information in the design of both conventional and aerated grit chambers.
2. Determine the scouring velocities for different types of sludge particles in a flume in order to calculate the minimum shear stress required in an aeration unit to prevent settling of particles.
3. Determine the yield stress of different types of sludges to obtain the upper limit for shear stress that can be permitted in an aeration unit without shearing the floc.
4. Develop a model to predict horizontal velocity near the bottom of an aeration tank under different operating conditions.

Chapter II

LITERATURE REVIEW AND HISTORICAL BACKGROUND

2.1 Aeration Process

2.1.1 General

The aeration process is of great importance for its wide range of applications in the treatment of water and wastewaters. Diffused air is used most widely in the aeration basins, but it is also used in grit chambers, equalization basins, aerated lagoons, air stripping columns, and mixing chambers. Raw wastewaters are often aerated for short periods prior to conventional treatment to increase the efficiency of subsequent operations. Flotation with air is used for grease removal. Aeration is also used for flocculation purposes in the wastewater treatment. Recently, there has been renewed interest in the potentialities of forced instream aeration as a supplemental means for water quality control [96][1].

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[1] Numbers in brackets are references listed in the References.

2.1.2 Preaeration Basins

A careful study and review of the subject of preaeration reveals that, despite its versatile, extentive and beneficial use, probably no other single step of modern sewage treatment practice has received so little attention [74]. Preaeration is defined by the Glossary-Water and Wastewater Control Engineering [37] as 'a preparatory treatment of wastewater consisting of aeration to remove gases, add oxygen, promote flotation of grease, and aid coagulation'.

Early use of preaeration of raw sewage was for the purpose of odor control and/or prevention of septicity. Generally short aeration periods, ranging from 15 min. down to less than 1 min., were used. Additional benefits of grease separation and flocculation of solids became evident as the period of aeration was increased. The later benefits now are considered the major objectives of the process. An additional benefit, where the preaeration tank is adjacent to settling units, is to provide uniform distribution of flow and solids to settling tank inlets. Within the last few years preaeration has been used successfully for grit separation and this unit is called an aerated grit chamber.

Obvious benefits of preaeration, as reported by consulting engineers and plant operators, can be summarized as follows [42]:

1. Increase in reduction of BOD and suspended solids in primary treatment units
2. Increase in grease removal in primary treatment units
3. Sweetening of stale sewage
4. Reduction of odors
5. Prevention of septic primary tanks during periods of low flow
6. Treatment of digester supernatant
7. Improved flocculation for chemical precipitation
8. Removal of undesirable gases from the wastewaters

Preaeration of raw wastewater is normally practised prior to primary sedimentation unit. The detention period in preaeration basins is generally less than 20 min. [92].

Hatfield [40] discussed the operation of preaeration unit at Decatur, IL in 1931. The results of two years of study and testing indicated that 2.5 hours aeration could reduce the BOD from 30-40 percent and that the settled, aerated effluent could be successfully applied to trickling filters at three times the rate of unaerated sewage. Currie [19] discussed the improvement in the performance of several sewage treatment plants in the United States, after preaeration was introduced in the process and followed by primary sedimentation unit.

The design criteria and air requirement for preaeration basins, suggested by different researchers, are given in Table 2.1. It is expected that these air flow rates will both satisfy the oxygen demand and prevent the particles from settling.

Table 2.1 - DESIGN CRITERIA FOR PREAERATION UNITS

REFERENCE	DESIGN PARAMETER	RANGE
Metcalf & Eddy (60)	Tank depth	3 - 6 m
	Detention time	10 - 45 min.
	Air Requirements	0.075 - 0.30 m^3/m^3 of wastewater (typical 0.20 m^3/m^3 of wastewater) 0.02 - 0.05 m^3/min.-m of length (for aerated channel)
Steel & McGhee (80)	Detention time	About 30 min.
	Aeration rate	0.01 to 0.05 m^3/m^3 of wastewater
	Dimensions	Same as for aerated grit chambers
Viessman & Hammer (91)	Detention time	Less than 20 min.
	Air Requirements	0.37 to 1.49 m^3/m^3 of wastewater (0.05 to 0.20 $ft.^3$/ gal. of wastewater
Kappe & Neighbor (42)	Detention time	30 min.
	Velocity	0.61 m/s (2 ft./s) is necessary to prevent deposition of solids
	Air requirements	Minimum 0.7392 m^3/m^3 of wastewater (0.1 $ft.^3$/ gal. of wastewater) or amount necessary to maintain tank circulation

2.1.3 Aerated Equalization Basins

The proper operation of both in-line and off-line equalization basins require proper mixing and sufficient dissolved oxygen. Mixing is provided to blend the contents of the tank and to prevent deposition of solids in the basin. Grit removal facilities should precede equalization basin, wherever possible, to minimize mixing requirements. Compressed air aeration system can provide both the mixing and the oxygen to prevent the wastewater from becoming septic [60]. The other method of providing both mixing and aeration is through the use of mechanical aerators. Properly designed equalization facilities reduce wide fluctuations in waste-stream characteristics, and provide a system that is less susceptible to upsets and consistently provides a better quality effluent than an unequalized system [7]. Also it has been proven that the operating power requirements of the equalized system can be appreciably lower than that of an unequalized system [7]. Proper mixing can make the volume of an equalization basin much smaller than a poorly mixed basin, at the same time providing better results at reduced capital investment and operating costs.

The design criteria for equalization basins, as given by various researchers are given in Table 2.2.

Table 2.2 - DESIGN CRITERIA FOR AERATED EQUALIZATION BASINS

REFERENCE	DESIGN PARAMETER	RANGE
Metcalf & Eddy (60)	Air Requirement to Maintain Aerobic Conditions in Aerated Equalization Basins	0.01 to 0.015 m^3/m^3-min.
Metcalf & Eddy (60)	Power Requirement to Blend a Medium-Strength Municipal Wastewater	4 to 8 w/m^3 of storage

2.1.4 Aeration Basins in Biological Treatment of Wastewater

Air is used for two purposes in the biological treatment process: first to supply metabolic oxygen requirements of micro-organisms and second to provide proper mixing within the reactor to keep the biological flocs in suspension. The most common method of aeration in biological treatment processes is diffused bubble aeration. The cost of compressing air constitutes the largest portion of the operating cost in an activated sludge process. Therefore, any improvement in the efficiency of the aeration process would certainly reduce these operating costs[57].

The process of diffused aeration is in the form of small air bubbles introduced through small openings into the liquid. These openings or outlets are usually located near the bottom and along one side of the tank. Because of the resulting low density of the air water mixture above the air outlets, as well as the direction of liquid flow, a rising, circulating, spiral motion of the mixture results throughout the entire tank as shown in Figure 2.1. This circulatory motion keeps the activated sludge flocs in suspension. The air bubbles also provide necessary oxygen needed by the biological suspension in the system[57].

There are various methods of supplying oxygen to the aeration basin but the two most common means are by mechanical or surface aeration and by diffused bubble

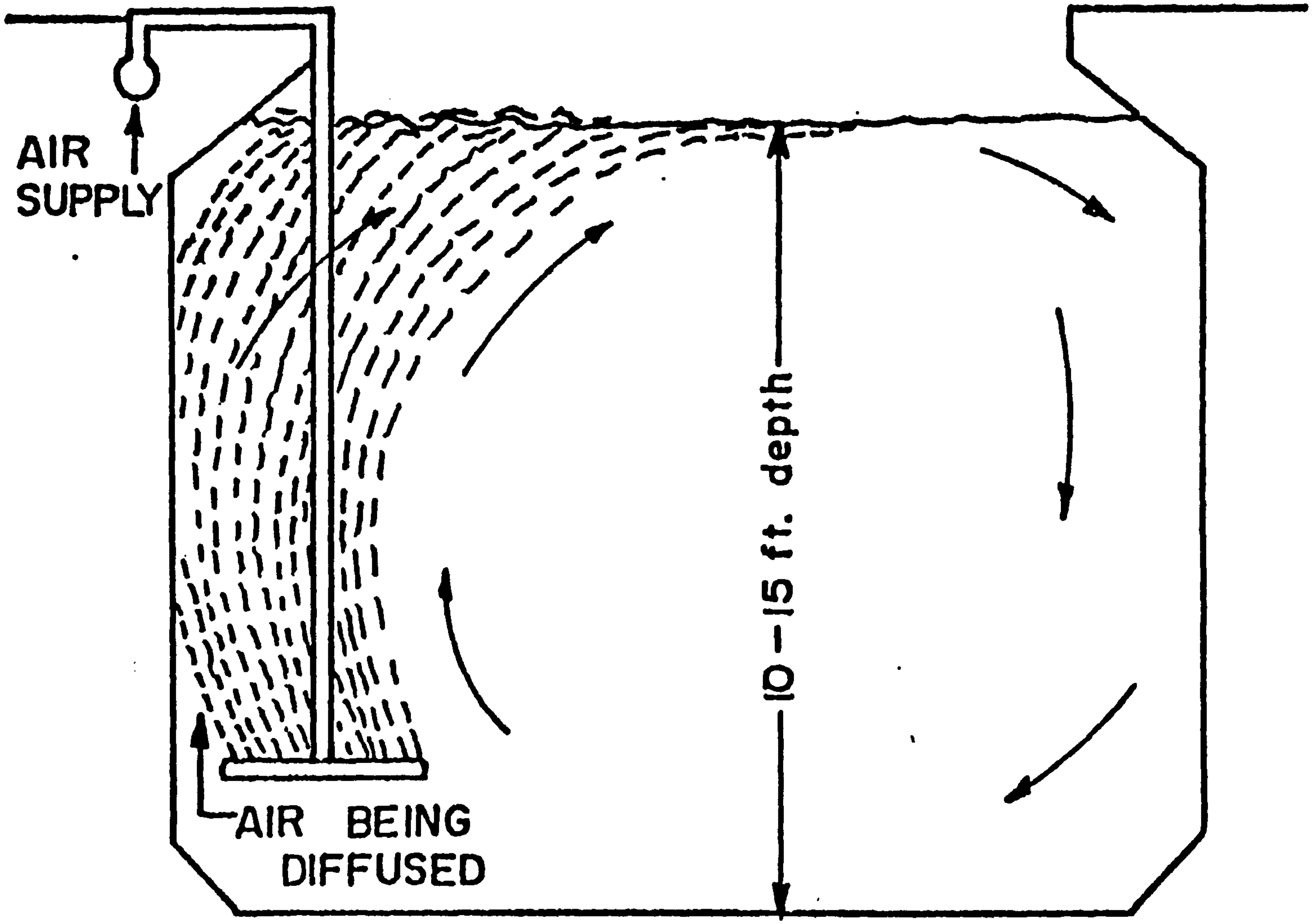


Figure 2.1: Cross-Section of a Typical Diffused Air, Spiral Flow, Conventional Activated Sludge Aeration Tank

aeration. The latter can be further divided into fine bubble and coarse bubble aeration. However, despite higher efficiencies generally associated with fine bubble diffusers, they have limitations in practice due to their tendency to clog: both internally from the impurities in compressed air and externally from the wastes in the aeration basins. The coarse bubble aeration process, commonly employed in different wastewater treatment units, has been the object of many extensive investigations for improving the transfer of oxygen into wastewater [57]. Substantial amount of work has been done in recognizing and improving the factors affecting the rate of oxygen transfer [9,20,30,31,57]. However, limited literature is available on the mixing aspects of aeration to keep the biological solids in suspension without shearing them. Mixing in aeration basins is discussed in detail later in this chapter.

2.2 Grit Chambers

It is a common practice to remove grit in such a way as to avoid the inclusion of excessive amount of decomposable organic solids with the removed grit. Grit includes sand, silt, coal dust, coffee grounds, fruit seeds, egg shells etc.. For design purposes of a grit chamber, grit is defined as fine sand of 0.2 mm or larger in diameter with a specific gravity of 2.65 [18,92]. Grit is removed in municipal wastewater treatment to protect mechanical equipment and pumps from abnormal abrasive wear, to prevent pipe clogging by grit deposition, to maintain the capacities of settling tanks, digesters etc. [92], and to prevent the cementing effects on the bottom of sludge digesters and primary sedimentation tanks [73]. Grit chambers may be located ahead of all other units in treatment plants where removal of grit would facilitate operations. However, the installation of mechanically cleaned bar racks or comminutors ahead of grit chambers makes the operation of grit removal and cleaning facilities easier. Table 2.3 shows the advantages and disadvantages of having a grit removal facility installed at different locations [73].

Most grit chambers are designed to maintain a certain mean velocity depending on particle characteristics, as shown in Table 2.4. It is expected that at this velocity only decomposable organic particles will be resuspended.

The conventional type chamber has a two-fold function (i) to remove the grit from the sewage, and (ii) to separate the grit from the decomposable particles so that it may be disposed of without nuisance. The mechanism of this removal process has not been well understood in practice and has generally been referred to as 'differential settling'. There are in fact two processes at work: (a) settling of both grit and organics which is 'differential' only in the sense that grit settles faster than most of the organic particles and (b) 'scour' or 'bed load movement' of the settled solids

Table 2.3 - COMPARISON OF VARIOUS LOCATIONS OF GRIT REMOVAL FACILITY, Qasim (73)

LOCATION	ADVANTAGES	DISADVANTAGES
Ahead of lift station	Maximum protection of pumping equipment.	Frequently deep in the ground, high construction cost, not easily accessible, and difficult raising the grit to ground level.
After pumping station	Ground level structure. Accessible and easy to operate.	Some abnormal wear to pumps.
Degritter in conjunction with primary sludge	Usually low capital and operation and maintenance costs. Cleaner and drier grit.	Pumping equipment not adequately protected.

Table 2.4 - RECOMMENDED MEAN DESIGN VELOCITIES IN GRIT CHAMBERS

REFERENCE	PARTICLE CHARACTERISTICS	FLOW CONDITIONS	VELOCITY RANGE
Kappe & Neighbor (42)	Sand particles, 0.2 mm size	Move along the tank bottom.	0.23 m/s (0.75 ft./s)
Kappe & Neighbor (42)	Sand particles, 0.2 mm size	Start an upward vertical movement coupled with the additional resistance caused by the sharp turn at the tank edge.	1.83 m/s (0.6 ft./s)
Kappe & Neighbor (42)	Lighter organic particles	Stay in suspension.	0.61 m/s (2.0 ft./s)
Harremoes (38) & Pallasch (69)	Grit particles	Bottom velocity that would deposit grit particles but not the organic matter in aerated grit chambers.	0.3 m/s
Lodholze & Pentz (52)	Organic particles	Keep organic particles in the removed grit at a minimum level.	0.23 to 0.37 m/s (0.75 to 1.2 ft./s
Hardenbergh & Rodie (39)	Sewage	Just enough to permit the particles with greater specific gravity to settle out while the organic material is carried away.	0.3 m/s (1.0 ft./s)
Camp (18)	Grit particles	For American-type grit chambers.	0.15 to 0.37 m/s (0.5 to 1.2 ft./s

Table 2.4 - RECOMMENDED MEAN DESIGN VELOCITIES IN GRIT CHAMBERS (cont'd)

REFERENCE	PARTICLE CHARACTERISTICS	FLOW CONDITIONS	VELOCITY RANGE
Konicek & Pardus (46)	Grit particles	Critical velocity in a grit chamber without baffle.	0.30 m/s
Viessman & Hammer (91)	Grit particles, 0.2 mm size, 2.65 specific gravity	Prevent scouring.	0.30 m/s (1.0 ft./s)
Steel & McGhee (80)	Grit and organics	Horizontal velocity to remove grit, without removing organic material.	<0.056 m/s and >0.23 m/s
Steel & McGhee (80)	Grit and organics	Recommended velocity to allow deposition of grit while scouring out organics.	0.23 - 0.38 m/s (preferred 0.3 m/s)
Hardenbergh & Rodie (39)	Particles of specific gravity 2.65	For grit removal.	0.3 m/s (1.0 ft./s)
Qasim (73)	Grit particles	Typical design value for a grit chamber.	0.3 m/s
MOP #8 (58)	Grit	Average design value.	0.3 m/s (1.0 ft./s)
Metcalf & Eddy (60)	Grit	Horizontal design velocity.	0.25 - 0.40 m/s

which is more effective in separating the organics than settling [18]. In a properly designed grit chamber the full advantage of both processes is taken. Camp [18] had developed an equation to calculate the mean scouring velocity in a grit chamber by utilizing the theoretical study and extensive experimental work done by Shields [81] on the movement of granular materials in a flowing stream. Proposed Camp Shields equation for scouring velocity [18]:

$$V_c = \sqrt{\frac{8\beta}{f} g(S_s - 1)d} \qquad \text{----[2.1]}$$

Where V_c = critical velocity required to start scour of particles whose size is d and specific gravity is Ss, m/s

g = acceleration due to gravity, m/s^2

f = Weisbach-Darcy friction factor which may be considered equal to about 0.03 for grit chambers

β = an experimental constant

The value of experimental constant, β, was found by Shields to be approximately 0.04 for unigranular material. For non-uniform and sticky material, like grit, a value of about 0.06 is probably safe for design. According to this equation the depth does not influence scour, although it does affect settling.

There are two general types of grit chambers : (a) horizontal flow and (b) aerated. In a horizontal flow type, the flow passes through the chamber in a horizontal direction and the straight line velocity of flow is controlled by the dimensions of chamber or by the use of special weir sections at the effluent end. In case no velocity control is provided, settled particles have to be washed to separate the decomposable organic particles from grit. The aerated grit chamber consists of a spiral flow aeration tank where the spiral velocity is controlled by the dimensions and the quantity of air supplied to the unit [60]. Different kinds of horizontal flow type grit chambers are in use in wastewater treatment and selection depends on the amount of grit in the wastewater, size of the plant and cost. Standard systems include : (a) channel shaped grit chamber, and (b) clarifier type units with mechanical scraping arms [29,60].

In practice the length of the tank is up to 50 percent larger than theoretically required to allow for turbulence and inlet and outlet disturbances [58]. The design criteria for grit chambers as suggested by various researchers are given in Table 2.5.

Table 2.5 - DESIGN CRITERIA FOR HORIZONTAL FLOW GRIT CHAMBERS

REFERENCE	DESIGN PARAMETER	RANGE
Metcalf & Eddy (60)	Detention time	45 - 90 s
	Horizontal mean velocity	0.25 - 0.4 m/s
	Settling Velocity for the removal of: 65 mesh material (0.21 mm) 100 mesh material (0.15 mm)	 1.0 to 1.3 m/min. 0.6 to 0.9 m/min.
	Head loss in control section as percentage of depth in channel	30 to 40%
	Allowance for inlet and outlet turbulence	2 x maximum depth of grit chamber 0.5 x theoretical length of grit chamber
Viessman & Hammer (91)	Settling velocity for the removal of 0.2 mm diameter particles with specific gravity of 2.65	0.023 m/s
	Horizontal mean velocity	0.3 m/s
Steel & McGhee (80)	Length of grit chamber	Depends upon the trajectory of slowest settling particles and the depth of flow. Length≃ 12 x depth of flow.
Qasim (73)	Detention time	60 s
	Horizontal mean velocity	0.3 m/s
	Settling velocity for 65 mesh (0.21 mm) particles	1.15 m/min.
	Head loss	30 to 40% of the maximum water depth in the channel

Table 2.5 - DESIGN CRITERIA FOR HORIZONTAL FLOW GRIT CHAMBERS (cont'd)

REFERENCE	DESIGN PARAMETER	RANGE
Camp (18)	Horizontal mean velocity	0.15 - 0.3 m/s
	Detention time	1 min.
	Settling velocity for 0.2 mm sand	0.023 m/s
Eckenfelder (29)	Horizontal mean velocity	0.23 - 0.38 m/s
	Chamber length	Based on horizontal mean velocity and settling velocity of particles
	Cross-sectional area	Based on flow rate and horizontal mean velocity

2.2.1 Aerated Grit Chambers

Conventional grit chambers are incorporated in water pollution control plants to remove sand and other abrasive or inert materials which could be detrimental to the proper operation of the mechanical equipment and treatment units. Aerated grit chambers are finding general application because they exhibit certain advantages in operation and design over conventional grit chambers. These advantages are [1,73] are listed below:

1. The sewage is freshened (kept more aerobic) by oxygen in air
2. Low hydraulic head loss is required in the design
3. The controllable air-induced water velocity enhances the removal of grit with a low organic content
4. Grit larger than desired size can be preferentially removed, assuming a constant specific gravity for all the grit involved
5. The grit removal efficiency can be maintained over a large flow range
6. Comparatively clean grit can be obtained.
7. An aerated grit chamber can also be used for chemical addition, mixing and flocculation ahead of primary treatment
8. Grease removal may be achieved if skimming is provided

At design conditions, the normal flow retention time in an aerated grit chamber is small (a matter of a few minutes); therefore, the freshening of the sewage may be minimal. However, if the aerated grit chamber is incorporated with a preaeration unit, the dual benefits of grit removal and sewage freshening can be achieved.

The hydraulic head loss in an aerated grit chamber is kept small because a simple horizontal overflow weir may be employed. This compares with the relatively large head loss associated with Sutro or other constant velocity weirs often used with conventional grit chambers. Complex constant velocity weirs are not required with aerated grit chambers because the air-induced water velocity, rather than the flow through velocity, control the grit removal process. This control, maintained by the air-induced velocity, also explains why grit removal efficiencies can be maintained over the entire designed flow range.

The aerated grit chamber has been developed to provide a system of grit removal which can be installed ahead of comminutors, raw sewage pumps, and other mechanical equipment. Maximum protection may be given to these units by removing clean washed grit that will be useable for filling without causing any nuisance. Aerated grit chambers are normally rectangular in cross-section with an aeration header on each side, or only on one side, creating a rolling action to separate the lighter organic material from the grit particles. The grit drops to the bottom of the tank and rolls to the collection hopper while the organics remain in suspension [53].

In application, an aerated grit chamber is similar to a standard spiral flow aeration tank with air diffusion tubes located on one side, approximately 0.61 m. (2 ft.) above the bottom of the tank. Hoppers are provided beneath the swing diffusers for collecting the grit. Swing diffusers are preferred because of their accessibility for servicing and other advantages over submerged fixed diffuser system. The velocity of roll or agitation governs the size of particles of a given specific gravity that will be removed. If the velocity is too high, grit will be carried out of the chamber; if it is too small, organic material will be removed with the grit. Grit chambers traditionally have been designed to remove inorganic material of minimum 0.2 mm size at the design flow rate [36].

A study has shown that the performance of an aerated grit removal system can be substantially improved by adjusting aeration rate and distribution [36]. An optimum rate can decrease operational problems in distribution channels, digesters and other areas by reducing the amount of grit, rags, sticks, and plastics passing through the grit removal system into those areas from which they must be removed manually. Further tapered aeration equalizes loading on grit pumping and dewatering equipment. The Renton Treatment Plant at Seattle [35] improved grit removal by adjusting the air flow rate in its aerated grit chamber to the optimum rate. This resulted in a decrease in operational problems in distribution channels, digesters and other areas. Aerated grit chambers are normally designed on the basis of detention time [52]. The air requirements in aerated grit chambers suggested by various researchers are shown in Table 2.6.

The design criteria for aerated grit chambers recommended by various researchers are given in Table 2.7. It can be seen that very little work has been done on aerated grit chambers, especially on the critical location of diffusers, effect of depth of liquid on velocity, and effect of tank geometry on velocity.

Table 2.6 - AIR REQUIREMENT IN AERATED GRIT CHAMBERS

REFERENCE	PARTICLE CHARACTERISTICS	DESIGN CONDITIONS	AIR REQUIREMENT
Kappe & Neighbor (42)	Organic material	Develop a velocity of 0.6 m/s (2 ft./s) to hold particles in suspension	0.28 m^3/min./m (3 $ft.^3$/min./ft.) of tank length
Bewtra (8)	Grit particles	Design factor in aerated grit chamber	0.28 to 0.465 m^3/min./m (3 to 5 $ft.^3$/min./ft.) of tank length
Steel & McGhee (80)	Grit and organic particles	Prevent scouring of grit while keeping organics in suspension	0.3 to 0.5 m^3/min./m of tank length. Detention time is usually less than 3 min.
Metcalf & Eddy (60)	Grit and organic particles	Settle grit while keeping organics in suspension	0.15 - 0.45 m^3/min./m of length. Typical value = 0.3 m^3/min./m Detention time at peak flow = 2.5 min.
Qasim (73)	Grit particles	Typical design value for the design of aerated grit chamber	4.6 - 12.4 L/s/m of tank length. Detention time at peak flow = 2.5 min.

Table 2.7 - DESIGN CRITERIA FOR AERATED GRIT CHAMBERS

REFERENCE	DESIGN PARAMETER	RANGE
Metcalf & Eddy (60)	Depth	2 - 5 m
	Width	7.5 - 20 m
	Length	7.5 - 20 m
	Width to depth ratio	1:1 - 5:1
	Detention time at peak flow	2 - 5 min.
	Air flow rate	0.15 - 0.45 m^3/min.-m of tank length
	Depth of grit hopper (with steep sloping sides)	0.9 m
	Location of diffuser	0.45 - 0.60 m (above the normal plane of bottom)
	Tank geometry	Wastewater should be introduced in the direction of roll.
Albrecht (1)	Chamber geometry	Depth to width ratio of 1:1 with side slopes at 45 degrees. The collection channel size is based on anticipated amount of grit. A long and narrow tank minimizes short-circuiting.
Kappe & Neighbor (42)	Location of diffusers	0.6 m (2ft.) above the bottom of tank
	Recommended kind of diffusers	Swing
	Velocity	0.6 m/s (2 ft./s)
	Detention time	1.1 min. at peak flow
	Depth	Up to 4.6 m (15 ft.)
	Width	Up to 9.2 m (30 ft.)
	Typical tank size	6.25 m (20.5 ft.) wide x 3.50 m (11.5 ft. deep) x 15.25 m (50 ft.) long for 100 MGD plant. For 200 MGD plant: 9.15 m (30 ft.) wide x 4.60 (15 ft.) deep x 21.35 m (70 ft.) long.
	Air flow rate	0.28 m^3/min./m of tank length

Table 2.7 - DESIGN CRITERIA FOR AERATED GRIT CHAMBERS
(cont'd)

REFERENCE	DESIGN PARAMETER	RANGE
Steel & McGhee (80)	Air flow rate	0.3 - 0.5 m^3/min.-m of tank length
	Detention time	Less than 3 min.
	Depth	70 to 100 percent of width (3 to 5 m)
Qasim (73)	Depth	2 - 5 m
	Length	7.5 - 20 m
	Width	2.5 - 70 m
	Width to depth ratio	1:1 - 5:1
	Length to width ratio	2.5:1 - 5:1
	Transverse velocity at surface	0.6 - 0.8 m/s
	Detention time at peak flow	2 - 5 min.
	Air flow rate	4.6 - 12.4 L/s/m of tank length (3 - 8 cfm/ft. of tank length)
	Inlet and outlet structure	Must be such as to prevent short-circuiting and turbulence.
	Baffles	Longitudinal and transverse baffles improve grit removal efficiency.
	Chamber geometry	Location of air diffusers, sloping tank bottom, grit hopper, and accomodation of grit collection and removal equipments should all be given consideration in chamber geometry.
Neighbor & Cooper (62)	Location of diffusion equipment	0.6 m (2 ft.) above the sloping tank bottom
	Air supply	0.28 m^3/min./m of tank length (3 cfm/ft. of tank length)
	Surface velocity	0.46 - 0.6 m/s (1.5-2 ft./s)

Table 2.7 - DESIGN CRITERIA FOR AERATED GRIT CHAMBERS (cont'd)

REFERENCE	DESIGN PARAMETER	RANGE
Neighbor & Cooper (62)	Horizontal mean velocity	0.9 m/s (3 ft./s)
	Detention time	1.5 - 2 min.
	Shape	Longer, narrower tanks produce grit of better quality.
	Inlet and outlet structures	Must minimize short-circuiting.
	Baffles	Transverse baffles are desirable on larger tanks. Longitudinal baffles and effluent baffles improve performance.

2.3 Mixing in Water and Wastewater Treatment

2.3.1 General

Mixing is defined as the intermingling of two or more dissimilar portions of materials, resulting in the attainment of a desired level of uniformity, either physical or chemical, in the final product.

Mixing operations have a considerable importance in water as well as wastewater treatments. The term 'mixing' has been used to describe processes which tend to reduce nonuniformities or gradients in composition of material in bulk [89]. As an example, mixing is employed (i) in aeration tanks to keep the biological solids in suspension and also to keep the conditions aerobic, and (ii) in high rate digesters to prevent separation of solids and to maintain homogeneous conditions of raw sludge and seed sludge, and also to provide an even temperature throughout the tank. Another very common and important purpose served by mixing is to bring together different molecular species in order to have a reaction. Mixing may also be used to disperse a variety of chemicals such as coagulants, coagulant aids, or to contact substances such as activated carbon.

Different kinds of mixing devices are in use depending upon the purpose of mixing, volume, cost, extent of desirable uniformity and operating conditions. The common mixing devices are [82]: (a) gravitational, (b) pneumatic, and (c) mechanical. The baffled channel and hydraulic-jump mixers are examples of gravitational mixers. Impellers such as paddles, turbines and propellers are generally used for mechanical mixing. In pneumatic mixing, compressed air is diffused in the liquid content which generates mass circulation of liquid and turbulence [33,80]. Pneumatic mixing has been the least investigated of all the types of mixing.

2.3.2 Mixing in Air Agitated Tanks

In wastewater treatment as well as in other mixing operations, two types of air agitated tanks are in use: continuous and batch operated. Despite the widespread use of these units, there is limited literature available on either the theoretical or the practical aspects of designing these tanks [3].

Most of the reported work is on continuous air agitated tanks in which air agitation is used to achieve oxygen transfer from diffused air to the liquid content of the tank. Some fundamental research work on mixing characteristics of continuous air agitated tanks has been reported by Thomas and Mckee [88], Murphy and Timpany [56] and Murphy and Boyko [59]. All their studies were confined to fixed geometry tanks and fixed location of diffusers. None of them studied the effect of geometry or location of diffusers on the mixing or the horizontal velocities near the tank bottom.

For batch air-agitated tanks, the nature of mixing has not been studied extensively. Kaufman [44] has suggested various amounts of air for various intensities of agitation, referring specifically to the petroleum industry. According to him the following quantities of air per unit of tank cross-sectional area may be used to obtain an acceptable degree of agitation in a liquid depth of 2.75 m (9 ft).

$m^3/min/m^2$ $(ft^3/min/ft^2)$

	$m^3/min/m^2$ $(ft^3/min/ft^2)$
Moderate Agitation	0.183 (0.6)
Complete Agitation	0.396 (1.3)
Violent Agitation	0.945 (3.1)

Szabo [82], studied the mixing characteristics of a small scale batch mixing tank. Air was diffused through a pipe located either at the center or the periphery of the tank. Based on the experimental results, Szabo developed the following correlations relating the performance of the mixing time with the tank geometry and the air flow rate.

$$\log t_{max} = 1.19 + 0.34 \frac{D}{H} + 0.35 \log \frac{V}{Q_{al}} \qquad \text{----[2.2]}$$

$$V_{sur} = \frac{Q_{al}}{c + mQ_{al}} \qquad \text{----[2.3]}$$

Where t_{max} = mixing time, s

D = diameter of tank, m

H = liquid depth, m

Q_{a1} = air flow rate under atmospheric pressure and at 20°C, m^3/min

$\forall$ = volume of fluid in tank, m^3

V_{sur} = surface velocity, m/s

c and m = correlation constants

The successful operation of an air agitated tank in waste treatment system is dependent on the degree of mixing in the system. Function of mixing include [67]:

1. Gross mixing of the waste influent with the biological solids
2. Mixing of the incoming waste with the bulk liquid present in the aeration basin (extent depending on the degree of 'complete mixing' desired)
3. Mixing to cycle deoxygenated liquor to the aerators
4. Mixing turbulence to maintain biosolids in suspension
5. Mixing to produce small scale turbulence for promoting the mass transfer of dissolved oxygen and substrate into the cell mass

The mathematical description of mixing is useful for directing the designer toward the provision of adequate mixing in activated sludge systems, but application of these principles alone does not permit the completion of a design for a system. Parameters such as power input per unit volume, aerator pumping capacity per unit volume, and velocity measurements have been employed as guides to ensure adequate mixing [67,28,43,51,68]. In most cases, design has centered around obtaining the desired oxygen transfer capacity [67,28,51].

Power input is generally regarded as a poor criterion since a number of combinations of impeller diameter and rotational speed, in the case of a surface aerator, can result in the same power consumption with markedly different mixing characteristics. The same argument could be applied in the case of diffused aeration systems. However, in systems with similar geometries this parameter can still be very useful [68].

Aerator pumping capacities have been correlated with radius of influence for dispersion of dissolved oxygen and suspension of solids in activated sludge systems. Again these correlations have been keyed to particular types of equipment, and therefore representative values cannot be cited [67]. Velocities have been widely employed as guides for estimating the extent of mixing required to keep the biosolids in suspension.

The most common type of air agitated tanks are 'spiral-flow' aeration tanks and aerated grit chambers, in which air is usually released near the bottom of one side of the tank resulting in a spiral bulk flow of the contents. The bulk rotation of the fluid in a rectangular tank, combined with the mixing effects of the rising air bubbles, results in a high degree of turbulent mixing. This mixing can be influenced by variations in many factors including [56]:

1. temperature
2. air flow rate
3. type of air injectors
4. mean residence time
5. tank geometry
6. solids level
7. entrance and exit conditions

Price et al. [67] have given an excellent description of surface aerators and submerged turbine aerators, discussing for example the spacing of aerators and extent of mixing. The minimum power requirement to suspend the biological solids given in the literature [28,67] is 7.9 W/m^3 (0.04 hp/1000 U.S. gal) of mixed liquor. The velocities required to keep the biological solids in suspension, given by different researchers, are shown in Table 2.8.

Table 2.8 - VELOCITIES REQUIRED IN ACTIVATED SLUDGE AERATION TANKS

REFERENCE	PARTICLE CHARACTERISTICS	FLOW CONDITIONS	VELOCITY RANGE
Eckenfelder, et al (28) Kumke, et al (43)	Activated sludge	Minimum velocity for suspending biomass	0.15 m/s (0.5 ft./s)
Harremoes (38)	Mixed liquor suspended solids	To keep biomass in suspension, bottom velocity	0.3 m/s
Price, et al (67)	Biosolids	Minimum velocity to suspend biosolids	0.15 m/s (0.5 ft./s) up to biosolid concentration of 5,000 mg/L

2.4 Initiation of Motion of Particles

Very little theoretical and experimental work has been done on the design of grit chambers based on the initiation of motion of grit and organic particles. The only theoretical approach, found in the literature, has been taken by Camp [18], who considered the theory of sediment transportation by Shields [81] and made use of it in the design of grit chambers. Grit chambers can be treated as small channels with a light sediment load. Excellent background is available in the field of sediment transport which can be used in a rational design of grit chambers.

Water flowing over a bed of particles exerts forces on the grains and tends to move or entrain them. The forces that resist the entraining action of the flowing water differ according to the grain size and grain size distribution of the sediments. For coarse sediments, e.g. sands and gravels, the forces resisting motion are caused mainly by the weight of the particles. Finer sediments that contain appreciable fractions of silt or clay, or both, tend to be cohesive and resist entrainment mainly by cohesion rather than by weight of the individual grains. Critical or threshold conditions are said to have been reached, when the hydrodynamic forces acting on a grain of sediment or on particles of cohesive sediments has reached a value, that, if increased even slightly will put the grain or aggregate into motion [83].

2.4.1 Sediment Properties

The fundamental properties of sediment particles have been studied quite intensively by two separate professions, geology and engineering. The geologists are concerned mainly with ancient sediments and they have studied the properties of sediment particles to find clues to the nature and movement of the transporting agent. The hydraulic engineers emphasize the interaction between the fluid and the particles, as they are primarily interested in the movement and deposition of sediments. The entrainment, transportation and subsequent deposition of a sediment depend not only on the characteristics of the flow involved, but also on the properties of the sediment itself [75].

2.4.1.1 Size

The most important property of a sediment particle or grain is its size. In many studies average size alone has been used to describe the sediment as a whole. Particle size may be defined by its volume, diameter, weight, fall velocity, or by sieve mesh size. With the exception of volume, the definitions are generally influenced by the shape or density of the particle. The following definitions taken from the the U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation [90], are used to describe the particle size:

1. Nominal diameter- diameter of sphere having the same volume as the particle.

2. Sieve diameter- the diameter of a sphere equal to the length of the side of a square sieve opening through which measured quantities (by weight) of a sample will pass. As an approximation the sieve diameter is equal to the nominal diameter.
3. Sedimentation diameter- diameter of a sphere of the same fall velocity and same specific gravity as the particle in the same fluid under the same conditions.
4. Fall diameter or Standard fall diameter- diameter of a sphere that has a specific gravity of 2.65 and also has the same terminal uniform settling velocity as the particle when each is allowed to settle alone in quiescent, distilled water of infinite extent at a temperature of 24°C.

The sieve and sedimentation diameters obviously have come into common use because of the convenience in measuring them. The sedimentation diameter is actually a fictitious size that enables the calculation of the settling velocity. For this reason, it has greater physical significance in sediment transportation than the other diameters [83]. Sieving has two definite disadvantages: (a) the lower sieve limit corresponds to approximately the midpoint of the size range of hydraulic interest; (b) sieve data are biased by particle shape, because the nominal sieve size is that size of square mesh through which a group of particles will just pass in a given interval of time, regardless of the extent to which they depart from the ideal spherical shape [10].

2.4.1.2 Shape

The size of a sediment particle alone is usually not sufficient to describe it. Generally speaking, shape refers to the overall geometric form of a particle regardless of size or composition. The most pertinent shape parameter has been known as sphericity which is defined [45,98] as the ratio of surface area of a sphere having the same volume as the particle to the surface area of the particle. Sphericity should be distinguished from roundness, which is defined as the ratio of the average radius of curvature of the edges to the radius of a circle inscribed in the maximum projected area of the particle [10]. The shapes of the particles have been expressed by a shape factor, SF, given by [83]:

$$SF = \frac{c}{\sqrt{ab}} \qquad \text{----[2.4]}$$

in which a, b, and c are, respectively, the lengths of the longest, intermediate, and shortest mutually perpendicular axes of the particles.

2.4.1.3 Specific Weight of Sediment Particles

Specific weight is the dry weight per unit volume of the sediment. Most of the sediments whether borne by wind or water have their origin in rock material, and all constituents of the parent material can usually be found in the sediment. Quartz, because of its great stability, is the commonest mineral found in sediments or grit. The average specific gravity of sand is very close to that of quartz i.e. 2.65, and this value is used often in calculation and analysis dealing with the grit. The specific gravity of particles in sediment transport is an important quantity and is used in many calculations.

2.4.1.4 Fall Velocity

The relative motion between sediment particles and the surrounding fluids under various conditions of entrainment, transportation, and deposition appears to depend upon essentially the same factors as the velocity at which the particles would fall through the fluid under their own weight. As a result, fall velocity has come to represent a characteristic of considerable practical as well as analytical value[10].

For a sphere of diameter d, the fall velocity V_s, for values of Reynolds number less than approximately 0.1 is given by Stokes law:

$$V_s = \frac{g\,d^2}{18\nu}(S_s - 1) \qquad \text{----[2.5]}$$

$$R_e = \frac{V_s\ d}{\nu} \qquad \text{----[2.6]}$$

in which ν = kinematic viscosity of the fluid, m^2/s

g = acceleration due to gravity, m/s^2

S_s = specific gravity of the sphere

V_s = settling or fall velocity, m/s

d = diameter of a sphere, m

The fall velocity over the entire range of Reynolds number in terms of the drag coefficient, C_d, is given by:

$$V_s = \sqrt{\frac{4}{3}\ \frac{g\ d}{C_d}\ (S_s - 1)} \qquad \text{----[2.7]}$$

Although fall velocity is a complex function of the Reynolds number, shape, and concentration, the fact remains that it is the relative behaviour of the particle rather than the exact correlation of size, shape and fall velocity which is of paramount importance in the hydrodynamics of sediment movement. To utilize the actual fall velocity as the significant particle characteristics, expressing this in terms of size when necessary through use of the Sedimentation Diameter, i.e. the diameter of a quartz sphere having the same terminal velocity of fall in the same fluid [10]. In some suspensions, electrochemical forces tend to hold particles together once they come into contact.

2.4.2 Mechanism of Entrainment

For many years, efforts have been made to express analytically the resultant force acting upon a typical sediment particle at the moment of its entrainment by the flow [47,99]. However, application of this rational approach to sediment particles in the aggregate on the stream bed becomes very complex statistically. For more than two centuries, workers have attempted to formulate the conditions of incipient motion. One of the earliest expressions is due to Brahms [11] which gives the critical velocity of water near the bed as:

$$V_c = k\ W_g^{1/6} \qquad \text{----[2.8]}$$

Where V_c = critical velocity of water

k = an empirical constant

W_g = weight of the grain

This equation is also called the Sixth Power Law.

Airy and Law [4,53] rediscovered this law by equilibrium consideration. Wisner [100] pointed out that the factor of proportionality in the Sixth Power Law is likely to vary with the shape of the cross-section. Assuming that weight is proportional to the third power of a 'characteristic' grain diameter, Sternberg [84] showed that for incipient motion critical velocity varies with the square root of grain diameter. Sternberg's theory is close to the present usage where the weight of the grains is rarely used since it is easier to measure grain diameter (by sieving).

Shields [81], published a paper in 1936 on this subject which has become a standard reference. It basically confirms the Sixth Power Law for large Reynolds Number [75]. A significant achievement by Shields was the dimensionless presentation of his results, which are illustrated in Figure 2.2. During the last four decades a number of papers have been published, most of them more or less intensive variations of the original Shields publications. These papers seemed to originate from what became known as the Shields diagram. The research efforts were almost exclusively directed toward uniform grain size material. Shields avoided the initial attempt at rationality by making certain gross assumptions and then confirmed and supplemented the analysis experimentally. Similar, though more involved, procedures were followed by Einstein[32] and Kalinske[47].

For the specific case of a level bed of uniform particle size investigated by Shields, he came up with a relationship

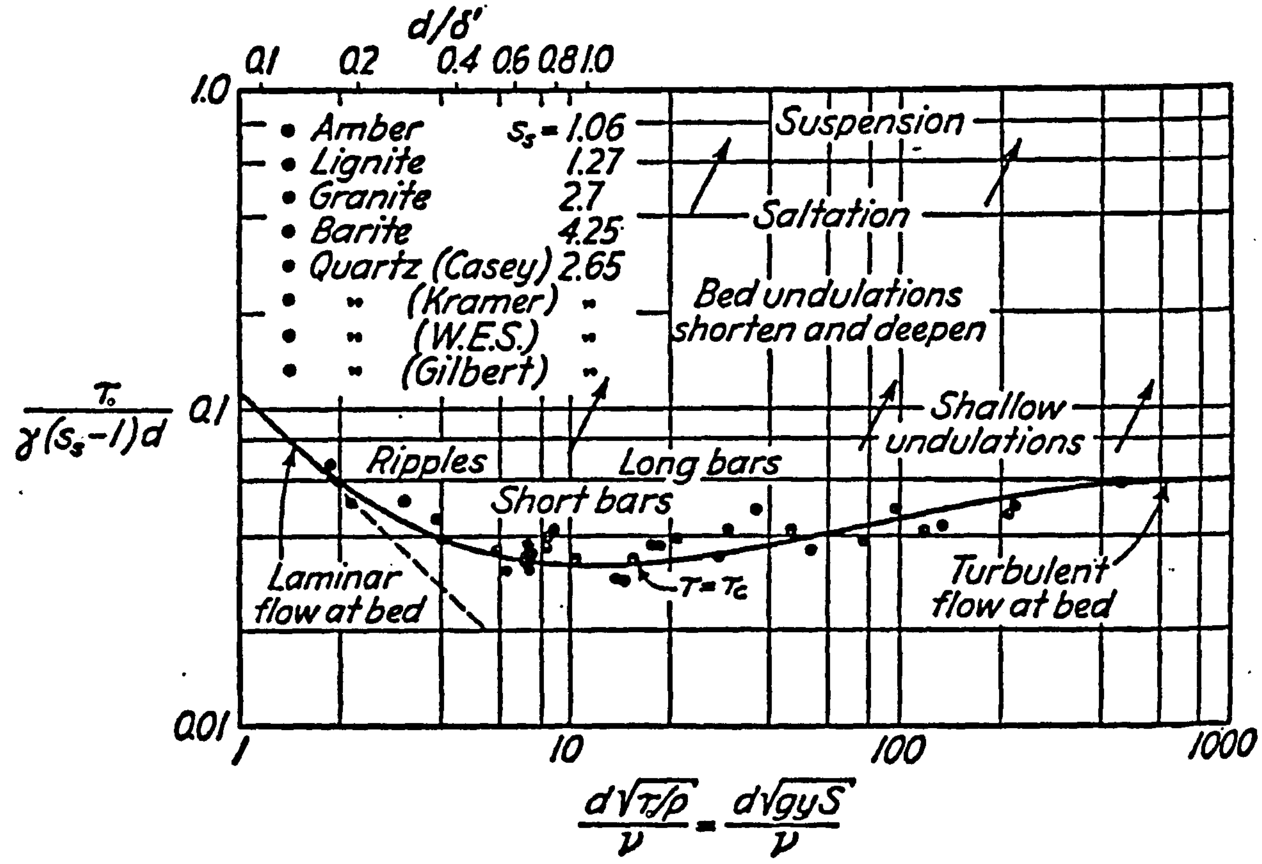


Figure 2.2: Analysis by Shields of the Entrainment Function [10].

$$\frac{\tau_{oc}}{\gamma_f(S_s-1)d} = \phi \frac{d\sqrt{gys}}{\nu} \qquad \text{----[2.9]}$$

$$\frac{\tau_{oc}}{\gamma_f(S_s-1)d} = \phi \frac{d\,U_*}{\nu} \qquad \text{----[2.10]}$$

Where τ_{oc} = critical tractive force, N/m^2

g = acceleration due to gravity, m/s^2

ν = kinematic viscosity of fluid, m^2/s

S_s = specific gravity of particles

d = particle size, m

γ_f = specific weight of fluid, N/m^3

y = depth of flow, m

s = slope

U_*= friction or shear velocity, m/s

$\frac{\tau_{oc}}{\gamma_f(S_s-1)}$ = critical entrainment function

$\frac{d\,U_*}{\nu}$ =particle Reynolds number

The critical entrainment function and particle Reynolds number are plotted in Shields diagram, Figure 2.2.

Novak and Nalluri[63] have developed equations for critical values of velocities, shear stresses and particle Froude numbers for incipient motion of sediment particles over fixed beds. They concluded that for single particle resting on a smooth bed, the critical velocity or shear stress is a function of the particle size, shape, and density and the depth of flow; for grouped particles, in addition to the above, the space between the particles and the mode of grouping influences the result. In case of rough fixed beds, the size of the roughness and its relation to the particle size is an important parameter.

Neil[64] has presented experimental data on incipient motion of uniformalized bed materials. These data are correlated with comparable data obtained by previous investigators including Shields, to develop a dimensionless expression for scour of coarse uniform material. He presented a design nomogram, relating competent mean velocity to grain size, specific gravity of sediment particles and depth of flow.

$$V_{mc} = \text{function of } (\rho_f, \rho_s, \mu, d_g, y, g) \quad \text{----[2.11]}$$

Where V_{mc} = competent mean velocity for first displacement of bed material, m/s

ρ_f = fluid mass density, kg/m^3

ρ_s = bed material mass density, kg/m^3

μ = fluid dynamic viscosity, N.s/m^2

d_g = effective diameter of bed grains, m

y = depth of flow, m

g = acceleration due to gravity

It may be argued from physical considerations that since the flow is uniform, and since incipient motion is basically a question of static equilibrium, neither g nor ρ_s can be relevant as independent characteristic parameters. They can only occur in the combination $g(\rho_s - \rho_f)$, the specific weight of the bed material in the fluid, denoted γ_s'. If this view is adopted, and μ is replaced by $\nu = \mu/\rho$, the revised statement becomes:

$$V_{mc} = \text{function of } (\rho_f, \gamma_s', \nu, d, y) \quad \text{----[2.12]}$$

This results in,

$$\frac{\rho_f V_{mc}^2}{\gamma_s' \, d} = 2.50 \left(\frac{d}{y}\right)^{-0.20} \quad \text{----[2.13]}$$

The results obtained using his approach were comparable with the results obtained by many other researchers including Shields.

2.5 Concept of Critical Shear Force and Critical Shear Velocity

When water flows in a channel, a force is developed that acts in the direction of flow on the channel bed. This force, which is simply the pull of water on the wetted area, is known as the shear force or tractive force. The critical shear force on a sediment particle is defined as the minimum shear force necessary for the initiation of motion of a particle [104]. The critical shear stress was determined by

Shields as the value of the stress for zero sediment discharge obtained by extrapolating a plot of observed sediment discharge versus shear stress [81].

In an uniform flow, the shear force, F, is apparently equal to the effective component of the gravity force acting on the body of water, parallel to the channel bottom and can be written as:

$$F = \gamma_f ALs \qquad \text{----[2.14]}$$

Where γ_f = unit weight of water

A = wetted area

L = length of channel reach

s = slope of channel

Thus, the average value of the shear force per unit wetted area is also called unit tractive force, τ_o, [17] or simply shear stress and is equal to:

$$\tau_o = \frac{\gamma_f ALs}{P_e L} = \gamma_f Rs \qquad \text{----[2.15]}$$

Where P_e= wetted perimeter

R = hydraulic mean radius

The shear or friction velocity, U_*, can be obtained from Eq. 2.15 as follows:

$$U_* = \sqrt{\frac{\tau_o}{\rho}} = \sqrt{\frac{\gamma_f Rs}{\rho}} \doteq \sqrt{gRs} \qquad \text{----[2.16]}$$

Where ρ = density of fluid

Under critical conditions, the shear stress becomes critical shear stress and the shear or friction velocity at this point is called critical shear or friction velocity, U_{*c}. Thus,

$$U_{*c} = \sqrt{\frac{\tau_{oc}}{\rho}} \qquad \text{----[2.17]}$$

Where τ_{oc} = critical shear stress

The critical shear stress of a sediment particle is defined as the minimum boundary shear stress necessary to initiate the motion of the particle [17]. Its magnitude depends on a number of factors including:

1. densities of the particle and the fluid
2. size of the particle
3. viscosity of the fluid, which in turn varies with the fluid temperature

Critical shear stress is normally determined by laboratory experiments. However, for naturally occurring particles, such as sand, empirical formulae and experimental graphs are available for estimating their values in a limited range [104]. An observation of a large area of sediment bed, when subjected to a shear stress near the critical value, will show that the incidence of gusts of sediment motion appears to be random in both time and space. This suggests, as observed by Shields[81], that the process of initiation of motion is statistically random in nature. Einstein [32] was the first to develop a transport relation based on statistical concepts. Because of the statistical nature of the entrainment process, there is no truly critical condition for initiation of motion for which motion begins suddenly as the condition is reached [83].

White[99] concluded that the true critical shear stress required to move a particular grain has a fixed value and this value is obtained from the experiments with laminar flow. His equation of critical bed shear (τ_{oc}) for sediment in a horizontal bed is:

$$\tau_{oc} = 0.18\ (\gamma_s - \gamma_f)\ d_s \tan\theta \qquad \text{----[2.18]}$$

in which the constant was obtained from the experiment with laminar flow, and

τ_{oc} = critical bed shear

γ_s = specific weight of sediment

γ_f = specific weight of fluid

d_s = particle mean size

θ = angle of repose

If it is assumed that initiation of motion is determined by τ_{oc} $(\gamma_s - \gamma_f)$, d_s, ρ_f and μ, then the dimensional analysis yields [83]:

$$\frac{\tau_{oc}}{(\gamma_s - \gamma_f)d_s} = f\left(\frac{U_{*c}\, d_s}{\nu}\right) \qquad \text{----[2.19]}$$

The same equation was obtained by Shields by analysis of experimental data.

The value of τ_{oc}. recommended by Lane[54] for the coarse material, is given by:

$$\tau_{oc} = 0.0164\ d_{75} \qquad \text{----[2.20]}$$

in which d_{75} = size for which 75% of the bed material is finer, mm

τ_{oc} = critical bed shear in pounds force per square foot

2.5.1 Critical Shear Stress of Grit Particles Found in Wastewaters

In designing grit chambers, the normal criterion is complete removal of particles with a specific gravity of 2.65 and a size of 0.2 mm [33] or greater. This size, however, represents only the lower limit and some grit particles larger than 0.2 mm are also removed. Table 2.9 presents the critical shear stresses for grit particles of 0.2 mm and 1 mm in size under different entrainment conditions, estimated from the Shields diagram and methods suggested by other researchers [104]. The water temperature is assumed to be 20°C. It is important to note in Table 2.9 that the critical shear stress increases appreciably with the content of colloidal or sediment particles in water [104]. For domestic sewage, the sum of the concentration of suspended and colloidal particles is often less than 0.1% [34], which is far less than 2.5% indicated in the Russian literature. However, considering the high solid load in the initial period of stormwater runoffs, the critical shear stresses given in Table 2.9 for high solid contents could be significant for storm sewer design. Otherwise, grit particles are the dominating consideration in designing the grit chambers and self cleansing domestic wastewater sewers.

Table 2.9 - CRITICAL SHEAR STRESS FOR 1 mm and 0.2 mm SAND PARTICLES (103)

REFERENCE	CONDITION	CRITICAL SHEAR STRESS	
		1 mm	0.2 mm
Shields diagram (23)	Packed bed flume	3.063 N/m^2 (0.064 $lb./ft.^2$)	1.149 N/m^2 (0.024 $lb./ft.^2$)
Russian results (78)	Clear water	9.573 N/m^2 (0.20 $lb.ft.^2$)	2.393 N/m^2 (0.05 $lb./ft.^2$)
Lane (78)	Canals with sand bed (clear water)	9.573 N/m^2 (0.20 $lb./ft.^2$)	7.179 N/m^2 (0.15 $lb./ft.^2$)
DuBoys and Straub (79)	Packed bed flume	7.658 N/m^2 (0.16 $lb./ft.^2$)	3.829 N/m^2 (0.08 $lb./ft.^2$)
Lane (78)	Concrete canals with low sediments	13.880 N/m^2 (0.29 $lb./ft.^2$)	11.487 N/m^2 (0.24 $lb./ft.^2$)
Russian results (78)	2.5% colloids	18.666 N/m^2 (0.39 $lb./ft.^2$)	7.179 N/m^2 (0.15 $lb./ft.^2$)
Fortier and Scobey (78)	With colloids	18.666 N/m^2 (10.39 $lb./ft.^2$)	18.666 N/m^2 (0.39 $lb./ft.^2$)

2.5.2 Shear Stress Distribution

The shear stress distribution in a steady two-dimensional flow of a real and homogeneous fluid, having a free surface varies linearly with depth of flow and it becomes zero at the free surface. In fluid mechanics, it is normally assumed that, in a general case of turbulent flow, the total shear stress τ at any depth y can be expressed as a sum of two components:

$$\tau = \tau_{\ell} + \tau_t \qquad \text{----[2.21]}$$

Where τ_{ℓ} = laminar or viscous shear stress = shear stress due to molecular viscosity, μ

τ_t = turbulent shear stress

$$\text{The Laminar Shear Stress, } \tau_{\ell} = \mu \frac{du}{dy} \qquad \text{----[2.22]}$$

where $\frac{du}{dy}$ = Velocity gradient at a depth y .

The component τ_t is the apparent shear stress due to turbulent fluctuations,ie,

$$\tau_t = - \rho \, \overline{u'v'} \qquad \text{----[2.23]}$$

Where u'v' is the time average value of the product u'.v', the multipliers u' and v' being the components of the fluctuating velocity in x and y directions respectively. In terms of the time average velocity u, the magnitude of the turbulent shear stress τ_t can be given by the following expression of Prandtl [71].

$$\tau_t = \rho \ell^2 \left(\frac{du}{dy}\right)^2 \qquad \text{----[2.24]}$$

Where ℓ = Prandtl mixing length

$$\ell = \chi y \qquad \text{----[2.25]}$$

Where χ = proportionality factor known as Von Karman Constant. The accepted numerical value of this constant is 0.4

2.6 Velocity Distribution and Surface Roughness

2.6.1 General

When water enters a channel, the velocity distribution across the channel cross-section, owing to the presence of boundary roughness, will vary with the distance over which the water travels in the channel. If the flow is uniform and stable and if the channel is prismatic and of constant roughness, the velocity distribution will eventually reach a definite pattern. For simplicity of discussion, the following assumptions are made[17]:

1. The flow entering the channel is laminar and of uniform velocity distribution
2. No restriction exists at the entrance that will cause abrupt disturbance of the water surface and velocity distribution
3. Depth of flow is indefinitely large, so the depth of flow can be considered constant as the water enters the channel

In Figure 2.3 [17], the effect of velocity distribution due to boundary roughness is indicated by the line ABC. Outside the surface represented by ABC, the velocity distribution is practically uniform. Near the channel bottom and within the region ABC, velocity varies according to the distance from channel bottom. The region inside ABC though not distinctive is known as the boundary layer [84] and its thickness is designated by δ. Since the boundary layer is not distinctive, its thickness has been defined arbitrarily in various ways. A very common definition is that the thickness δ is the magnitude of the normal distance from the boundary bottom or bed at which the velocity u, is equal to 99% of the limiting velocity u_o.

The effect of the boundary layer in Figure 2.4 [17], on the flow is equivalent to a fictitious upward displacement of the channel bottom to a virtual position by an amount equal to the so-called displacement thickness δ^*. The value of the displacement thickness generally varies from one-eighth to one-tenth of the thickness of the boundary layer, depending upon the magnitude of the Reynolds number [17].

At the beginning of the flow in the channel, the flow is entirely laminar and a laminar boundary layer is developed along the channel bed as shown by the curve AB, Figure 2.3. The velocity distribution in this layer is approximately parabolic. As the water travels farther along in the channel, the flow in the boundary layer will eventually

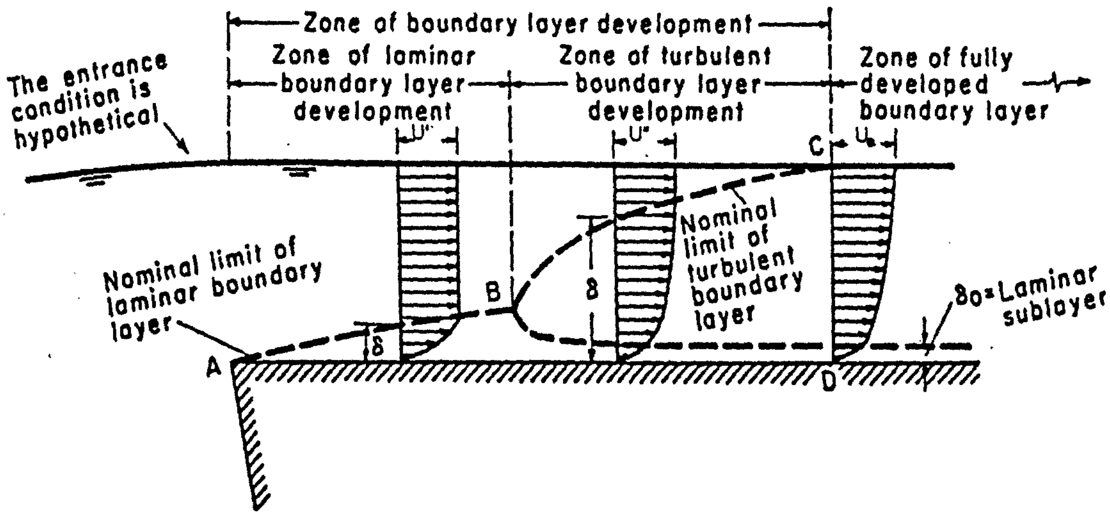


Figure 2.3: Development of the Boundary Layer in an Open Channel [17]

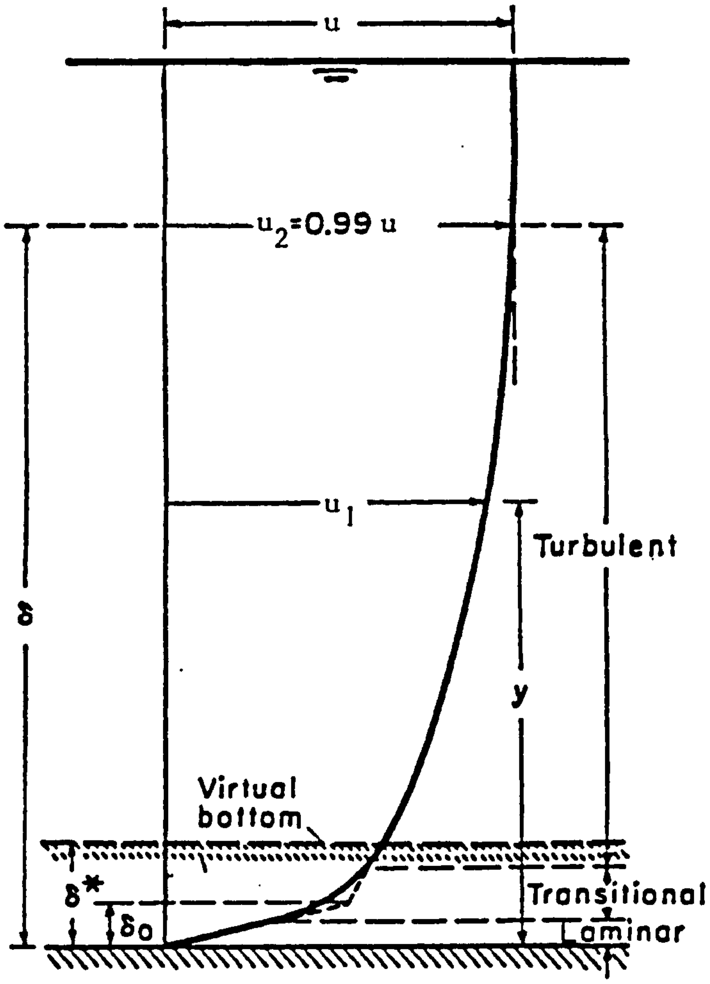


Figure 2.4: Distribution of Velocity Over a Smooth Channel Surface [17]

change to turbulent. The point where the change takes place is indicated by B. Downstream from B, a turbulent boundary layer is developed, as shown by BC. The velocity distribution in this layer can be shown analytically to be approximately logarithmic.

If the channel bottom is relatively smooth, the velocity close to the channel bottom is low; thus a very thin stable film of flow known as the laminar sublayer will be developed on the bottom. Within the laminar sublayer the flow is kept laminar. If the conditions for uniform flow exist throughout the channel, the turbulent boundary layer will be fully developed at section CD; thereafter the velocity distribution will have a definite pattern.

In a laboratoray channel or flume, the laminar boundary layer can be eliminated easily by placing a roughness element at the entrance. Thus, the turbulent boundary layer will be developed at the very beginning of the channel, and the total length of this zone for the full development of boundary layer can be shortened [17].

2.6.2 Concept of Surface Roughness

The concept of existence of a laminar sublayer in the turbulent boundary layer offers an appropriate explanation of the behaviour of bottom or bed roughness. When the bottom or bed profile of a channel is enlarged, it can be seen that the bottom or bed is composed of irregular peaks and valleys. The effective height of the irregularities forming the roughness elements is called the roughness height, k_s. The ratio of the roughness height to the hydraulic radius, k_s/R, is known as the relative roughness.

If the roughness height is less than a certain fraction of the thickness of the laminar sublayer, the bottom or bed irregularities will be so small that all roughness elements will be entirely submerged in the laminar sublayer. Under this condition, the roughness has no effect upon the flow outside the laminar sublayer and the bottom or bed is said to be hydraulically smooth.

In connection with flow in pipes or on flat plates, Schlichting [84] and Yalin[105] have given the following conditions for a bottom or bed to be hydraulically smooth or rough:

1. Turbulent flow given by the condition $U_* k_s/\nu \leq 5$ is called hydraulically smooth flow. Hydraulically smooth flow is distinguished by the fact that its velocity distribution does not depend upon the size and nature of roughness, provided $k_s <<$ depth of flow.
2. Turbulent flow given by the condition $U_* k_s/\nu \geq 70$ is called fully developed turbulent flow or rough turbulent flow. Rough turbulent flow is distinguished by the fact that the velocity distribution does not depend upon the viscosity μ or ν. If the thickness of the viscous sublayer is small in comparison to the size of the roughness, then the elements of roughness

are almost totally exposed to the turbulent fluid motion. This means that the turbulence has penetrated even into the flow between the elements of roughness and hence the fully developed turbulent flow conditions exist.

3. Turbulent flow given by the condition $5 \leq U_* k_s / \nu \leq 70$ is said to be in the transitional regime and the velocity distribution is dependent on both viscosity and roughness.

2.6.3 Velocity Distribution

Keulegan [48] had attempted to apply the work of Prandtl [71], Karman [49] and Nikuradse [65,66] to the problem of turbulent flow in open channel, mainly for the purpose of developing formulas for resistance or for mean flow velocity in forms similar to those obtained for circular pipes. Keulegan [48] developed a set of equations for velocity distribution both for the smooth walls and for rough walls. Yalin [105] simplified these equations as shown below:

For smooth walls, i.e., when $U_* k_s / \nu \leq 5$

$$\frac{u}{U_*} = 5.75 \log \left(\frac{y}{k_s}\right) + Bs \qquad \text{----[2.26.a]}$$

$$Bs = 5.75 \log \frac{U_* k_s}{\nu} + 5.5 \qquad \text{----[2.26.b]}$$

For Rough Walls, i.e., when $U_* k_s/\nu \geqq 70$

$$\frac{u}{U_*} = 5.75 \log \left(\frac{y}{k_s}\right) + Bs \qquad \text{----[2.27.a]}$$

$$Bs = 8.5 \qquad \text{----[2.27.b]}$$

where u = velocity at a distance y from the channel bed

k_s = size of roughness, which can be taken equal to the particle size

U_* = friction or shear velocity

Bs = a dimensionless property of the flow in the vicinity of the bed. In general, it is a function of particle Reynolds number, $U_* k_s/\nu$

Turbulent flow given by the condition $5 \leqq U_* k_s/\nu \leqq 70$ is said to be in the transitional regime. In the transitional regime, the velocity distribution is dependent on both viscosity and roughness. For this case the value of Bs cannot be given analytically and it must be estimated from the plot shown in Figure 2.7 [105].

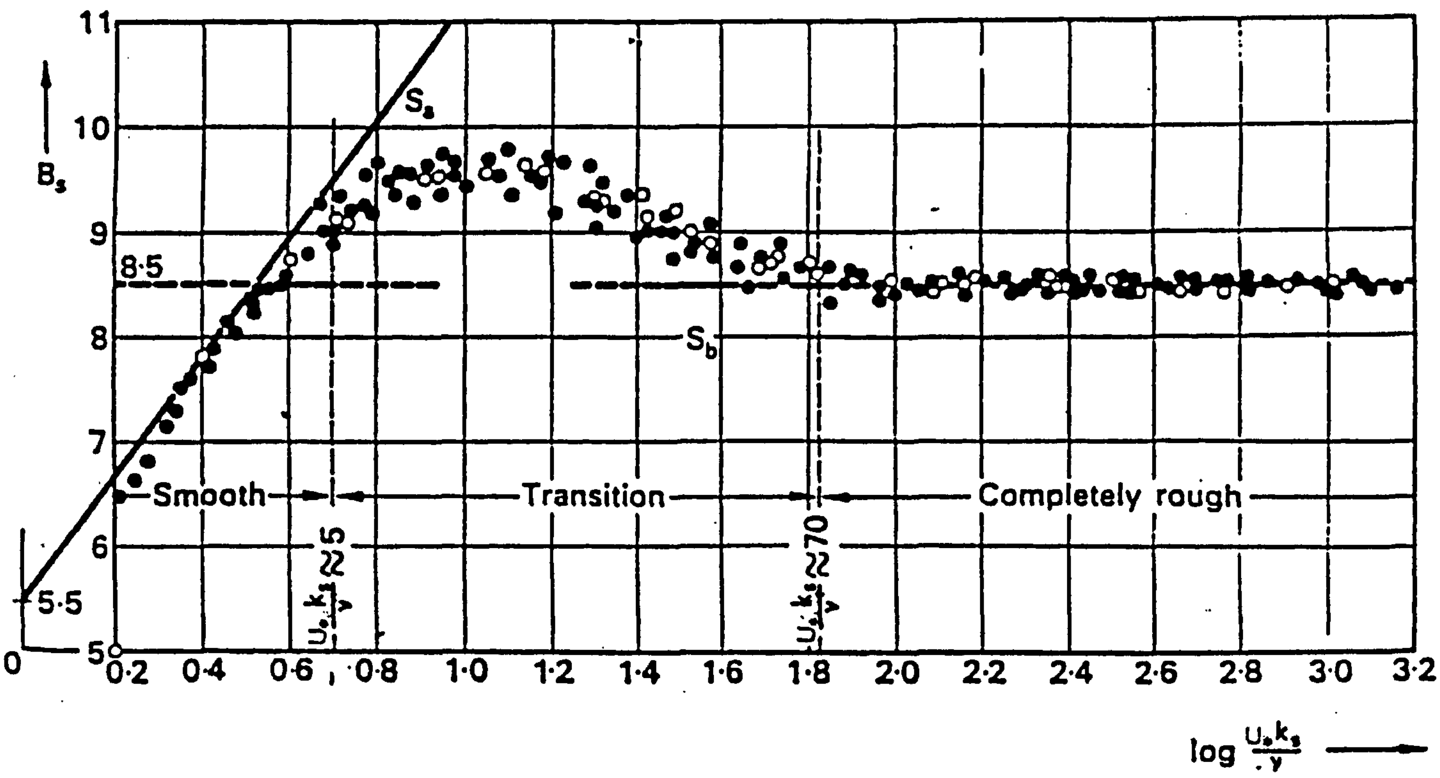


Figure 2.5: Relationship Between Particle Reynolds Number and Bs [104]

2.7 Physical Characteristics of Sludges

The characteristics of sludges produced in water and wastewater treatments can vary greatly, due to the tremendous difference in types of wastewaters and chemicals used during treatment processes. It is important to be able to measure some of the characteristics that can be used in design and operation of water or/and wastewater treatment plants. Because of the complex nature of sludge, basic parameters are of limited value, and it has been necessary to develop some operational parameters which can be used in practice. Some of the physical characteristics of sludges which have been used in the operation and design of a treatment plant are listed below [93]:

1. Specific Gravity: specific gravity is defined as the ratio of the weight of the material to that of an equal volume of water. Most sludges have a specific gravity of almost 1.0.
2. Solid Concentration: the relative solid and liquid fractions of a slurry are most commonly described by solids concentration, expressed as mg/L or percent solids. There are three types of solids (A) total (B) dissolved (C) suspended. Normally suspended solids concentration is used to describe the physical properties of sludges.
3. Settling Characteristics: sludge often can be characterized by how well the particles settle.

Settling velocity of a specific sludge is an inverse function of sludge solids concentration.

4. Particle Size: sludge particles vary not only in size but also in consistency and shape. Thus it is extremely difficult to characterize sludges by particle size, although this has been attempted by several researchers. Not only is sludge composed of many different sized particles, but these sizes change with time and test conditions.
5. Rheology: all fluids can be classified in terms of their flow properties. This field of water and wastewater engineering, has not received much attention. Although researchers have started to realize the importance of rheological properties of sludges in designing different waste treatment units, it will take time before proper design parameters are established. This physical characteristic of sludge is discussed in detail in the following section.

2.7.1 Rheology of Different Kinds of Sludges

Rheology is the science of the deformation and flow of matter [24]. Extensive use has been made of rheological measurements in studying the fundamental properties of suspensions such as the size and shape of particles, degree of hydration, state of aggregation, rigidity of particles, and forces acting between particles[24]. However, very few of these applications have been in the field of water and wastewater engineering.

2.7.1.1 Types of Fluids

Real fluids can be divided into two categories:

1. Newtonian Fluids
2. Non-Newtonian Fluids

Newtonian Fluids: Pure single - phase liquids characteristically demonstrate Newtonian behaviour, that is the shearing stress, τ, is directly proportional to the rate of shear or velocity gradient, du/dx, in laminar flow conditions:

$$\tau \propto \frac{du}{dx} \qquad \text{----[2.28]}$$

$$\tau = \mu \frac{du}{dx} \qquad \text{----[2.29]}$$

The constant of proportionality, μ, for a given liquid at a given temperature is a characteristic physical constant and is known as absolute or dynamic viscosity or Newtonian viscosity. The Newtonian viscosity, μ, depends only on temperature and pressure. Therefore the diagram relating shear stress and rate of shear for Newtonian fluids, the so-called 'flow-curve', is a straight line of slope μ as shown in Figure 2.6. This single constant completely characterizes the fluid [101]. Newtonian behaviour is exhibited by fluids in which the dissipation of viscous energy is due to the collision of comparatively small molecular species. All gases, liquids and solutions of low molecular weight come into this category. Notable differences are observed in colloidal suspensions and polymeric solutions where the molecular species are large. The flow curve for such suspensions show considerable changed behaviour from Newtonian behaviour [101].

Non-Newtonian Fluids: Non-Newtonian fluids are those for which the flow curve is not linear, i.e. the viscosity of a non-Newtonian fluid varies not only with temperature and pressure but also depends on other factors such as the rate of shear in the fluid, the apparatus in which the fluid is contained or even on the previous history of the fluid.

The real non-Newtonian fluids can be classified into two major categories:

1. Time independent non-Newtonian fluids
2. Time dependent non-Newtonian fluids

Each of these categories can be further subdivided into different types.

A. Time Independent Fluids

Time independent fluids are those fluids whose properties are independent of time. Most of the sludges fall in this category. Time independent fluids may conveniently be subdivided into three distinct types depending on the nature of their flow curve:

i. Bingham plastic fluids
ii. Pseudoplastic fluids
iii. Dilatant fluids

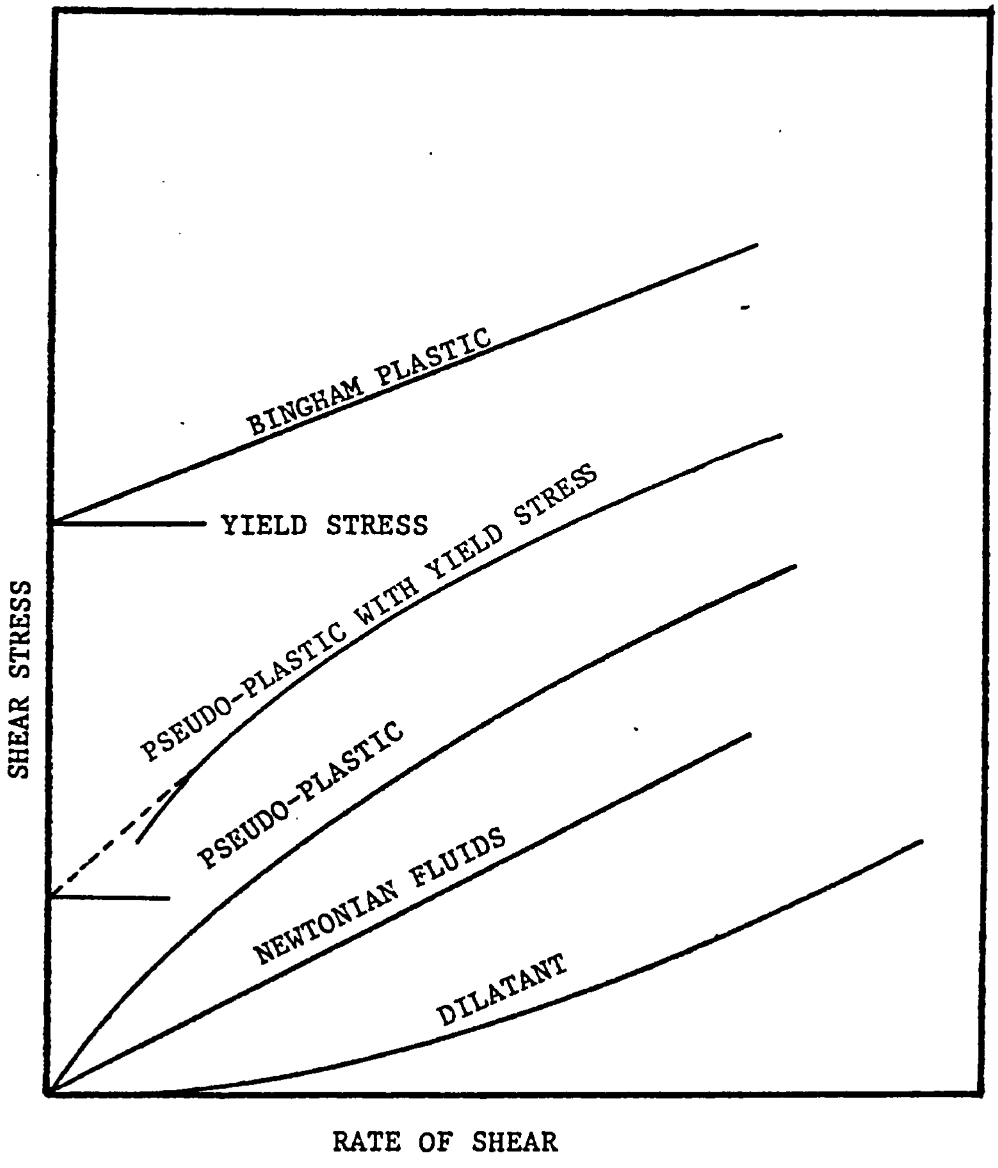


Figure 2.6: Typical Flow Curves for Different Fluids

Typical flow curves for these three fluids are shown in Figure 2.6.

B. Time Dependent Fluids

Time dependent fluids are those fluids whose properties change with time when a shear force is applied. These fluids may be divided into two classes according to shear stress increase or decrease with time when the fluid is sheared at a constant rate

i. Thixotropic fluids

ii. Rheopectic fluids

2.7.2 Sludge as a Non-Newtonian Fluid

The classic work of Babbitt and Caldwell [12,13] is apparently the basis on which the sewage sludge is classified as a Bingham plastic. However, their conclusions were based on digested sludge. Behn [14] has summarized the work of other workers in wastewater and the weight of evidence indicates that the digested sludge behaves as a Bingham plastic. Bokil and Bewtra [15] also found the behaviour of digested sludge to be very close to Bingham plastic. Dick [24,25] has done considerable work on different kinds of sludges recently, and found the sludges to behave very close to non-Newtonian, especially a Bingham plastic. Very limited work has been done with raw wastewater sludges. No information could be found in the literature on the behaviour of sludges such as alum sludge, sludge from chemically treated wastewater, primary sludge, etc.

2.7.3 Use of Rheological Informations

The obvious application of rheological information has been the head loss calculations when sludge is pumped and piped. However, there are other applications which might be equally useful [25]:

1. Rheological measurements provide a fundamental description of flow and deformation properties of sludges.
2. The performance of many processes for separating and treating activated sludge solids depends on physical properties of sludge. Therefore, the rheological measurements may be useful in developing an understanding of process performance.
3. Dick [26] has shown that the deviation of the thickening behaviour of activated sludge from the ideal thickening properties, as defined by Kynch [50], could be related to the yield strength of the sludge as determined by a coaxial cylinder rotational viscometer.
4. Wood and Dick [102] have demonstrated that in dissolved air pressure floatation of activated sludge, the rise rate and float concentration are related to the rheological properties of the sludges. It is reported that high yield strength values interfere with effective performance of floatation.

5. Campbell, et al. [21] have noted that due to the polymer conditioning of activated sludge, yield stress increased with polymer dose until the optimum dosage was reached.

2.7.4 Rheological Models to Represent Behaviour of Different Fluids

Bingham and Green [16] proposed the following model for a plastic material, which has come to be known as Bingham plastic:

$$\tau = \tau_y + \mu_p \frac{du}{dx} \qquad \text{----[2.30]}$$

where τ = shear stress

τ_y = yield stress

μ_p = plastic viscosity

$\frac{du}{dx}$ = rate of shear

Intermediate in behaviour between plastic materials or Bingham plastic materials and dilute suspensions with altered Newtonian viscosity are suspensions displaying pseudoplastic behaviour. Because size and other characteristics of flocculent particles are influenced by the rate of shear, the effect of the particles on flow behaviour of the suspension varies with the rate of shear. The resulting shear-thinning (pseudoplastic) behaviour has been described by Van Wazer, et al. [94] by the power function as shown below:

$$\tau = k_1 \left(\frac{du}{dy} \right)^n \qquad \text{----[2.31]}$$

where k_1 = a constant with dimensions of viscosity

n = a dimensionless constant with a value less than one

Improved models are now available in the literature, especially in the chemical engineering field, to describe those real fluids which behave somewhere between Bingham plastic and pseudoplastic. In fact, most of the water and wastewater sludges in higher concentrations show this kind of behaviour.

The Herschel Bulkley model [27], which has been used successfully and extensively in chemical engineering to represent behaviour of several foodstuff data, is a 3 parameter model as shown below:

$$\mu' \left(\frac{du}{dx} \right) = {}_y \left(\frac{du}{dx} \right)^{-1} + m \left(\frac{du}{dx} \right)^{n-1} \qquad \text{----[2.32]}$$

where $\mu'\left(\frac{du}{dx}\right)$ = non-Newtonian viscosity at shear rate of du/dx

n and m = constants

τ_y = yield stress

An improvement to the Herschel Bulkley model was proposed by De Kee and Turcotte [27], with another 3 parameter model as shown below:

$$\mu'\left(\frac{du}{dx}\right) = \tau_y \left(\frac{du}{dx}\right)^{-1} + \mu'_1 e^{-t_1\left(\frac{du}{dx}\right)} \qquad \text{----[2.33]}$$

where t_1 = time parameter

u'_1 = viscosity parameter

τ_y = yield stress

$\mu'\left(\frac{du}{dx}\right)$ = non-Newtonian viscosity at shear rate of du/dx

The 3 unknown parameters in this model are τ_y, t_1 and μ'_1. This model appears to be more interesting since it contains a time constant, which may be useful in the study of materials showing time dependent behaviour.

Chapter III

APPARATUS AND EQUIPMENT

This experimental work was carried out in several steps using different sizes of grit particles and different types of sludge particles collected both from water and wastewater treatment plants. A laboratory scale model of a diffused air aeration tank and a recirculating rectangular flume were used during the experiments to measure various parameters. This chapter briefly describes the details of each equipment used during the experimental work.

3.1 Experiments With Laboratory Flume

The flume was used during the experiments to establish critical values for the initiation of motion of different sizes of grit particles and for different types of sludges.

3.1.1 Description of Flume

The flume was 2.74 m (9.00 ft) long, 0.31 m (1.00 ft) deep and 0.15 m (0.50 ft) wide. A recirculation tank 0.61 m (2.00 ft) wide and 0.61 m (2.00 ft) deep was located at the bottom of the flume. This recirculation tank was used to collect and recirculate the discharge from the flume. A flow adjuster (gate valve) was provided to adjust both the depth and the rate of flow in the flume. At the begining of the flume a constant head tank 0.91 m (3.00 ft) deep, 0.15 m (0.50 ft) wide and 0.61 m (2.00 ft) long was provided. A honeycomb was placed at the entry point of the flume to stream-line the flow. The flume and the constant head tank were made of plexiglass and angle iron, whereas the recirculation tank was made of steel plates. The details of the flume are shown in Figure 3.1 and the photographs are shown in Figure 3.2.

3.1.2 Measurement of Velocity in the Flume

A small current meter model # MINIFLO-PROBE 265-3 as shown in Figure 3.3, made by Kent Lea was used to measure the velocity of flowing water close to the bed during the critical conditions of entrainment. The measuring range of the equipment was from 0 - 1.3 m/s with an accuracy of ± 2%. At the upper limit, however, at a lower velocity range a higher error is expected. This current meter was calibrated against March McBirney Electromagnetic current meter, which is discussed in detail in section 3.3.4.

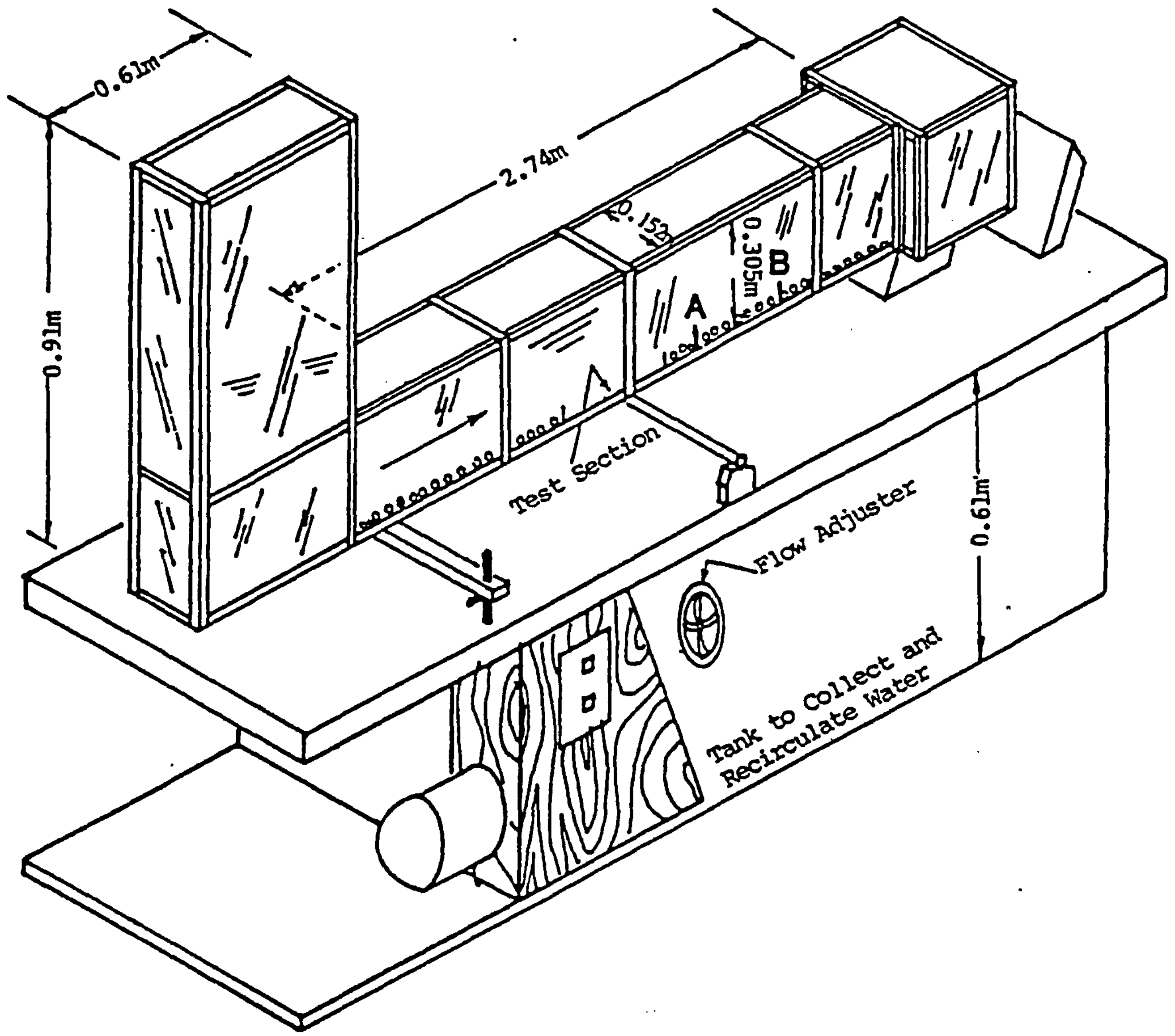


Figure 3.1: Flume Used for Experiments

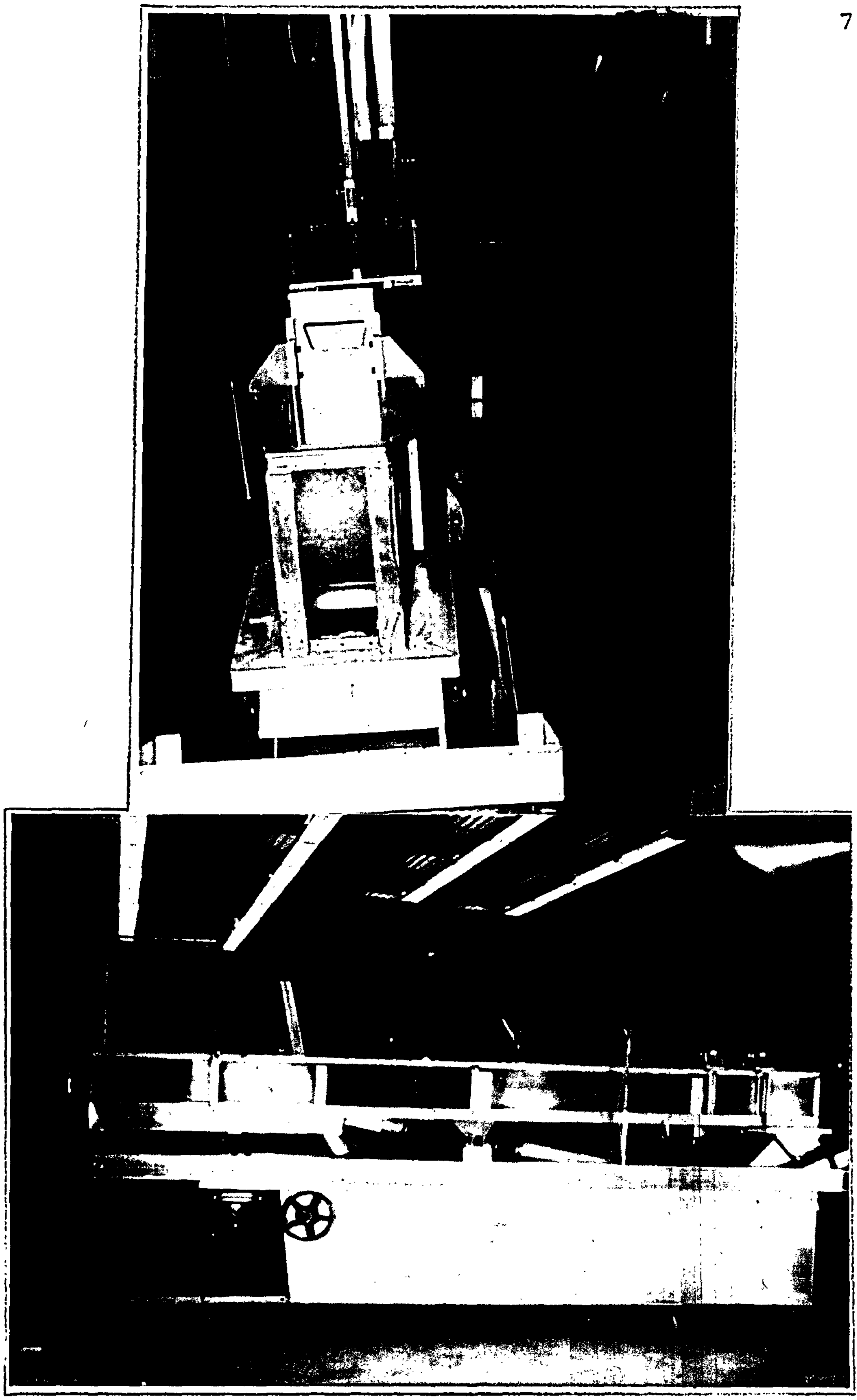


Figure 3.2: Pictures of Flume Taken From Various Angles

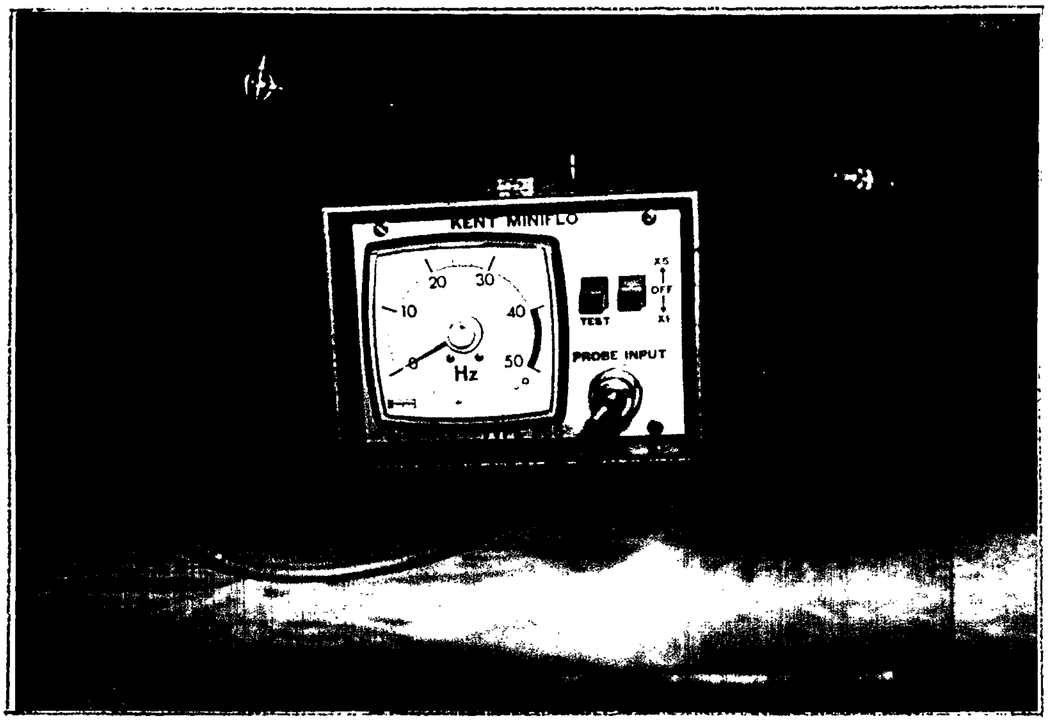


Figure 3.3: Current Meter MINIFLO-PROBE 265-3

3.2 Determination of Rheological Properties of Different Types of Sludges

A Brookfield Synchro-Lectric Viscometer was used to determine the rheological properties of different types of sludges both before and after thickening by settling. Some of the results obtained using the Brookfield Viscometer were rechecked by Rheomat 30 Viscosity Meter.

3.2.1 Viscosity Meters

The rheological properties of both water and wastewater sludges were determined using Brookfield Synchro-Lectric Viscometer Model # LVF, Figure 3.4. It was a four speed, 60, 30, 12 and 6 rpm, rotational co-axial type viscosity meter with four different types of spindles. This equipment worked on the principle of measuring the force required to rotate a spindle with a constant known speed, RPM, in a fluid, and this force value was used to calculate the viscosity. The speed of the spindle gave the rate of shear in 1/s, and the force required to rotate the spindle in that fluid gave the shear stress. Out of the four spindles equipped with the Brookfield Viscometer, only spindle #1 was used for all the tests. This spindle was a cylindrical shaped with 9.421 mm (0.371 in.) radius and 74.93 mm (2.95 in.) effective length.

Some of the tests were repeated by using a very sophisticated and sensitive viscosity meter made by Contraves (Switzerland), Model # Rheomat 30, to check the

Figure 3.4: Brookfield Synchro-Lectric Viscometer

Figure 3.5: Contraves, Model # Rheomat 30 Viscosity Meter

accuracy of the Brookfield Viscometer. This viscosity meter Figure 3.5, also was a rotational co-axial type with many options. The range for the rate of shear obtained by this equipment was fairly wide and eight different rates of shear were used. The calibration procedure of the Brookfield Viscometer is presented in Appendix A.

3.2.2 Water Bath

A water bath, Figure 3.6, was used to maintain a constant temperature of the sample during the experiments to determine the rheological properties of sludges using viscosity meters. Since rheological properties are very sensitive to temperature, it was made sure that the temperature of the samples remained at 20°C during these experiments.

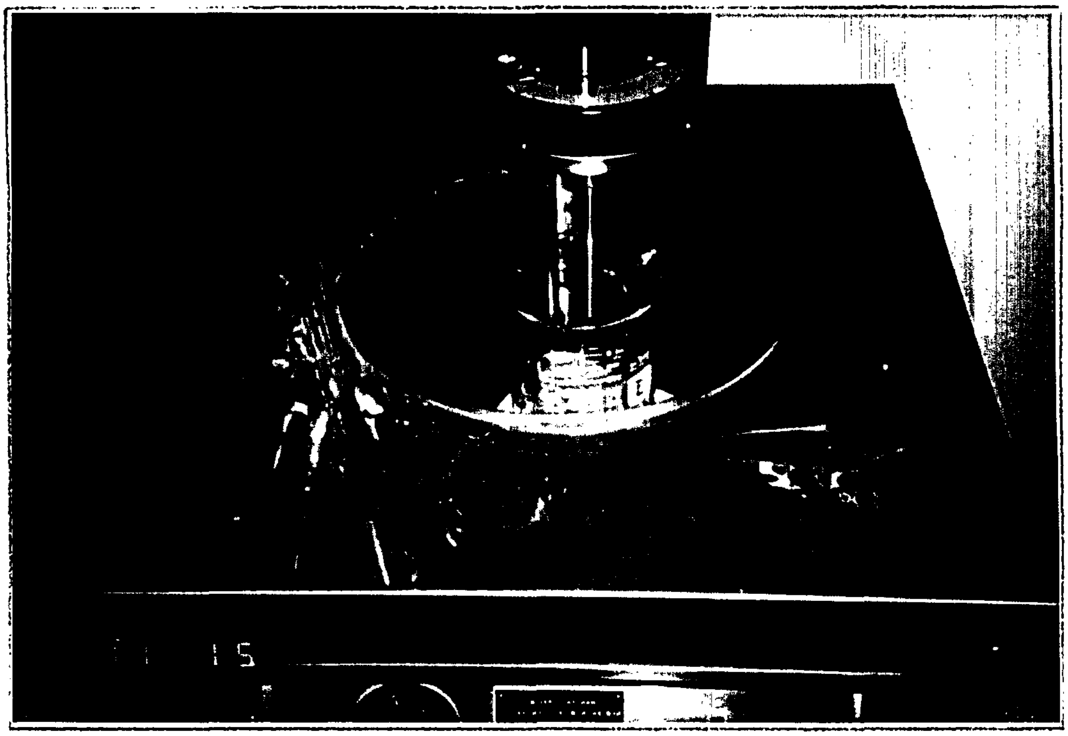


Figure 3.6: Water Bath Used during Experiments on Sludges

3.3 Experiments With Aeration Tank Model

A laboratory scale tank was used to obtain velocity profile and mixing behaviour under various operating conditions of air agitation.

3.3.1 Aeration Tank Model

The model tank was rectangular in shape with a line diffuser placed along the length of the tank, Figure 3.7. Photographs showing different mixing conditions are shown in Figure 3.8. The Aeration tank was 2.44 m (8.00 ft) wide, 0.69 m (2.25 ft) long and 1.22 m (4.00 ft) high. The width of the tank was altered by using a movable partition made of iron plate. The tank itself was made of 12.5 mm (0.5 in.) thick plexiglass segments reinforced with iron frame. The diffuser consisted of 25 mm (1.0 in.) diameter copper pipe 0.69 m (2.25 ft) long, with fourteen 3 mm (1/8 in.) diameter orifices 50 mm (2 in.) apart and facing the surface of the tank. The diffuser covered the entire length of the tank.

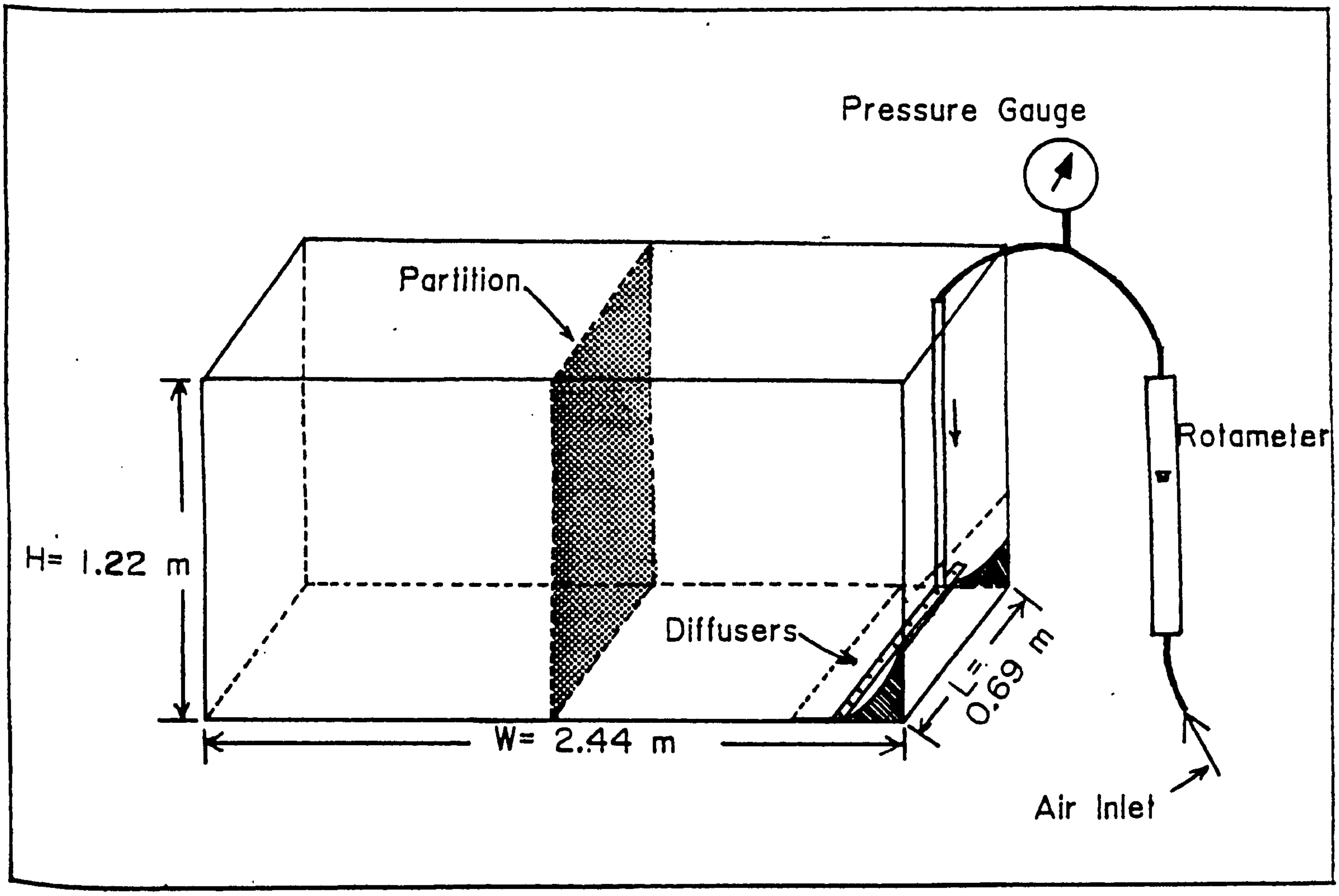


Figure 3.7: Aeration Tank Model Used for Experiments

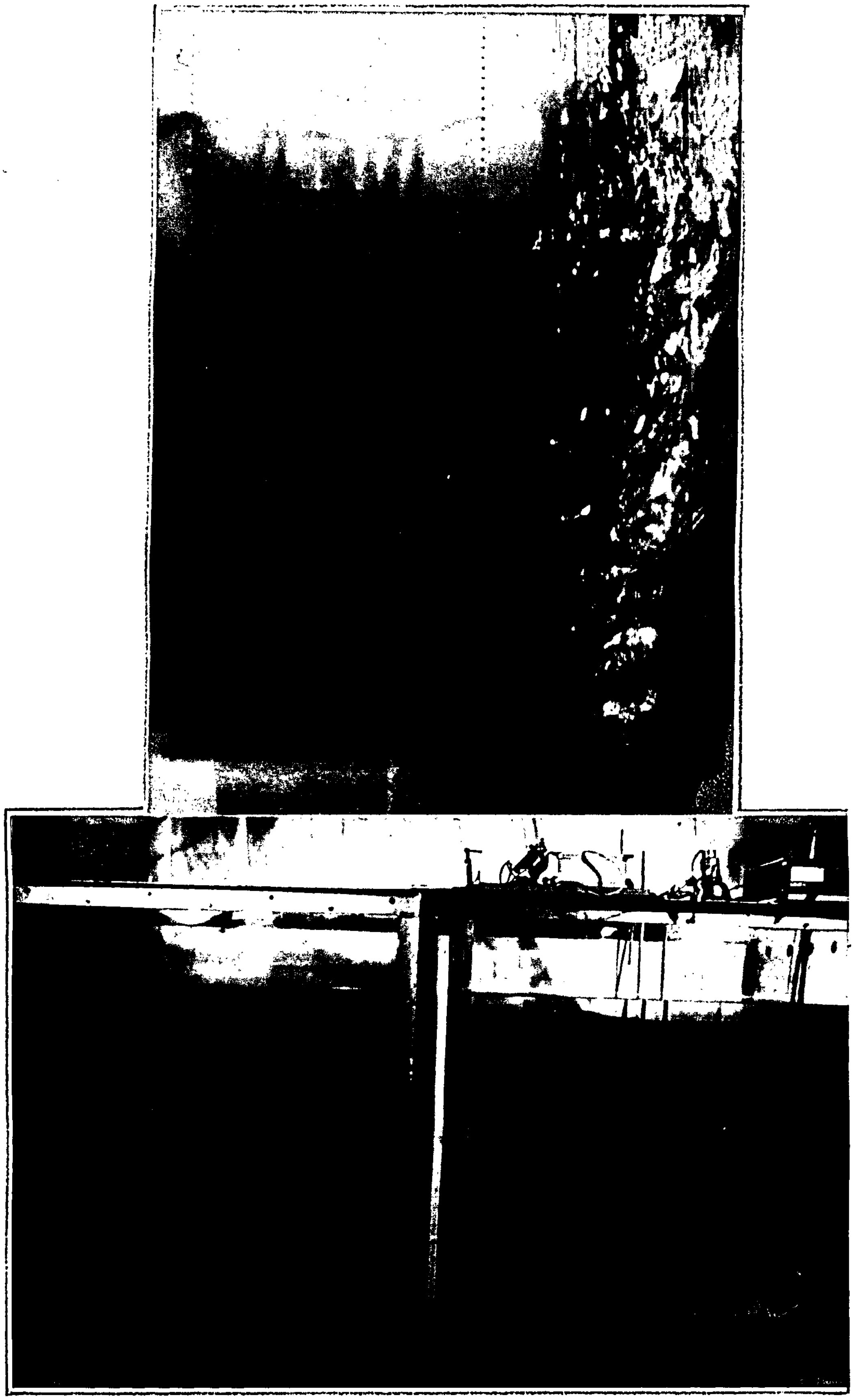


Figure 3.8: Different Mixing Conditions in Aeration Tank Model

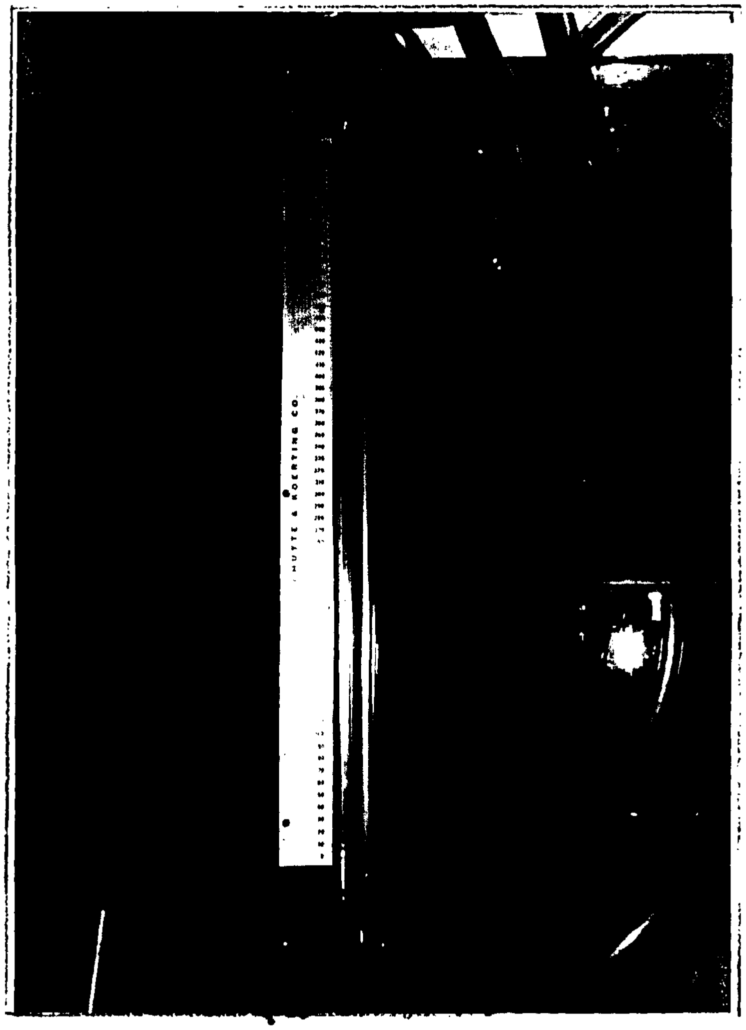


Figure 3.9: Safeguard Rotameter Model No: 5-HCFXB and Float No: 3/4-HGNV-4

3.3.2 Measurement of Air Flow Rate

The air flow to the tank was monitored by using a Safeguard Rotameter Model No: 5-HCFXB and Float No: 3/4-HGNV-4, supplied by S.K. Instruments. The scale of rotameter was precalibrated for air at STP (14.7 psia and 70° F) in Standard Cubic Feet Per Minute, SCFM, in the range of 0 - 20 SCFM with an accuracy of ± 1%. The picture of rotameter is shown in Figure 3.9.

3.3.3 Measurement of Air Pressure

The pressure of air diffused into the aeration tank through line diffusers was measured using a Bourdon-Tube type pressure gauge, supplied by Thermo Gauge. This pressure gauge was calibrated for the pressure range of 0 - 30 psig. The air pressure in the aeration tank was held steady using a constant pressure control valve in the air supply line. The picture of pressure gauge is shown in Figure 3.10.

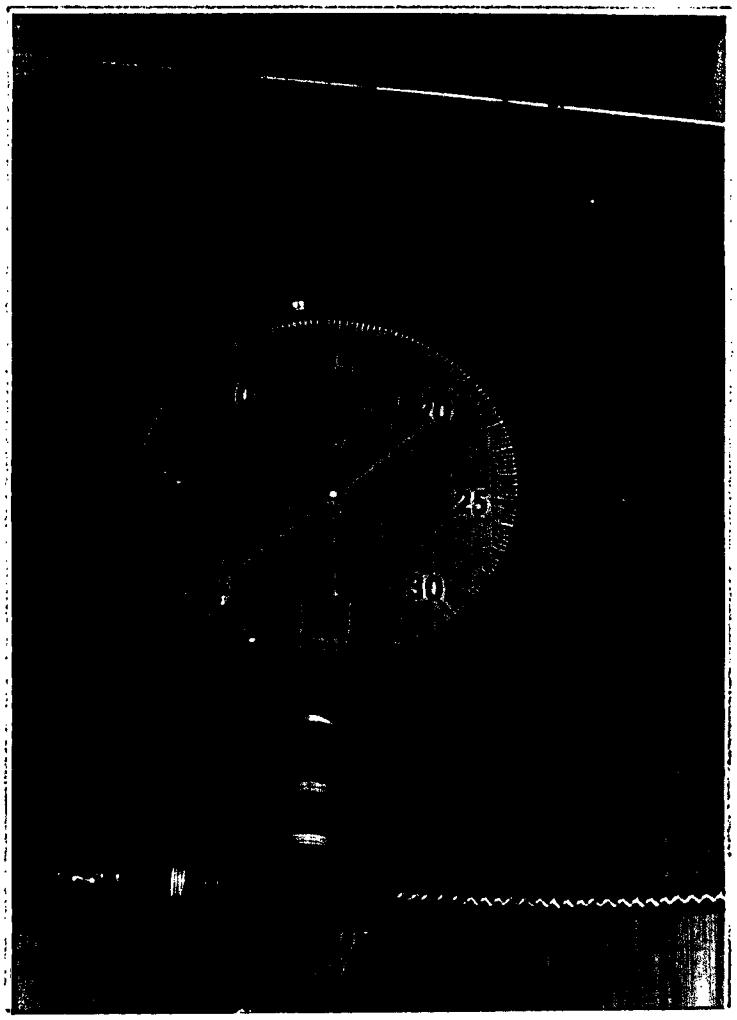


Figure 3.10: Air Pressure Gauge Used during Experiments

3.3.4 Measurement of Velocity

The accurate measurement of horizontal velocity was necessary in the development of the model. The velocity was measured at the middle of the tank width at different depths in order to develop velocity profiles. Two different types of velocity meters were used for this purpose as described below:

1. Detflow Ultrasonic Velocity Meter
2. Marsh McBirney Electromagnetic Current Meter

1. Detflow Ultrasonic Velocity Meter: A Detflow Ultrasonic Velocity Meter model # 3 CM was used for the velocity measurement. This meter was designed on Ultrasonic Doppler Principle. The velocity measuring range of this meter was 0 - 3 m/s. The expected error in the measurement of velocity was ± 2 % of the actual velocity at the upper range and as high as ± 20% in the lower range of velocities. This meter had a cylindrical shaped probe which was placed facing the direction of flow at the required depth and position at which the velocity measurement was desired. The meter was precalibrated by the manufacturer for the velocity measurement in water. Precaution was taken to keep the probe clean of any kind of deposit, oil and grease. A picture of the Detflow Ultrasonic Velocity Meter is shown in Figure 3.11.

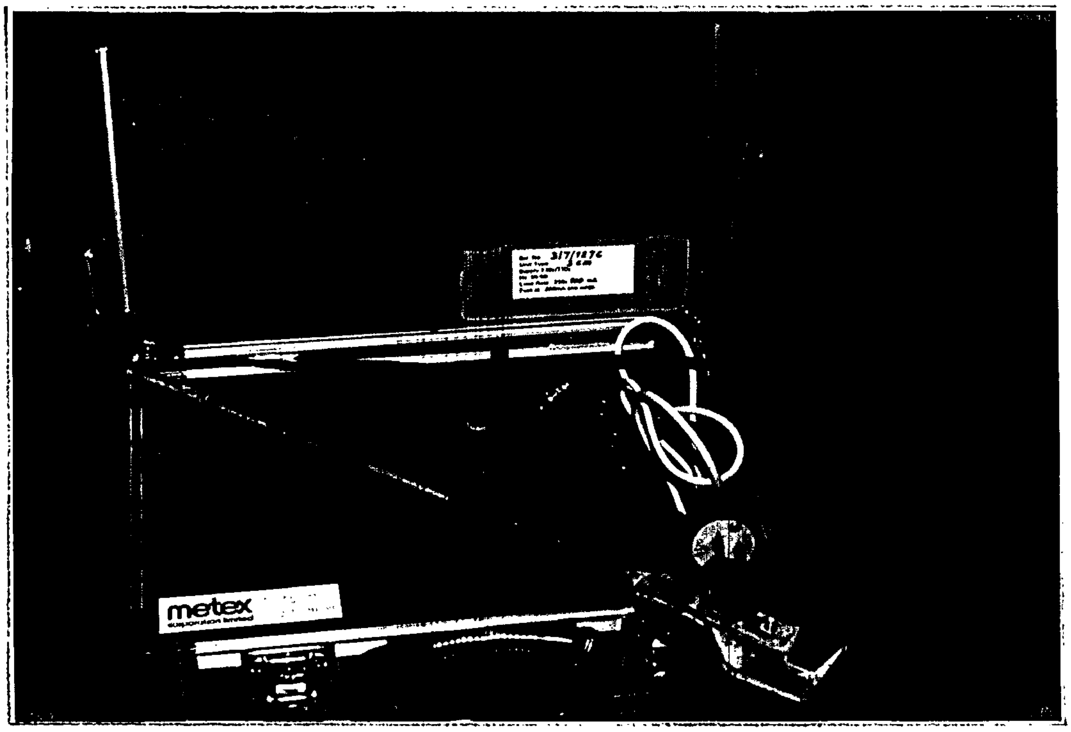


Figure 3.11: Detflow Ultrasonic Velocity Meter

2. Marsh McBirney Electromagnetic Current Meter: A Marsh McBirney Electromagnetic Current Meter, Model # 201M was used for the velocity measurement. This meter worked on the principle of Faraday's Law. When water, as a conductor, moved in a magnetic field, a voltage was produced which was linearly proportional to the water velocity. The velocity range was 0 - 3 m/s. The accuracy of this velocity meter was expected to be ± 2% in the upper range; however, in the lower range of velocities, this error could go as high as ± 20%. This meter had a conical shaped probe which was placed at the required depth and position facing the direction of flow. The probe was mounted on a clamp made of plexiglass (non-magnetic material) to avoid any kind of interference in the magnetic field formed by the probe. The probe was protected from getting damaged and kept clean of any kind of deposit, oils, grease etc.. The meter was calibrated by the manufacturer to measure the velocity directly in water. The picture of Marsh McBirney Electromagnetic Current Meter is shown in Figure 3.12.

Velocities were measured using both the meters at the same time to compare the readings.

Figure 3.12: Marsh McBirney Electromagnetic Current Meter

Chapter IV

EXPERIMENTAL PROCEDURE

The experimental work was divided into four major parts as described below:

a. Measurement of velocity during critical conditions for the initiation of motion of different sizes of grit particles in a flume.

b. Measurement of velocity during critical conditions for the initiation of motion of different kinds of sludge particles in a flume.

c. Determination of rheological properties of different kinds of sludges.

d. Measurement of velocity in the aeration tank under different operating conditions.

4.1 Experiments in Laboratory Flume with Grit Particles

The experiments in the laboraotry flume were conducted to measure horizontal velocities at different locations and at different depths during the critical conditions.

4.1.1 Preparation of Grit Samples

The grit samples were collected from the West Windsor Pollution Control Plant. The grit was cleaned several times with water to wash off all the decomposable organic matter and then dried in the oven. The washed grit was sieved and separated into various sizes. Some bigger size gravel particles were also included in the experiments to extend the scope of this study. Information on different grit and gravel sizes used in these experiments are provided in Table 4.1 and Table 4.2.

Table 4.1 - SIZE CLASSIFICATION OF GRIT USED DURING THE EXPERIMENTS

PASSED		RETAINED		GEOMETRIC MEAN SIZE, mm	GEOMETRIC MEAN PARTICLE SIZES USED IN EXPERIMENTS, mm
Sieve No.	Sieve Opening, mm	Sieve No.	Sieve Opening, mm		
		8	2.380		
8	2.380	10	2.000	2.1817	
10	2.000	14	1.400	1.6733	1.6733
14	1.400	16	1.180	1.2853	
16	1.180	18	1.000	1.0860	1.0860
18	1.000	20	0.850	0.9220	
20	0.850	25	0.710	0.7770	0.7770
25	0.710	30	0.600	0.6527	
30	0.600	35	0.500	0.5477	0.5477
35	0.500	40	0.425	0.4610	
40	0.425	45	0.355	0.3880	0.3880
45	0.355	50	0.300	0.3263	
50	0.300	60	0.250	0.2739	0.2739
60	0.250	80	0.180	0.2121	0.2121
80	0.180				

Table 4.2 - SIZE CLASSIFICATION OF GRAVEL USED DURING EXPERIMENTS

PASSED		RETAINED		GEOMETRIC MEAN SIZE, mm	GEOMETRIC MEAN PARTICLE SIZES USED IN EXPERIMENTS, mm
Sieve No.	Sieve Opening, mm	Sieve No.	Sieve Opening, mm		
3/4"	19.050	5/8"	15.875	17.40	17.40
5/8"	15.875	1/2"	12.700	14.20	14.20
1/2"	12.700	7/16"	11.633	12.20	12.20
7/16"	11.633	3/8"	9.525	10.50	10.50
3/8"	9.525	5/16"	7.925	8.70	8.70
5/16"	7.925	4	4.750	6.10	
4	4.750	8	2.380	3.40	3.40

4.1.2 Determination of Specific Gravity of Grit and Gravel Particles

The specific gravity of the grit particles collected from the waste treatment plant and larger size gravel particles, was determined by measuring the volume of water displaced by the known mass of grit and gravel particles. For both types of particles, experiments were repeated five times and the average values were used for subsequent calculations.

4.1.3 Measurement of Velocity During Critical Conditions

A laboratory flume, Figure 3.1, was used to establish the critical conditions for initiation of the motion of particles. The flume was completely levelled during the experiments and a water depth of 150 mm to 175 mm was maintained in the flume. Since the flume length was short, the flume bed was roughened with the same size of particles as were used for scouring during the experiment, in order to develop the flow fully. However, in the middle of the flume, about 650 mm test section was not roughened and this section was used to observe the movement of particles. The loose grit particles were placed uniformly in this test section for determining the critical conditions to initiate the motion of the particles. The sizes of all grit and gravel particles used in the experiments are listed in Table 4.1 and Table 4.2. It was assumed that the critical conditions had been established when the particles just started moving.

For each size of particle, the experiment was repeated at least twice to confirm the established critical conditions. The velocities at different depths and at different locations along the length of the flume were measured. The Kent Lea current meter was used to measure the velocities in the flume. The velocity along the length of the flume was measured at two locations, 1.83 m (6.00 ft) and 2.13 m (7.00 ft) from the reservoir. Along the depth, velocities were measured at 7.6 mm and at 38 mm above the bed, and subsequent readings were taken at 38 mm intervals.

4.2 Experiments in Laboratory Flume with Sludge Particles

Experiments were conducted to measure the horizontal velocity in the laboratory flume at different locations and depths during the critical conditions for the initiation of motion of the sludge particles. Different types of sludges, Table 4.3. were studied. Only the settled sludge particles were used in the experiment. Before starting the experiment, the flume was filled with tap water and a low velocity was maintained in the flume by adjusting the valve so that the sludge particles would not be washed away. Then a layer of sludge was spread on the flume bed. The velocity of water in the flume was slowly increased by opening the valve until the sludge flocs started to move. At this critical condition, the velocity of flow was measured at different locations along the length of the flume and also along the depth of the flow. Each set of experiment was repeated at least twice to make sure that a true critical condition had been achieved. The Kent Lea Current Meter was used for the measurement of velocity. The flume was completely levelled during the experiment and a constant water depth of 150 mm to 175 mm was maintained in the flume. The velocity along the length of the flume was measured at two locations, 1.83 m (6 ft) and 2.134 m (7 ft) from the reservoir. Along the depth, velocities were measured at 7.6 mm and at 38 mm above the bed, and subsequent readings were taken at 38 mm intervals.

Table 4.3 - TYPES OF SLUDGES USED AND THEIR SOURCES

SLUDGE TYPE	WATER/WASTEWATER TREATMENT PLANT	LOCATION/SOURCE
Mixed liquor, biological sludge	Little River Pollution Control Plant, Windsor	Aeration tank
Alum sludge	Water Treatment Plant, Amherstburg	Clarifier underdrains
Physico chemical sludge	West Windsor Pollution Control Plant, Windsor	Secondary clarifiers
Physico chemical sludge	West Windsor Pollution Control Plant, Windsor	Secondary clarifier underdrains
Secondary digested sludge	Wastewater Treatment Plant, Chatham	Secondary digester underdrains
Mixture of primary and secondary sludges	Wastewater Treatment Plant, Chatham	Primary clarifier underdrains

4.3 Determination of Properties of Sludges

The following properties of all types of sludges were determined during each experiment:

a. suspended solids concentration

b. zone settling rate

c. rheological properties of sludge

4.3.1 Suspended Solid Concentration

The total suspended solid concentration in all sludge samples, both before and after thickening by settling, were determined using the procedure given in the Standard Methods [86]. A 10 to 15 mL well mixed sludge sample was filtered through a glass fibre filter paper, Whatman # 541. The filter paper with the retained material was dried at 103 to 105 degrees C for at least 1 hour and then the residue was weighed to calculate the suspended solids concentration.

4.3.2 Zone Settling Rate

In order to study the settling properties of sludges, the zone settling rate for all types of sludges was determined in a settling column using the procedure given in the Standard Methods [86]. At high concentrations of suspended solids, suspensions settle in zone settling regime. This type of settling takes place under quiescent conditions and is characterized by a distinct interface between the supernatant liquor and sludge zone. The height of this distinct interface was measured with time.

4.3.3 Rheological Properties of Sludges

The rheological properties of all types of sludges were determined using a Brookfield Viscometer with spindle #1 (cylindrical shaped). Both the rate of shear and the torque input to maintain that rate of shear were obtained with the viscosity meter. Then these two parameters were used to calculate other characteristics of sludges. Since rheological properties of any non-Newtonian fluid are sensitive to change in temperature, a constant temperature was maintained by using a water bath for each sample during the experiment. Since sludge suspensions have a tendency to form a layer of supernatant and sludge flocs, all samples were stirred periodically using a glass stirrer. The Brookfield Viscometer Model # LVF is a four speed viscosity meter; therefore, only four readings could be obtained for each sample. Each set of experiment was repeated at least twice, and the average values were used for further calculations.

4.4 Experiments With Aeration Tank Model

The experiments in the aeration tank filled with the tap water were carried out by measuring the velocity under different operating conditions. The operating conditions which were varied during the experiments are listed below:

a. Location of line diffuser in the liquid depth
b. Air flow rate
c. Tank Width

d. Liquid depth in the tank

Different combinations of these variables were used, as shown in Table 4.4. and the horizontal velocities at different depths were measured so that the velocity profile could be developed. Two different types of velocity meters were used simultaneously to measure and compare the velocity readings. Visual observations on circulations patterns were also recorded under different operating conditions.

Table 4.4 - DIFFERENT OPERATING CONDITIONS USED DURING EXPERIMENTS WITH AERATION TANK

WATER DEPTH, m	DIFFUSER SUBMERGENCE, m	AIR FLOW RATE (Rotameter Reading) SCFM	TANK WIDTH, m
0.50	0.416	14.2	2.44
	0.355	10.8	2.21
	0.228	8.1	1.98
		4.2	1.75
		3.0	1.52
			1.29
			1.06
0.65	0.566	14.2	2.44
	0.505	10.8	2.21
	0.378	8.1	1.98
	0.345	4.2	1.75
		3.0	1.52
			1.29
			1.06
0.80	0.716	14.2	2.44
	0.655	10.8	2.21
	0.528	8.1	1.98
	0.495	4.2	1.75
	0.394	3.0	1.52
			1.29
			1.06
0.95	0.866	14.2	2.44
	0.805	10.8	2.21
	0.675	8.1	1.98
	0.645	4.2	1.75
	0.544	3.0	1.52
	0.467		1.29
			1.06

Table 4.4 - DIFFERENT OPERATING CONDITIONS USED DURING EXPERIMENTS WITH AERATION TANK (cont'd)

WATER DEPTH, m	DIFFUSER SUBMERGENCE, m	AIR FLOW RATE (Rotameter Reading) SCFM	TANK WIDTH, m
1.10	1.016	14.2	2.44
	0.955	10.8	2.21
	0.828	8.1	1.98
	0.795	4.2	1.75
	0.694	3.0	1.52
	0.617		1.29
	0.541		1.06

Chapter V

THEORY AND COMPUTATIONAL PROCEDURES

The theory and computational procedures used in this research are discussed in this chapter.

5.1 Concept of Critical Shear Stress for the Design of Grit Chamber

Grit particle characteristics are the most important parameters in the design and operation of grit chambers in wastewater treatment plants. Generally, the grit chambers are designed to remove all grit particles that are retained on a 65-mesh screen (0.21 mm opening), and have a specific gravity of 2.65. However, many grit chambers have been designed to remove grit particles that are retained on a 100-mesh screen (0.15 mm opening).

The design of gravity type grit chamber is generally based upon the concept of discrete particle settling under ideal conditions. It is assumed that (i) all particles settle in accord with Newton's law, (ii) liquid velocity is the same in all parts of the chamber, and (iii) there are no eddies in the flow stream. However, in an actual chamber the velocity is not uniform and also there are eddies present due to turbulence. These eddies retard settling. An increase in chamber velocity increases the scour of the settled material. Therefore, it is the scouring process and not the settling process which determines the design flow velocity for grit chambers.

Camp [18] proposed the following equation for mean critical scouring velocity, V_c. It was based on experimental and theoretical studies by Shields [81] on the movement of granular particles in flowing streams.

$$V_c = \sqrt{\frac{8\beta}{f} g (S_s - 1) d} \qquad \text{----[5.1]}$$

It is apparent from this Equation that the depth of flow in the channel has no influence on the critical mean scouring velocity. This is not quite true because, even if the mean velocity of flow in a channel remains the same for different depths of flow, the velocity profile will change with depth. Consequently, the scouring velocity on the channel bed is influenced by the depth of flow. Therefore, a new approach to design grit chambers has been developed on the concept of critical bed shear stress rather than critical mean velocity.

The bed shear stress in a fully developed flow is lower than the bed shear stress in an under developed flow for the same mean velocity, which again justifies the use of the concept of bed shear stress rather than mean velocity for grit chambers design.

The critical bed shear stress of a sediment particle is defined as the minimum boundary shear stress necessary to initiate the motion of that particle. Its magnitude depends on a number of factors including:

a. densities of particle and fluid

b. size of particle

c. viscosity of fluid, which in turn varies with the fluid temperature

5.1.1 Shear or Friction Velocity

In a uniform flow, the shear force, F, is equal to the effective component of the gravity force acting on the body of water, parallel to the channel bottom and can be written as [17]:

$$F = \gamma_f ALs \qquad \text{----[5.2]}$$

Where γ_f = unit weight of water

A = area of cross-section

L = length of channel reach

s = slope of channel

Thus the average value of the shear force per unit wetted area or simply shear stress, τ_o, is equal to:

$$\tau_o = \frac{\gamma_f ALs}{P_e L} = \gamma_f Rs \qquad \text{----[5.3]}$$

Where P_e = wetted perimeter

R = hydraulic mean radius

The shear or friction velocity, U_*, is defined as:

$$U_* = \sqrt{\frac{\tau_o}{\rho_f}} = \sqrt{\frac{\gamma_f R s}{\rho_f}} = \sqrt{gRs} \qquad \text{----[5.4]}$$

Where ρ_f = density of fluid

Under critical condition to initiate particle movement, the shear stress becomes critical shear stress and the shear or friction velocity at this point is called critical shear or friction velocity, U_{*c}.

$$U_{*c} = \sqrt{\frac{\tau_{oc}}{\rho_f}} \qquad \text{----[5.5]}$$

Where τ_{oc} = critical shear stress

The value of shear or friction velocity, U_*, changes with wall friction. Therefore, to calculate the value of U_*, the equations of velocity distribution in an open channel flow have to be obtained as discussed in the following section.

5.1.2 Velocity Distribution in Grit Chamber

Generally, the grit chambers have long and narrow rectangular sections and resemble open channels. The flow in a grit chamber is generally found to be fully developed turbulent flow. In a fully developed turbulent flow, the velocity distribution is logarithmic and is influenced by the regime of flow. Whether the regime of flow is hydraulically smooth or rough turbulent, is determined by the particles Reynolds number, $U_* k_s / \nu$, using the following conditions:

a. Turbulent flow with $U_* k_s / \nu \leq 5$ is called hydraulically smooth flow. Hydraulically smooth flow is distinguished by the fact that its velocity distribution does not depend upon the size and nature of roughness, provided $k_s <<$ depth of flow.

b. Turbulent flow with $U_* k_s / \nu \geq 70$ is called hydraulically rough turbulent flow or fully developed turbulent flow Rough turbulent flow is distinguished by the fact that the velocity distribution does not depend upon the viscosity μ or ν. If the thickness of the viscous sublayer is small in comparison to the size of the roughness, then the elements of roughness are almost totally exposed to the turbulent fluid motion. This means that the turbulence has penetrated even into the flow between the elements of roughness and hence the fully developed turbulent flow conditions exist.

c. Turbulent flow given by the condition $5 \leq U_* k_s / \nu \leq 70$ is said to be in the transitional regime and the velocity distribution is dependent on both viscosity and roughness.

The equations which have been used for the determination of velocity distribution are shown below:

For Smooth Walls, i.e., when $U_* k_s / \nu \leq 5$

$$\frac{u}{U_*} = 5.75 \log \left(\frac{y}{k_s}\right) + Bs \qquad \text{----[5.6.a]}$$

$$Bs = 5.75 \log \frac{U_* k_s}{\nu} + 5.5 \qquad \text{----[5.6.b]}$$

For Rough Walls, i.e., when $U_* k_s / \nu \geq 70$

$$\frac{u}{U_*} = 5.75 \log \left(\frac{y}{k_s}\right) + Bs \qquad \text{----[5.7.a]}$$

$$Bs = 8.5 \qquad \text{----[5.7.b]}$$

where u = velocity at a distance y from the channel bed

k_s = size of roughness, which can be taken to be equal to the particle size

U_* = friction or shear velocity

Bs = a dimensionless property of the flow in the vicinity of the bed. In general it is a function of particle Reynolds number $(U_* k_s / \nu)$

Turbulent flow with $5 \leq U_* k_s / \nu \leq 70$ is said to be in the transition regime. In the transition regime, the velocity distribution is dependent on both viscosity and roughness. For this case the value of Bs cannot be obtained analytically and must be estimated.

Using Equations 5.6 and 5.7 , the value of shear or friction velocity, U_*, can be calculated, provided a point velocity, u, at a given depth, y, from the bed is known. The constant, Bs, can be obtained by calculating the value of particle Reynolds number for different grit particles.

5.1.3 Mean Velocity

The value of mean velocity can be calculated if the location of mean velocity along the depth , i.e. distance from channel bed, y , is known. The location of the mean velocity in a channel flow can be obtained both for hydraulically smooth and rough turbulent regimes using Equations 5.6 and 5.7 as shown below [105]:

5.1.3.1 For Hydraulically Smooth Regime, $U_* k_s / \nu \leq 5$

Eq. 5.6 can be written as:

$$\frac{u}{U_*} = 2.5 \ln \left[9.0 \frac{U_* y}{\nu}\right] \qquad \text{----[5.8]}$$

The value of the mean or average velocity is given by:

$$u_m = \frac{1}{(y-\delta)} \int_{\delta}^{y} u \, dy \qquad \text{----[5.9]}$$

Where u_m = mean or average velocity

δ = laminar layer thickness

y = depth of water

u = point velocity

Substituting the value of u from Eq. 5.8 into Eq. 5.9 and solving it with the assumption that $\delta \ll y$, (ratio δ/y would even be smaller and can be neglected), gives

$$\frac{U_m}{U_*} = 2.5 \ln \left[9.0 \frac{U_* y}{\nu}\right] - 2.5 \qquad \text{----[5.10]}$$

$$\frac{u_m}{U_*} = 2.5 \ln \left[3.32 \frac{U_* y}{\nu}\right] \qquad \text{----[5.11]}$$

From Equations 5.8 and 5.11, the value of depth, y , can be calculated at which the point velocity will be equal to the mean velocity, u_m,: —

$$y_m = 0.368\ y \qquad \text{----[5.12]}$$

5.1.3.2 For Rough Turbulent Regime, $U_* k_s/\nu \geq 70$

Eq. 5.7 can be written as:

$$\frac{u}{U_*} = 2.5 \ln \left(30.0 \frac{y}{k_s}\right) \qquad \text{----[5.13]}$$

The value of the mean or average velocity is given by:

$$u_m = \frac{1}{(y-k_s)} \int_{k_s}^{y} u\, dy \qquad ----[5.14]$$

Where k_s = size of roughness, which can be taken equal to the particle size

Substituting the value of u from Eq. 5.14 into Eq. 5.15 and solving it with the assumption that $k_s << y$, (ratio k_s/y would even be smaller and can be neglected), gives:

$$\frac{u_m}{U_*} = 2.5\, \ell n \left[30.0 \frac{y}{k_s}\right] - 2.5 \qquad ----[5.15]$$

or $$\frac{u_m}{U_*} = 2.5\, \ell n \left[11.0 \frac{y}{k_s}\right] \qquad ----[5.16]$$

From Equations 5.13 and 5.16, the value of depth, y , can be calculated at which the point velocity will be equal to the mean velocity, u_m,:

$$y_m = 0.368\ y \qquad \text{----[5.17]}$$

Therefore, from the above derived equations, it is concluded that the location of mean velocity is the same relative to the depth of flow, y, both in hydraulically smooth or rough turbulent regimes.

5.1.4 Application

The application of the above concept of critical shear stress in practice is discussed below:

a. Knowing a point velocity, u, at any depth, y_1, obtained from a channel or a flume during critical conditions of entrainment, the shear or friction velocity, U_*, can be estimated from Equation 5.6 or 5.7.

b. Using this value of shear or friction velocity, U_*, and the known total depth of flow, y, in a channel or flume, the mean or average velocity, u_m, can be obtained from Equation 5.6 or 5.7 for $y_m = 0.368$ y.

c. The critical shear stress value for this particular kind of particle can be obtained from Eq. 5.4, where density of fluid (water), ρ_f, is known.

d. These mean velocity and critical shear stress values can be used for design of grit chambers.

5.2 Concept of Critical Shear Stress Applicable to Sludge

In the design of different water and wastewater treatment units, the knowledge of the characteristics of flocs or sludge particles is very important. Generally, the aeration tank in wastewater treatment and the flocculator in the water treatment are designed to enhance the size and the density of flocs without shearing or breaking them. These treatment units should not allow the settling of these flocs. All the settling and removal of flocs takes place in a settling or sedimentation tank. Therefore, in the aeration tank or in the flocculator, it can be assumed that the bed is smooth and the flow regime is turbulent. The shearing stress close to the bed of these treatment chambers has to be higher than the critical bed shear required to keep all the flocs in suspension all the time. Eqs. 5.6 and 5.5 can be applied to obtain the critical bed shear stress for different types of sludge particles, using the point velocity obtained in the flume close to the bed. Combining Eqs. 5.6.a and 5.6.b yield:

$$\frac{u}{U_{*c}} = 5.5 + 5.75 \left(\frac{yU_{*c}}{\nu}\right) \qquad \text{----[5.18]}$$

Where ν = kinematic viscosity, m^2/s

$= 1.01 \times 10^{-6}\ m^2/s$ at 20°C

5.3 Rheological Properties of Sludge

In this section, the analysis of the rheological properties of different types of sludges and their use in obtaining shear stress values required in various water and wastewater treatment units is discussed. Generally this shear stress should be just enough to keep the sludge flocs in suspension without shearing them. Appropriate models to calculate yield stress for non-Newtonian fluids are also discussed.

5.3.1 Development of Equation for the Rate of Shear and Shearing Stress

At least two experimental measurements are necessary on any non-Newtonian fluid in order to define its rheological properties, whereas a Newtonian fluid requires only one measurement, namely the viscosity. The rheological properties for any fluid can be determined by the direct relation between shear stress, τ, and shear rate, du/dx, by subjecting the fluid sample to a uniform rate of shear in a suitably designed instrument and measuring the corresponding shear stress. Viscometers using this principle are usually rotational instruments of the coaxial cylinder type.

The principle of operation of the coaxial-cylinder viscometer is shown in FIGREF REFID=F501.. The fluid is confined between long vertical coaxial cylinders, one of which can be rotated at different speeds, while the torque, M, on the other is measured. The variation of torque, M, with speed, ω, can be interpreted to give the relation between shear stress, τ, and rate of shear, du/dx.

Following are the assumptions made in this approach [94]:

a. Liquid is incompressible

b. Motion of liquid is laminar

c. Streamlines of flow are circles on the horizontal plane perpendicular to the axis of rotation (i.e. the velocity is a function only of radius; radial and axial flows are assumed to be equal to zero)

d. Motion is steady - all time derivatives in the equations of continuity and motion are zero

e. There is no relative motion i.e. no slippage between the surface of the cylinders and the fluid in immediate contact with the cylinders

f. Motion is two dimensional

g. System is isothermal

Assumption 3, implies that centrifugal forces are neglected, an assumption that is valid for small values of angular velocity.

Assumption 6, means neglecting the edge and end effects. This assumption also neglects normal forces (cross-viscosity, Weissenberg effect, etc.).

The relationship between angular velocity, ω, and linear velocity, v, is used to obtain the velocity gradient. It has been assumed that the inner cylinder or bob is rotating at an angular velocity, ω.

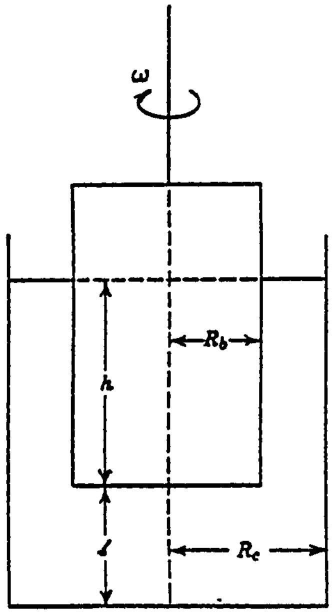


Figure 5.1: Principle of Operation of Coaxial-Cylindrical Viscosity Meter

The linear velocity, v, at any distance, r, from the axis given by:

$$v = r \; \omega \qquad \text{----[5.19]}$$

Similarly, the linear velocity, (v+dv), at a distance, dr, from , r, when the angular velocity at that point becomes (+d) is given by:

$$(v+dv) = (\omega+d\omega)\ (r+dr) \qquad \text{----[5.20]}$$

Solving Eq. 5.20, after neglecting the second order term:

$$\frac{dv}{dr} = \omega + r \ \frac{d\omega}{dr} \qquad \text{----[5.21]}$$

In this Equation the first term, ω, is the angular velocity of all the apparatus if no shearing takes place. Therefore, the internal stresses are derived from the second term r $(d\omega/dr)$.

By definition, the relation between shear stress and rate of shear in Newtonian fluid is:

$$\tau = \mu(- \frac{dv}{dr}) = \mu\ (- \frac{du}{dx}) \qquad \text{----[5.22]}$$

$$\tau = \mu \left(-r \frac{d\omega}{dr}\right) \qquad \text{----[5.23]}$$

Torque M = Shearing Stress x Surface Area of Bob x Radius of the Bob

$$= \tau \times 2 \pi r h \times r \qquad \text{----[5.24]}$$

Substituting the value of τ from Eq. 5.22 and solving it for $d\omega$:

$$-d\omega = \left(\frac{M}{2 \pi h \mu}\right) \frac{dr}{(r)^3} \qquad \text{----[5.25]}$$

The angular velocity is equal to zero at the wall of the outer cylinder for the condition of no slippage.

If the radius of the outer cylinder (container)=R_c and the radius of the inner cylinder (bob)= R_b then:

integration between $\omega = 0$ and $\omega = \omega$, for $r = R_c$ and $r = R_b$, yields

$$\int_0^{\omega} -d\omega = \int_{R_c}^{R_b} \frac{M}{2 \pi h \mu} \frac{dr}{r^3} \qquad \text{----[5.26]}$$

$$-\omega = -\frac{M}{4\pi h\mu}\left[\frac{1}{R_b^2} - \frac{1}{R_c^2}\right] \qquad \text{----[5.27]}$$

$$\mu = \frac{M}{4\pi h\omega}\left[\frac{R_b^2 - R_c^2}{R_b^2 R_c^2}\right] \qquad \text{----[5.28]}$$

Since μ = shear stress/ rate of shear = $\tau/(dv/dr)$, therefore, Eq. 5.28 can be divided into two parts:

The rate of shear is given by

$$-\frac{dv}{dr} = \frac{-2\omega}{r^2}\left(\frac{R_b^2 R_c^2}{R_c^2 - R_b^2}\right) \qquad \text{----[5.29]}$$

and the shear stress is given by

$$\tau = \frac{M}{2\pi r^2 h} \qquad \text{----[5.30]}$$

In case of plastic fluids such as sludges, the observed shear stress, τ, becomes [94]:

$$= \mu_p \frac{dv}{dr} + \tau_y \qquad \text{----[5.31]}$$

Where τ_y = yield stress

and viscosity for plastic fluids , μ_p , is called plastic viscosity or apparent viscosity.

In practice the rate of shear is determined at the surface of the bob (spindle). Therefore, r, becomes equal to R_b and Eq. 5.29 for rate of shear is reduced to

$$\frac{dv}{dr} = 2\omega \left(\frac{R_c^2}{R_c^2 - R_b^2} \right) \qquad \text{----[5.32]}$$

and the Eq. 5.30 for Shear Stress becomes

$$\tau' - \tau_y = \frac{M}{2 \pi R_b^2 L} \qquad \text{----[5.33]}$$

Where L = effective length of the spindle

All above mentioned equations are developed based on Newtonian fluids' theory. However, the validity of these equations for non-Newtonian fluids also has been proved [87].

5.3.1.1 Computation of Rate of Shear and Shear Stress

The rate of shear and shear stress using the Brookfield Viscometer were calculated with the help of Eq. 5.32 and Eq. 5.33 as shown below:

Rate of Shear

In Eq. 5.32, $\omega = \dfrac{2\pi n}{60}$

Where n = speed of the spindle, rpm

R_b = 9.4211 mm (provided by the manufacturer)

R_c = 5.00 cm (1000 mL beaker)

After substituting these values in Eq. 5.32, the rate of shear, $dv/dr = 0.217\ n\ \sec^{-1}$ ----[5.34]

Shear stress

In Eq. 5.33, $M = \dfrac{673.7\ \text{Dial}}{100}$

Where R_b= 9.421 mm

L = 74.93 mm (provided by the manufacturer)

After substituting these values in Eq. 5.33, the shear stress, $\tau = 16.1227$ Dial dynes/cm^2 ---[5.35]

where Dial= dial gauge reading for torque

M = torque in full scale, 673.7 dynes/cm

(Dial)

5.3.2 Model for Sludges

Among several models available to represent the non-Newtonian behaviour of different fluids and suspensions in the field of chemical engineering and food technology, the Dekee model [27] was found to be more flexible with the potential to use it beyond the purpose for which it was developed. The Dekee model [27] has been used successfully in determining the rheological properties of different types of biofluids and suspensions which show behaviour of pseudoplastic fluids with a yield stress. Since the behaviour of sludges was found to be very close to the biofluids and suspensions, it was decided to use the Dekee's model to fit the experimental viscosity data of different types of sludges.

5.3.2.1 Dekee Model

This model is an empirical 3 parameter model as shown below:

$$\mu'\left(\frac{du}{dx}\right) = \tau_y \left(\frac{du}{dx}\right)^{-1} + \mu'_1 e^{-t_1 \left(\frac{du}{dx}\right)} \qquad \text{----[5.36]}$$

where t_1 = time parameter

μ'_1 = viscosity parameter

τ_y = yield stress

$\mu'(\dot{\frac{du}{dx}})$ = non-Newtonian viscosity at shear rate, du/dx

A non-linear regression was performed using the SAS statistical package called NLIN to fit the experimental viscosity data to the Dekee model. A Taylor series expansion around these points was done and resulting linear equations were normalized. These normalized equations were then solved by Gauss Elimination Method using the initial values of the parameters, obtained by the experimental viscosity data as discussed in the following paragraphs. This method is called the Modified Gauss-Newton Method. The newly obtained values of the parameters became the initial value for the next iteration. The iterations were continued until convergence criteria were satisfied. The values of the parameters obtained in the last iteration were used as the corrected and final values.

Evaluation of the Parameters: The initial values of the parameters for each type of sludge were determined using the experimental viscosity data for non-linear regression as discussed below

Time Parameter and Viscosity Parameter: For a very high rate of shear, the yield stress term became very small which can be neglected and Eq. 5.36 reduces to Eq. 5.37.

$$\mu'\left(\frac{du}{dx}\right) = \mu'_1 \, e^{-t_1 \left(\frac{du}{dx}\right)} \qquad \text{----[5.37]}$$

taking ℓn of both sides,

$$\ell n \; \mu'\left(\frac{du}{dx}\right) = \ell n \; \mu'_1 - t_1 \left(\frac{du}{dx}\right) \qquad \text{----[5.38]}$$

which is similar to an equation for a stright line,

$Y = m X + C$

When this relationship between rate of shear and non-Newtonian viscosity is plotted on a semilog graph paper, the slope of the straight line portion of the curve at very high rate of shear will give the initial value of time parameter and the intercept of this straight line on the Y axis, i.e. non-Newtonian viscosity at zero rate of shear will give the initial value of viscosity parameter.

Yield Stress: For many pseudoplastic fluids with a yield value, flow properties can be successfully characterized by means of the Casson Equation [22]. However, Asbeck [5] emphasized the applicability of the Casson Equation in the high shear region by employing an alternate form as shown below:

$$\mu_1^{1/2} = \mu_L^{1/2} + \tau_y^{1/2} \left(\frac{du}{dx}\right)^{-1/2} \qquad \text{----[5.39]}$$

Where μ_1 = non-Newtonian viscosity

μ_L = limiting viscosity, i.e. independent of shear rate

τ_y = yield stress

If Eq. 5.39 is multiplied by$(du/dx)^{1/2}$, one obtains

$$\tau^{1/2} = \mu_1^{1/2} \left(\frac{du}{dx}\right)^{1/2} + \tau_y^{1/2} \qquad \text{----[5.40]}$$

Which is a useful form for a low shear viscometer and represents a linear relationship.

Therefore, if the square root of shear stress, $\tau^{1/2}$, is plotted against the square root of rate of shear, $(du/dx)^{1/2}$, a straight line analogous to a Bingham plastic fluid [77] will be obtained. The intercept of this straight line on the Y axis for zero rate of shear will give the square root of the initial value of yield stress. The slope of this straight line will give the value of limiting viscosity.

5.4 Development of Model for the Aeration Tank

A dimensional analysis was carried out to develop an empirical model, which will be able to predict the horizontal velocity, u, in the tank close to the tank bottom. In this dimensional analysis all the possible variables on which the horizontal velocity in an aeration tank could depend were considered. The units and dimensions of all variables involved in the development of the model are shown below:

$$u = f\,(P, L, W, g, \rho_f, \mu, H, X, h) \qquad \text{----[5.41]}$$

Where u = horizontal velocity close to the tank bottom

P = rate of power consumption

L = tank length

W = tank width

g = acceleration due to gravity

ρ_f = liquid density

μ = liquid viscosity

H = water depth in the tank

X = distance of diffuser from the sidewall of the tank

h = depth of water above the diffuser (submergence)

$$u = f[P^{A}\ W^{B}\ L^{C}\ g^{D}\ P^{E}\ u^{F}\ H^{G}\ X^{I}\ h^{J}] \quad \text{----[5.42]}$$

$$\frac{L}{T} = f[(\frac{ML^{2}}{T^{3}})^{A}\ (L)^{B}\ (L)^{C}\ (\frac{L}{T^{2}})^{D}\ (\frac{M}{L^{3}})^{E}\ (\frac{M}{LT})^{F}\ (L)^{G}\ (L)^{I}\ (L)^{J}]$$

$$LT^{-1} = f[L^{(2A+B+C+D-3E-F+G+I+J)}\ M^{(A+E+F)}\ T^{(-3A-2D-F)}] \text{-[5.43]}$$

Comparing the exponents on each side in Eq. 5.43

For L $\quad 1 = 2A+B+C+D-3E-F+G+I+J$ ----[5.44]

For T $\quad -1 = -3A-2D-F$ ----[5.45]

For M $\quad 0 = A+E+F$ ----[5.46]

Using the Buckingham II Theorem [76], the number of independent dimensionless groups of variables (dimensionless parameters) needed to correlate the variables in this system is equal to 10 -3 = 7, where 10 is the number of total variables involved and 3 is the number of basic dimensions. Therefore it was decided to substitute the values of E, F, and G in terms of other exponents to reduce the number of dimensionless groups to 7, as shown below:

From Eq. 5.45

$F = 1-3A-2D$ ----[5.47]

Substituting this value of F in Eq. 5.46

$0 = A+E+1-3A-2D$

or $E = 2A+2D-1$ ----[5.48]

Substituting the values of E and F from Equations 5.47 and 5.48 into Eq. 5.44, gives

$1 = 2A+B+C+D-3(2A+2D-1)-(1-3A-2D)+G+I+J$

$1 = B+C-A-3D+G+I+J+2$

$G = -B-C+A+3D-I-J-1$ ----[5.49]

Substituting the values of E, F, and G from Eqs. 5.47, 5.48 and 5.49 into Eq. 5.42, gives

$$u=f(P^{A}\,W^{B}\,L^{C}\,g\,P^{2A+2D-1}\,u^{1-3A-2D}\,H^{-B-C+A+3D-I-J-1}\,X^{I}\,h^{J})\text{[5.50]}$$

$$\frac{u\rho H}{\mu}=f\left[\left(\frac{P\rho^{2}H}{\mu^{3}}\right)^{A}\left(\frac{W}{H}\right)^{B}\left(\frac{L}{H}\right)^{C}\left(\frac{g\rho^{2}H^{3}}{\mu^{2}}\right)^{D}\left(\frac{X}{H}\right)^{I}\left(\frac{h}{H}\right)^{J}\right]\text{----[5.51]}$$

A few modifications and deletion were made in the Eq. 5.51 as described below:

a. The D powered term is called a depth factor and in order to show the effect of water depth directly, this term was changed in the form of H instead of H^3 by taking the cube root of all the variables in this dimensionless group.

b. In a rectangular aeration tank the diffusers are generally placed along the length of the tank. Since, the length of the tank (0.69 m) was not changed during experiments, it was decided to drop the length factor (L/H) from the Eq. 5.51. The width of the tank was changed during the experiments.

c. The distance of diffuser from the sidewall of the tank was not changed during the experiments, because it was observed that a small change in this distance made no significant change in the velocity distribution, it was decided to eliminate factor X/H from Eq. 5.51. Therefore:

$$\frac{u\rho H}{\mu} = f\left[\left(\frac{P\rho^{2}H}{\mu^{3}}\right)^{A}\left(\frac{W}{H}\right)^{B}\left(\frac{g^{1/3}\rho^{2/3}H}{\mu^{2}}\right)^{D}\left(\frac{h}{H}\right)^{J}\right] \qquad \text{----[5.52]}$$

Where $\left(\frac{u\rho H}{\mu}\right)$ = Reynold number or velocity factor, F1

$\left(\frac{P\rho^{2}H}{\mu^{3}}\right)$ = Power number X Reynold number^{3} or power factor, F2

$\left(\frac{W}{H}\right)$ = width factor, F3

$$\left(\frac{g^{1/3}\rho^{2/3}H}{\mu^{2/3}}\right) = \text{Galileo number}^{1/3} \text{ or depth factor, F4}$$

$$\left(\frac{h}{H}\right) = \text{submergence factor, F5}$$

Surface tension played an insignificant role in the experimental aeration tank due to its size. Surface tension is important in the formation and movement of bubbles in liquid. However, in this dimensional analysis , the details of air bubbles in the aeration tank was not considered. Therefore, the effect of surface tension on this analysis was neglected.

The variables and their values that were held constant during experiments on aeration tank are listed below:

Tank length, L = 0.69 m
Fluid density, ρ = 998 Kg/m^3 at 20°C
Fluid viscosity, μ = 1.0×10^{-3} N.s/m^2 at 20°C
Acceleration due to gravity, g = 9.8 m/s^2
Room temperature = 20°C

The velocity observations in the aeration tank were made for horizontal velocity for the entire depth. However, horizontal velocity, 25 mm above the tank bottom was considered for the development of model. Therefore, this model will predict the horizontal velocity at 25 mm above the tank bottom under different operating conditions.

5.4.1 Calculation of Different Dimensionless Factors

The calculation of various parameters used in different dimensionless factors are described below:

5.4.1.1 Reynolds Number or Velocity Factor, F1

$$\text{Velocity Factor, } F1 = \frac{u\rho H}{\mu}$$

This factor was calculated for the horizontal velocity, u, at a distance 25 mm above the tank bottom for different depths of water and operating conditions. The values of other parameters considered in the calculation were kept constant as discussed earlier.

5.4.1.2 Power Factor, F2

$$\text{Power Factor, } F2 = \left(\frac{P\rho^2 H}{\mu^3}\right)$$

A. The theoretical rate of power consumption, P is calculated using the following formula [80] based upon the assumption of adiabatic conditions.

$$P = \frac{WR_g T_i}{8.41} \left\{ \left(\frac{P_2}{P_1} \right)^{0.283} - 1 \right\} \quad \text{----[5.53]}$$

Where P = rate of power consumption, kw

w = air mass flow rate, kg/s

R_g = gas constant, 8.314 J/g.mol. °K

T_i = inlet temperature of air, °K

P_1=absolute inlet pressure, atmosphere

P_2=absolute outlet pressure, atmosphere

B. The useful power based on the isothermal expansion of the air at the outlet has been given by the Fair and Geyer [33] by the following equation:

$$P = 3891.26\ Q \ \log \left\{ \left(\frac{h+10.36}{10.36} \right) \right\} \quad \text{----[5.54]}$$

Where P = useful power dissipated, watts

Q = air flow rate, m^3/min

h = submergence of outlet port, m

The air flow rate is calculated for the standard conditions, i.e. 20°C temperature and 101.3 kN/m^2 pressure.

C. The useful power available at the outlet or diffuser can be calculated by modifying Eq. 5.53. The outlet pressure term, P_2, can be replaced by (h+10.36) m, inlet pressure term, P_1, can be assumed to be equal to atmospheric pressure of 10.36 m, and h is the submergence of outlet port or diffusers in m. The modified equation for useful power available at the outlet becomes:

$$P = \frac{W R_q T_i}{8.41} \left[\left(\frac{10.36+h}{10.36} \right)^{0.283} - 1 \right] \qquad \text{----[5.55]}$$

This value of power, P, ignores all the losses in the delivery system, in the fittings, at the diffusers, efficiency of the compressor and therefore is equal to the useful power available at the outlet. For all further calculations, this value of power, P, has been used. The air flow rates were obtained from a rotameter which was calibrated for air flow rate under standard conditions, STP.

D. In practice, standard conditions seldom exist at the outlet port. Therefore the air flow rate measured by the rotameter should be corrected for the operating conditions to obtain the air flow rate under standard conditions, using the following Equation:

$$Q_{STP} = [Q_{rota}] \left[\frac{(P_{STP})}{(P_{gage} + P_{atm})} \, \frac{(T_{ope})}{(T_{STP})} \right]^{1/2} \qquad \text{----[5.56]}$$

Where Q_{STP} = air flow rate under standard conditions, m^3/sec, 20° C and 101.3 kN/m^2 or cfm, 20° C and 14.7 psia

Q_{rota} = observed air flow rate (reading from rotameter), m^3/s or cfm

Q_a = actual air flow rate under operating conditions, m^3/sec or cfm

P_{rota} = pressure for which the rotameter was calibrated, 101.3 kN/m^2 or 14.7 psia

P_{gage} = pressure gauge reading, kN/m^2 or psig

P_{atm} = atmospheric pressure, 101.3 kN/m^2 or 14.7 psia

T_{ope} = operating temperature, °K

T_{STP} = standard temperature for which the rotameter was calibrated, 293.15°K

The actual air flow rate from diffuser, Q_a, m^3/s or cfm, corresponding to temperature, T_{ope}, and diffuser submergence, h, can be obtained from [61]:

$$Q_a = [Q_{rota}]\left[\frac{(P_{STP})}{(P_{gage} + P_{atm})}\,\frac{(T_{ope})}{(T_{STP})}\right]^{1/2}\left[\frac{(P_{gage}) + (P_{atm})}{(\gamma_f h + P_{atm})}\right]^{1/1.4} \text{-[5.57]}$$

5.4.1.3 Width Factor, F3

$$\text{Width Factor, F3} = \frac{W}{H}$$

This factor was calculated for different widths, W, 2.44 m, 2.21 m, 1.98 m, 1.75 m, 1.52 m, 1.29 m and 1.06 m of the aeration tank and for different depths of water, H, 0.50 m, 0.65 m, 0.80 m, 0.95 m and 1.10 m in the aeration tank.

5.4.1.4 Depth Factor, F4

$$\text{Depth Factor, F4} = \left(\frac{g^{1/3}\rho^{2/3}H}{\mu^{2/3}}\right)$$

In calculating the depth factor, all parameters except depth of water, H, in the aeration tank, such as density of water, ρ, viscosity of water, μ and acceleration due to gravity, g, were kept constant at 20°C. The various depths of water used in the experiment were 0.50 m, 0.65 m, 0.80 m, 0.95 m and 1.10 m.

5.4.1.5 Submergence Factor, F5

$$\text{Submergence Factor, F5} = \frac{h}{H}$$

This factor was calculated for different submergences, h, of the diffuser and for different depths of water, H, in the aeration tank.

5.4.2 Correlation Between Dimensionless Factors

An empirical model for the aeration tank to predict the horizontal velocity close to the tank bottom (25 mm above the floor) under various operating conditions was developed using the method of linear regression. A correlation was established between different dimensionless factors.

The statistical analysis of data was carried out using a standard statistical package program called Linear Regression [41]. Since Eq. 5.58 is in exponential form it was reduced to a linear form by taking log of both sides.

$$F1 = f\,(F2)^{A}\,(F3)^{B}\,(F4)^{D}\,(F5)^{J} \qquad \text{----[5.58]}$$

Where F1 =Reynolds number or velocity factor

F2 =power factor

F3 =width factor

F4 =depth factor

F5 =submergence factor

$$\text{or} \quad \log(F1) = \log(f) + A\log(F2) + B\log(F3) + D\log(F4) + J\log(F5) \qquad \text{----[5.59]}$$

The values of unknown multiplying constants such as f, A, B, D, and J were determined by applying a linear regression statistics to develop a correlation between the dependent variable, F1, and the independent variables F2, F3, F4, and F5 or any combinations of two or more of these independent variables. During the process of this analysis, any independent variable that had little or no influence on the dependent variable was discarded. The extent of influence of independent variables on dependent variable was identified by calculating different statistical parameters and they are listed below:

R - SQUARE Value - Coefficient of Determination
F Test Value
PR > F - Significance Probability
T FOR HO: PARAMETER=0 - Student's t test
PR > |T|

Chapter VI

RESULTS AND ANALYSIS

Results obtained through theoretical and experimental analyses are presented in this chapter.

6.1 Velocity Distribution in the Laboratory Flume

In this study, the Eqs. 5.6 and 5.7 have been used to calculate the critical shear or friction velocity, U_{*c} These equations are derived from 'Prandtl-von Karman Universal Velocity Distribution Law', which has been verified by many investigators [95]. This logarithmic law means that, during a turbulent flow when the boundary layer is fully developed, the velocity distribution is logarithmic. The experiments conducted in the laboratory flume indicate a striking similarity between observed and computed velocity distribution, Figure 6.1, and, therefore offer a reasonable justification for use of this logarithmic law in the analysis of data.

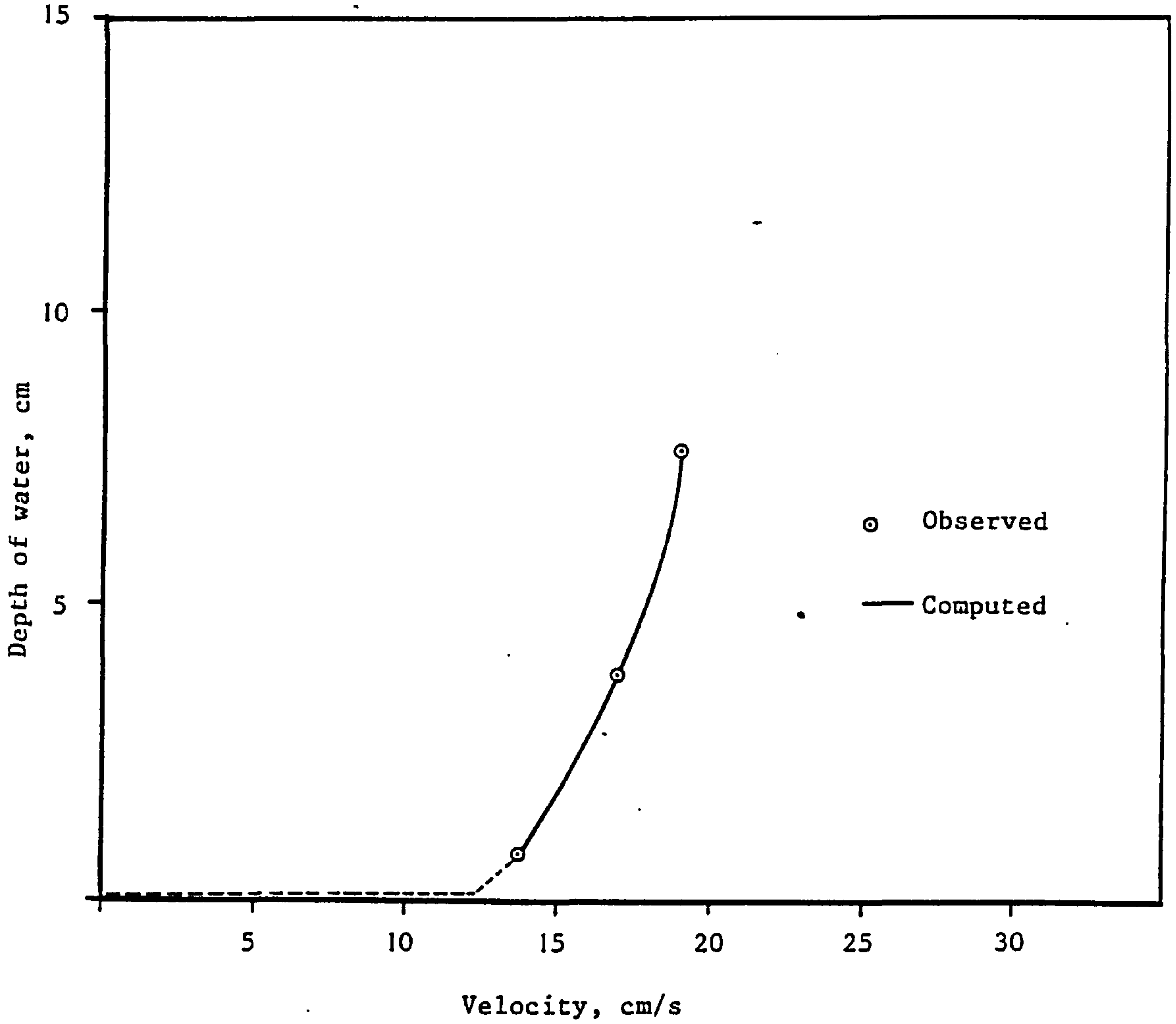


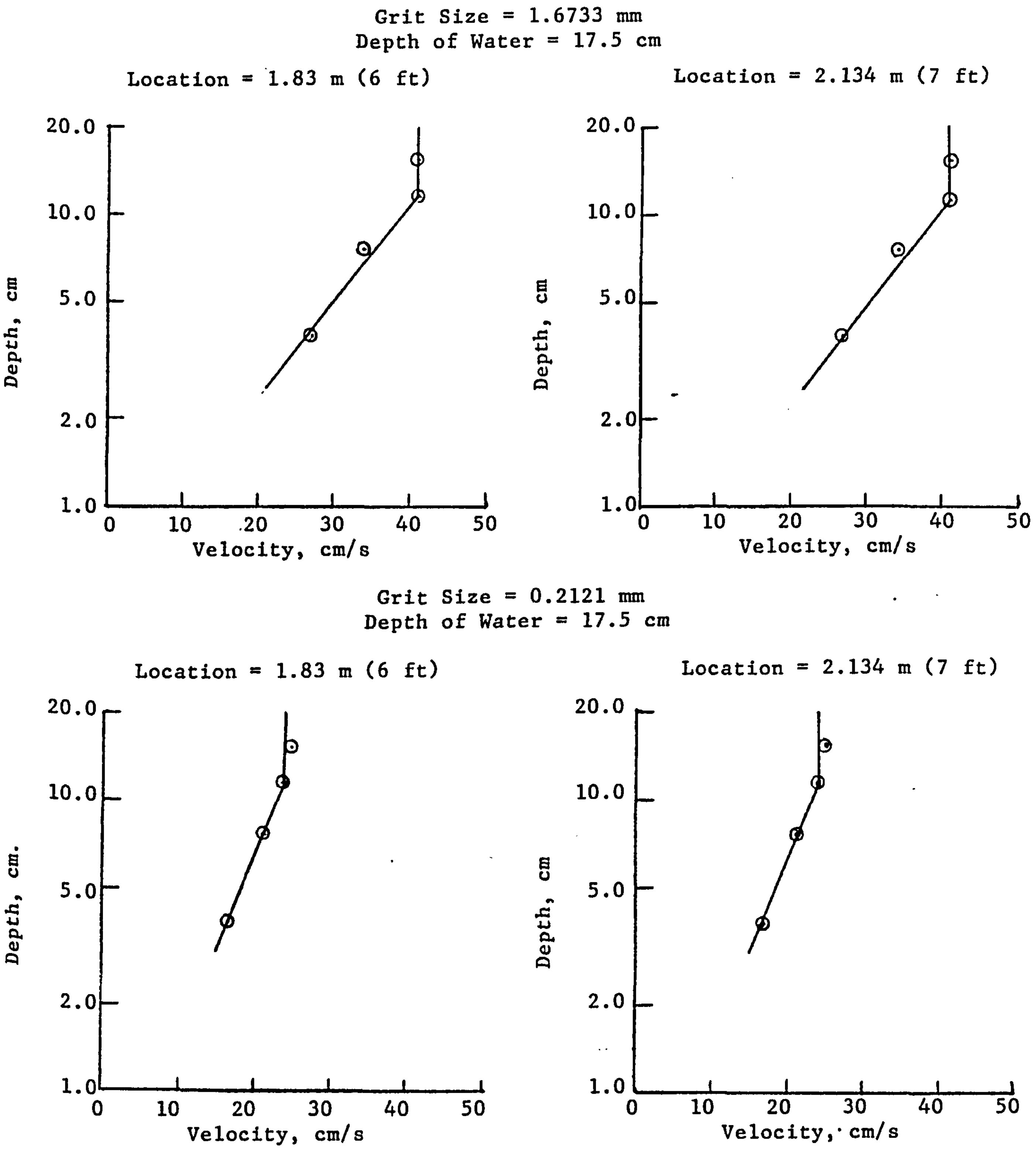
Figure 6.1: Observed and Computed Velocity Distribution in the Flume

6.2 Experiments in Laboratory Flume with Grit Particles

The experiments were conducted in a laboratory flume to determine the critical shear stress required to move grit particles of different sizes. For this purpose, velocity profiles were determined at different locations along the length of the flume. Since the length of the flume was short, the bed was roughened to develop the flow fully, with the same size of grit particles as were used for scouring during the experiment. The grit particles were separated into eight different geometric mean sizes, ranging from 2.1817 mm to 0.2121 mm. In order to widen the scope of this investigation, some larger gravel particles, ranging in size from 3.4 mm to 17.4 mm, were also included in the experiment.

All the velocity readings obtained at different locations and depths were used to verify whether the flow was fully developed during critical conditions for the initiation of the motion for different grit and gravel particles. Some typical velocity profiles for different grit and gravel particles during critical conditions are shown in Figure 6.2 and Figure 6.3. The velocity profile obtained at the end of the flume was neglected because exit conditions distorted the velocity profile.

From the velocity profile for the entire depth of flow, only the point velocity close to the bed, 7.6 mm above bed, was considered for further analysis to obtain critical shear



Grit Size = 1.6733 mm
Depth of Water = 17.5 cm

Location = 1.83 m (6 ft)

Location = 2.134 m (7 ft)

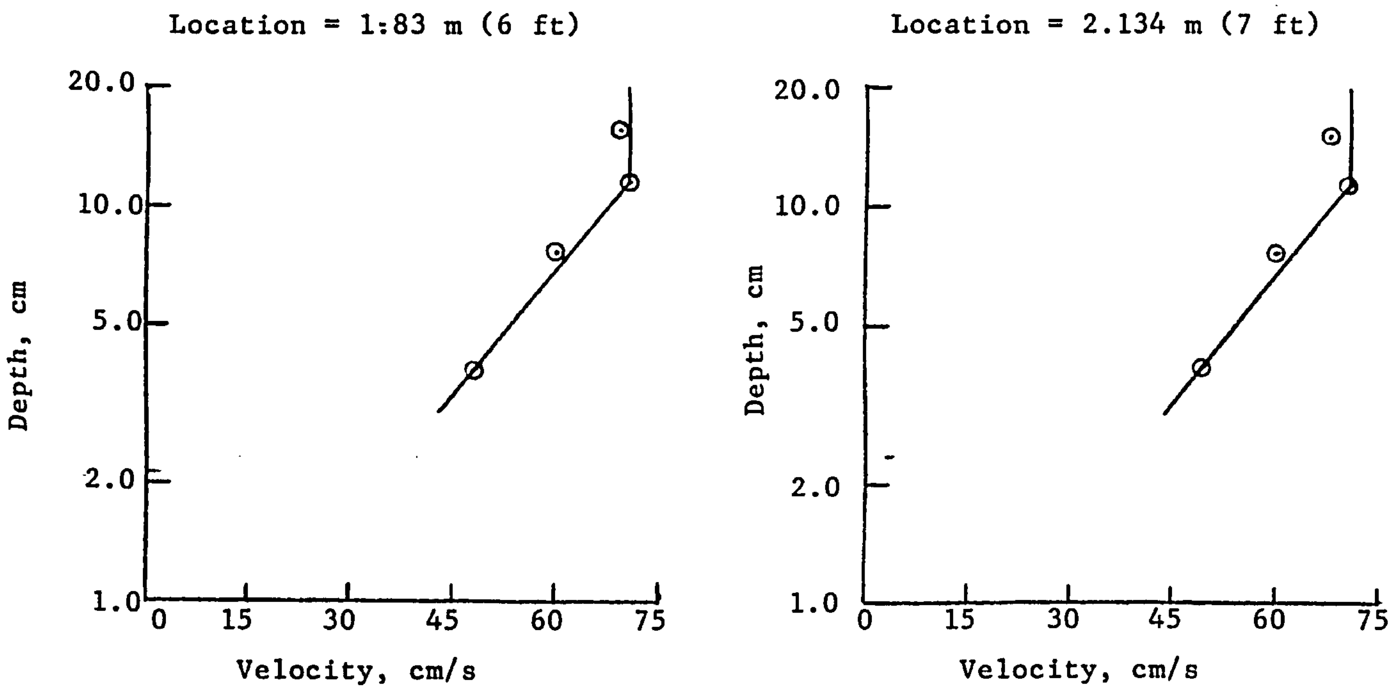
Grit Size = 0.2121 mm
Depth of Water = 17.5 cm

Location = 1.83 m (6 ft)

Location = 2.134 m (7 ft)

Fig. 6.2. Typical Velocity Profiles in Flume During Critical Conditions for Grit Particles

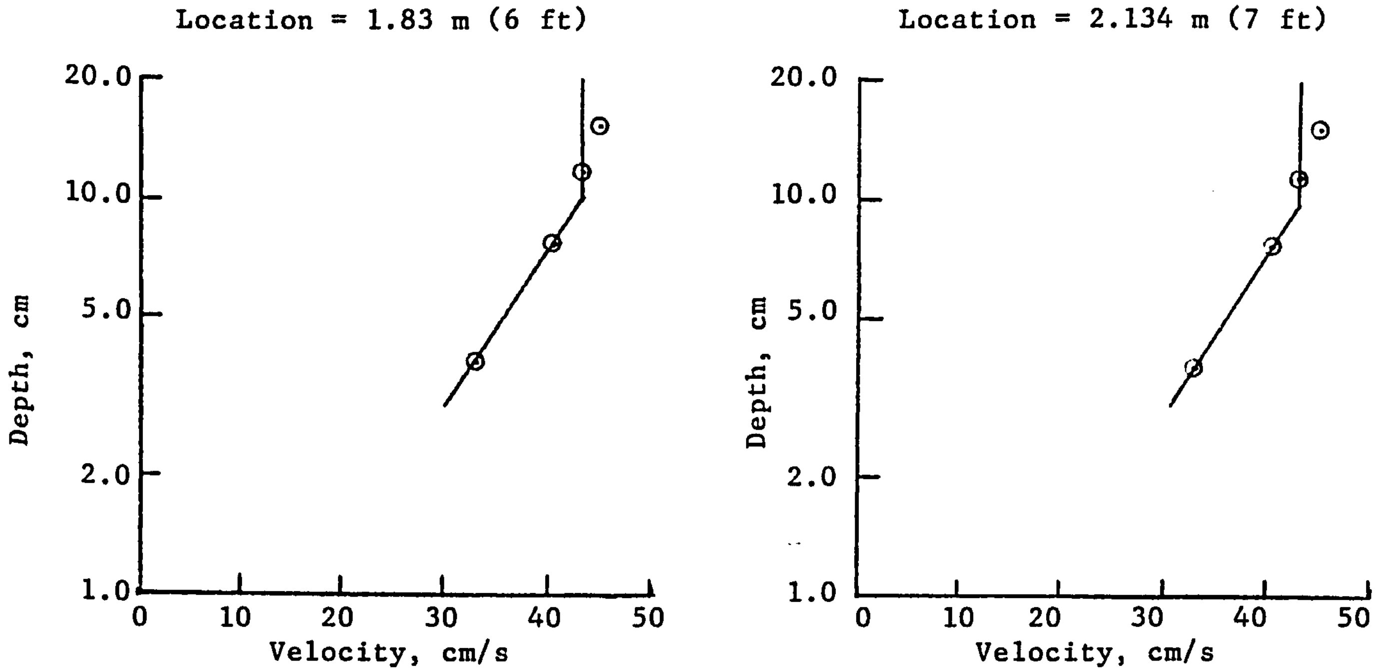
Gravel Size = 14.20 mm
Depth of Water = 18.0 cm



Location = 1.83 m (6 ft)

Location = 2.134 m (7 ft)

Gravel Size = 3.40 mm
Depth of Water = 17.5 cm



Location = 1.83 m (6 ft)

Location = 2.134 m (7 ft)

Fig. 6.3. Typical Velocity Profiles in Flume During Critical Conditions for Gravel Particles.

stresses. This point velocity was then converted to critical shear or friction velocity, U_{*c}, using Eq. 5.6 or 5.7. This critical shear or friction velocity was used to obtain the values for critical bed shear stress, τ_{oc}, using Eq. 5.5. The calculated shear velocities and corresponding particle Reynolds number, for different particles sizes and critical bed shear stress, are tabulated in Table 6.1 and Table 6.2. Since none of the velocity readings, except the point velocity, u, close to the bed of the flume, was used directly in further analysis, it was considered unnecessary to include all these data in these tables.

The particle sizes and the corresponding values of shear stress are plotted on log log scales in Figure 6.4. This plot shows that the curve is a straight line in the hydraulically smooth flow regime and becomes curvilinear for rough turbulent flow conditions. In the transitional state, the plot begins to change from straight line to a curve. This plot can be used directly in finding the critical bed shear stress required to initiate the motion of any size of grit particles. This will also indicate the regime of flow in a channel whose bed is made up of uniform size grit or gravel particles.

A linear regression analysis was performed, using a SAS statistical package called GLM, General Linear Models, to establish a correlation between the particle size in mm and the corresponding value of critical bed shear stress in

Table 6.1 - PARTICLE CHARACTERISTICS AND CORRESPONDING CRITICAL SHEAR OR FRICTION VELOCITY

TYPE OF PARTICLES	PARTICLE SIZE k_s mm	POINT VELOCITY u at 7.6 mm above the bed m/sec	CRITICAL SHEAR OR FRICTION VELOCITY, U_{*c} m/sec	PARTICLES REYNOLD NUMBERS $U_{*c}k_s/\nu$	REGIME OF FLOW
Gravel	17.40	0.3350	0.05210	898	Rough Turbulent
Gravel	14.20	0.3080	0.04440	624	Rough Turbulent
Gravel	12.20	0.2680	0.03660	442	Rough Turbulent
Gravel	10.50	0.2550	0.03310	344	Rough Turbulent
Gravel	8.70	0.2410	0.02950	254	Rough Turbulent
Gravel	3.40	0.2140	0.02040	69	Close to Turbulent
Grit	2.1817	0.2010	0.01690	37	Transitional
Grit	1.6733	0.2010	0.01550	26	Transitional
Grit	1.0860	0.1940	0.01330	14	Transitional
Grit	0.7770	0.1870	0.01230	9	Transitional
Grit	0.5477	0.1810	0.01130	6	Transitional
Grit	0.3880	0.1670	0.01016	4	Hydraulically Smooth
Grit	0.2739	0.1540	0.00947	3	Hydraulically Smooth
Grit	0.2121	0.1410	0.00877	2	Hydraulically Smooth

The depth of flow in the flume varied between 0.15 m and 0.2 m

Table 6.2 - PARTICLE CHARACTERISTICS AND CORRESPONDING CRITICAL BED SHEAR STRESS

TYPE OF PARTICLES	PARTICLE SIZE k_s mm	CRITICAL SHEAR OR FRICTION VELOCITY, U_{*c} m/sec	CRITICAL BED SHEAR STRESS $\tau_{oc} = U_{*c}^2 \cdot \rho$ N/m^2
Gravel	17.40	0.05210	2.710
Gravel	14.20	0.04440	1.970
Gravel	12.20	0.03660	1.340
Gravel	10.50	0.03310	1.100
Gravel	8.70	0.02950	0.870
Gravel	3.40	0.02040	0.420
Grit	2.1817	0.01690	0.290
Grit	1.6733	0.01550	0.240
Grit	1.0860	0.01330	0.177
Grit	0.7770	0.01230	0.151
Grit	0.5477	0.01130	0.127
Grit	0.3880	0.01016	0.103
Grit	0.2739	0.00947	0.090
Grit	0.2121	0.00877	0.077

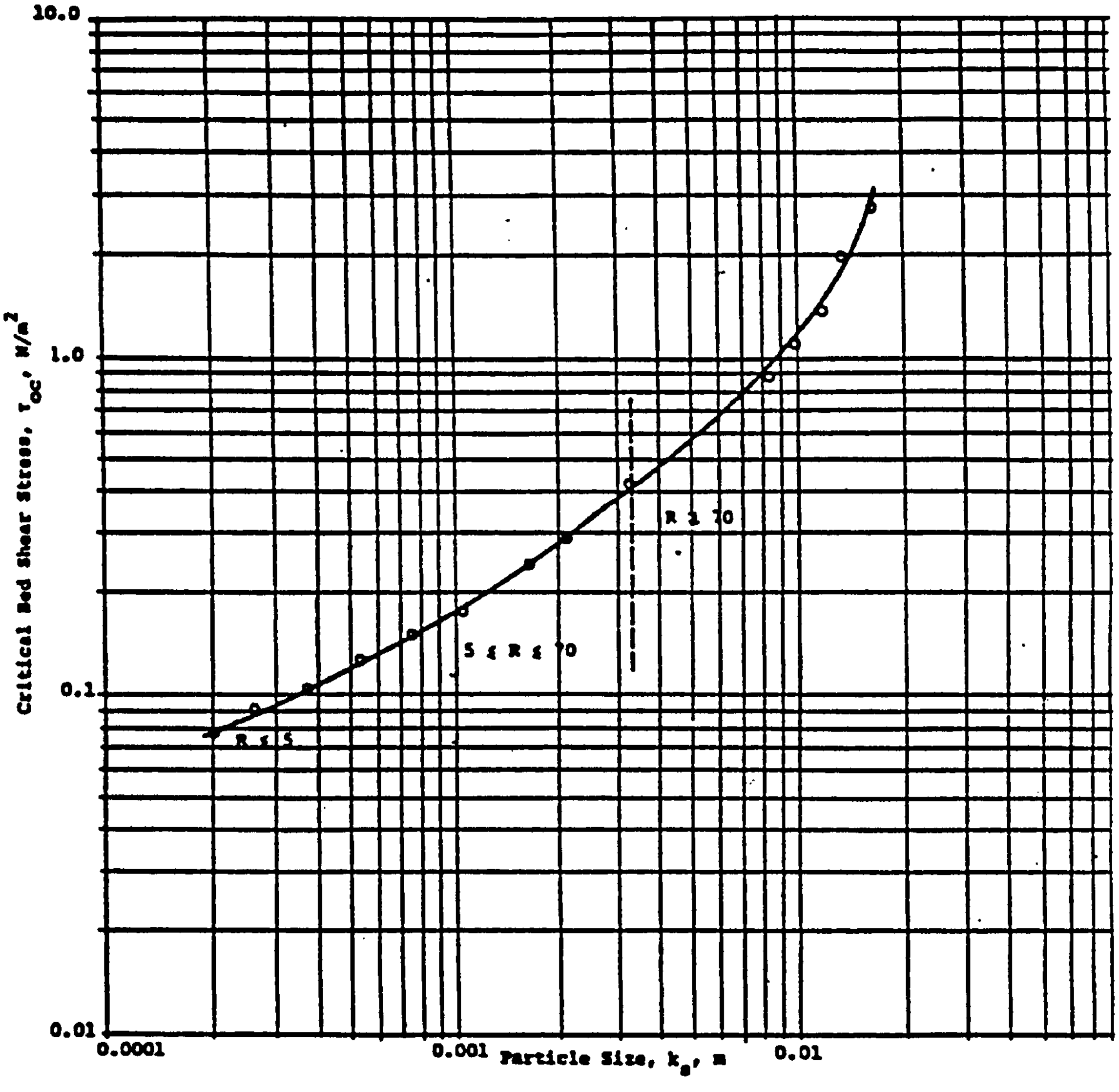


Figure 6.4: Relationship Between Particle Size and Critical Bed Shear Stress

N/m^2. The selection of best fit model was done on the basis of following statistical parameters.

R - SQUARE Value - Coefficient of Determination

F Test Value

PR > F - Significance Probability

T FOR HO: PARAMETER=0 - Student's t test

PR > |T|

The following best fit equation has been developed for the plot shown in Figure 6.4.

$$\log(\tau_{oc}) = 0.611 \log(k_s) + 0.244 [\log(k_s)]^2 - 0.779 \quad \text{--[6.1]}$$

Where τ_{oc} = critical bed shear, N/m^2

k_s = particle size, mm

The plot overlapping the measured value and estimated value of critical bed shear stresses using Eq. 6.1 is shown in Figure 6.5.

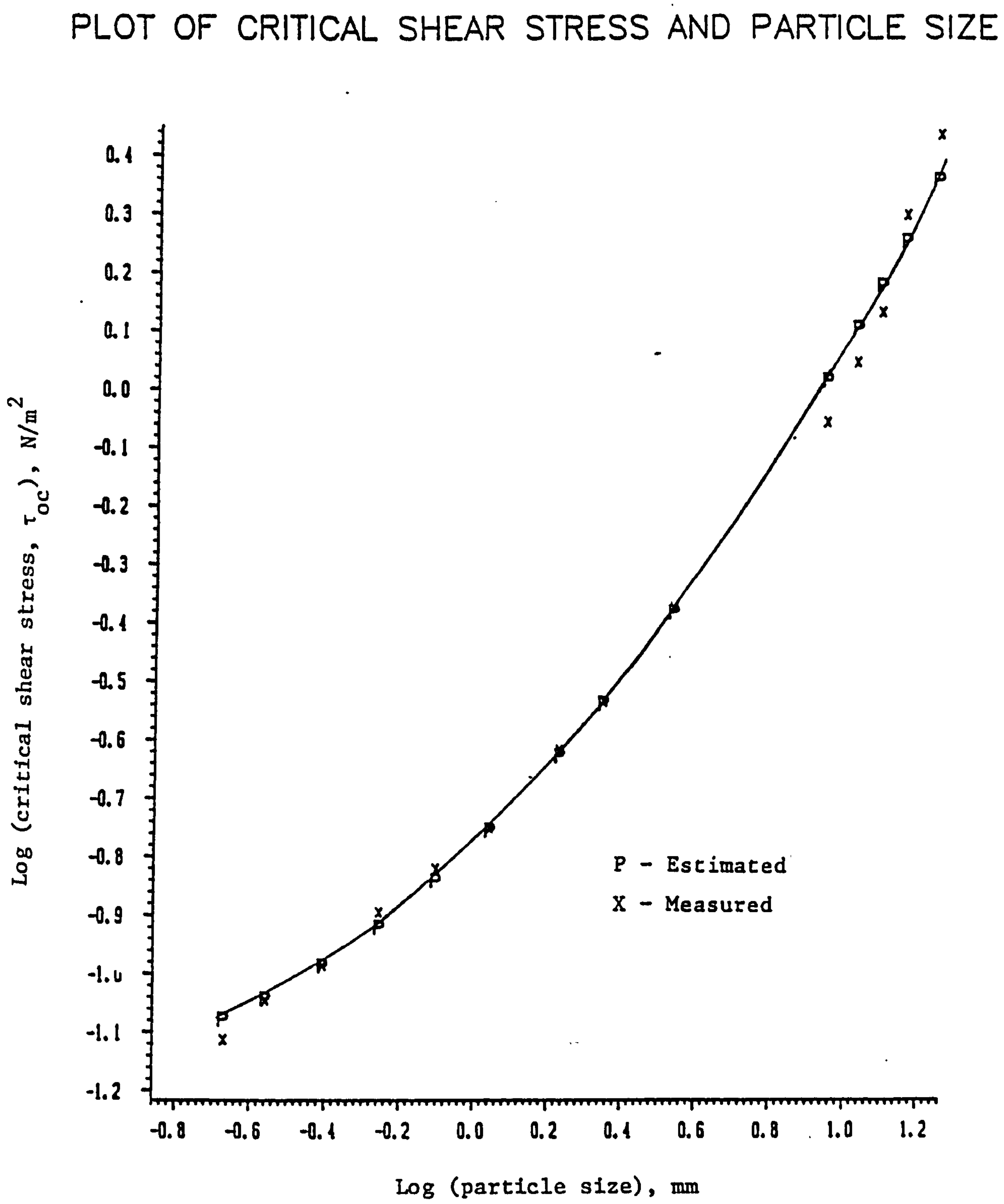


Figure 6.5: Measured and Estimated Values of Shear Stresses

6.3 Experiments on Sludges

Experiments on different kind of sludges were run in the flume. The Brookfield viscometer was employed to determine the rheological properties of sludges. The results obtained are presented below:

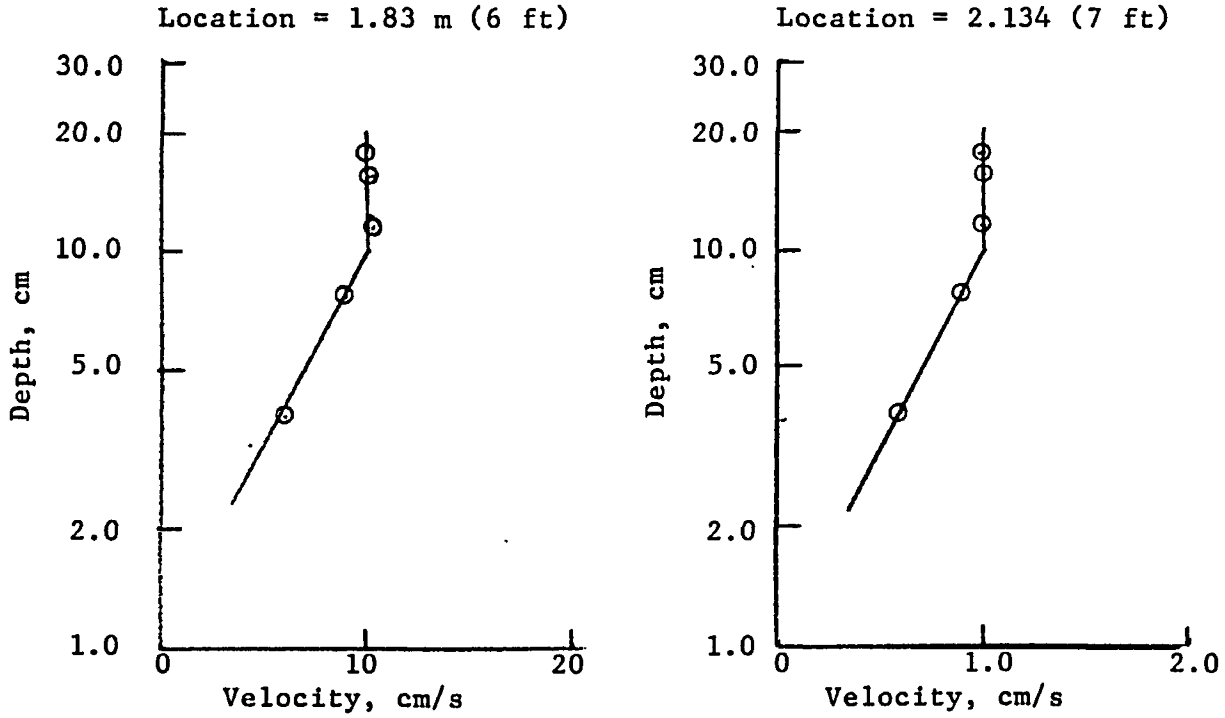
6.3.1 Laboratory Flume with Sludge Particles

Experiments in the flume were run to obtain the values of critical bed shear stress necessary to initiate the motion of sludge particles for different kinds of sludges. The depth of water in the flume was kept between 0.15 m and 0.175 m during these experiments. After establishing the critical conditions for the initiation of motion of particles, the horizontal velocites of flow in the flume were measured at different locations and depths.

The velocity profiles for the entire depth of flow and at different locations were obtained to check whether or not the regime of flow was fully developed. Some typical velocity profiles for critical conditions to initiate motion of different sludge particles are shown in Figure 6.6.

Since sludge particles are not supposed to settle in the aeration tank, it is assumed that the bed will be smooth and flow will be turbulent in calculating different parameters. Eq. 5.6 was used to calculate the critical shear or friction velocity, U_{*c}, and Eq. 5.5 was used to obtain the value of critical bed shear, τ_{oc}. The point velocity, u, close to the bed and calculated values of critical shear or friction

Physico-Chemical Sludge
Depth of Water = 25.0 cm



Biological Sludge
Depth of Water = 25.0 cm

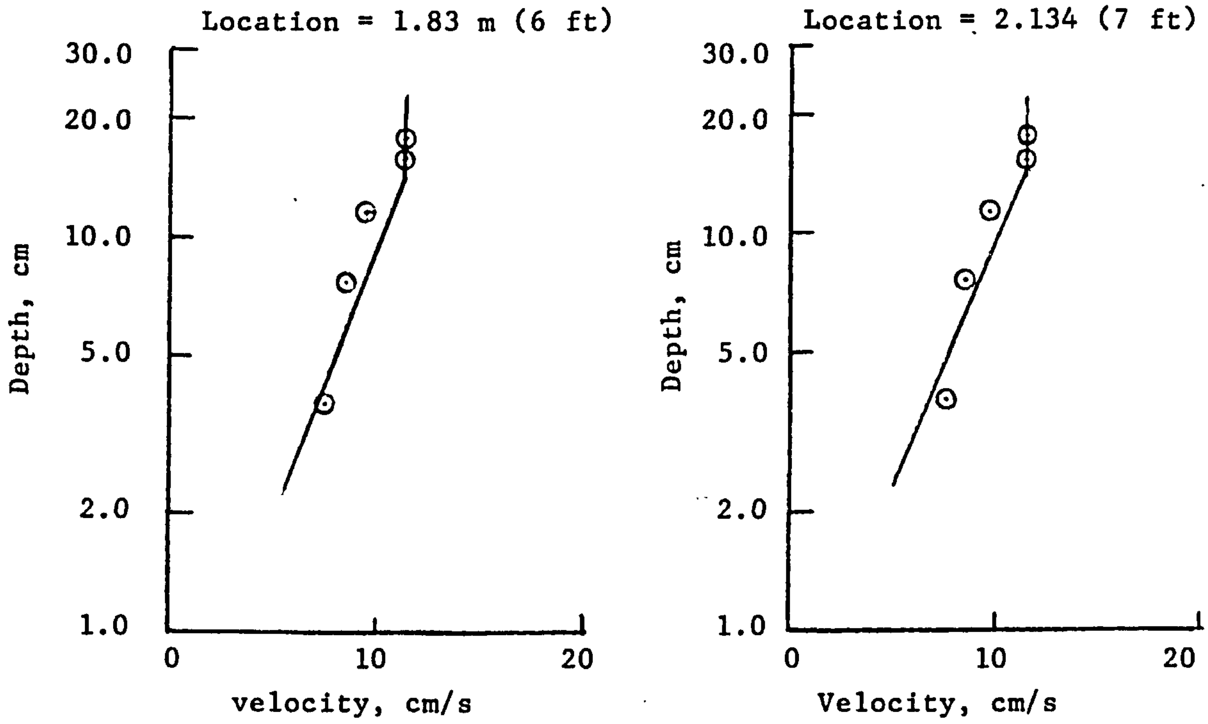


Fig. 6.6. Typical Velocity Profiles in Flume During Critical Conditions for Sludge Particles.

velocity and critical shear stress are shown in Table 6.3. Since none of the velocity readings, except the point velocity close to the bed of the flume, u, was used in any other calculation, it was considered unnecessary to include all the velocity readings in this table.

Table 6.3 - CRITICAL SHEAR STRESS VALUES FOR DIFFERENT TYPES OF SLUDGES

SLUDGE TYPE	VELOCITY, u at y = 7.6 mm above the bed m/sec	CRITICAL SHEAR OR FRICTION VELOCITY, U_{*c} m/sec	CRITICAL SHEAR STRESS, τ_y	
			N/m^2	$dynes/cm^2$
Biological Sludge (from aeration tank)	0.064	0.00445	0.01976	0.1976
Biological Sludge	0.066	0.00457	0.02084	0.2084
Biological Sludge	0.064	0.00445	0.01976	0.1976
Biological Sludge	0.064	0.00445	0.01976	0.1976
Biological Sludge	0.066	0.00457	0.02084	0.2084
Biological Sludge	0.069	0.00475	0.02252	0.2252
Alum Sludge	0.080	0.00539	0.02899	0.2899
Alum Sludge	0.084	0.00562	0.03152	0.3152
Alum Sludge	0.084	0.00562	0.03152	0.3152
Alum Sludge	0.082	0.00550	0.03019	0.3019
Alum Sludge	0.080	0.00539	0.02899	0.2899
Alum Sludge	0.075	0.00510	0.02596	0.2596
Physico-Chemical Sludge from underdrains)	0.070	0.00481	0.02309	0.2309
Physico-Chemical Sludge	0.075	0.00510	0.02596	0.2596
Physico-Chemical Sludge (from clarifiers)	0.061	0.00427	0.01820	0.1820
Physio-Chemical Sludge	0.070	0.00481	0.02309	0.2309
Physico-Chemical Sludge	0.058	0.00409	0.01669	0.1669
Physico-Chemical Sludge	0.061	0.00427	0.01820	0.1820

Table 6.3 - CRITICAL SHEAR STRESS VALUES FOR DIFFERENT TYPES OF SLUDGE (cont'd)

SLUDGE TYPE	VELOCITY, u at y = 7.6 mm above the bed m/sec	CRITICAL SHEAR OR FRICTION VELOCITY, U_{*c} m/sec	CRITICAL SHEAR STRESS, τ_y	
			N/m^2	$dynes/cm^2$
Diluted Secondary Digested Sludge	0.075	0.00510	0.02596	0.2596
Diluted Secondary Digested Sludge	0.070	0.00481	0.2309	0.2309
Mixture of Primary and Secondary Sludge	0.055	0.00391	0.01526	0.1526
Mixture of Primary and Secondary Sludge	0.065	0.00451	0.02030	0.2030

6.3.2 Determination of Rheological Properties of Sludges by Viscometer

A Brookfield Viscometer with cylindrical shaped spindle #1 was used to determine the rheological properties of the sludges. The spindle speed, rpm, and the torque required to maintain constant angular velocity were then used to calculate the rate of shear, dv/dr, and the shear stress, τ, using Eqs. 5.33 and 5.34. For each type of sludge, both raw and settled, the experiments were repeated at least twice or thrice depending upon the volume of sample available for the analysis. At each spindle speed or rate of shear, at least four torque readings were taken and the average of these readings was used for further analysis. Since it was considered unnecessary to include all the raw data, only the average values of shear stress for each rate of shear and for each set are shown in Appendix B, for different types of sludge samples analyzed.

6.3.2.1 Determination of Yield Stress, τ_y

The yield stress, τ_y, values for all types of sludges and at different concentrations of suspended solids were obtained using the following two methods:

a. Graphical Method

b. Dekee Model

1.Graphical Method: The rate of shear and shear stress values were plotted to obtain the value of yield stress for each type of sludge. Some of the typical plots between the rate of shear and the corresponding shear stress for different types of sludges, flow curves, are shown in Figure 6.7, Figure 6.8, Figure 6.9, Figure 6.10, Figure 6.11, Figure 6.12, Figure 6.13, Figure 6.14, Figure 6.15, Figure 6.16, Figure 6.17, Figure 6.18, Figure 6.19, Figure 6.20, Figure 6.21, and Figure 6.22. The yield stress, τ_y , was obtained by joining the first two points at lower rate of shear in the flow curve and extending this line to the Y axis drawn at zero rate of shear. This intercept on the Y axis was taken to be equal to the yield stress for that particular type of sludge at that concentration of suspended solids. By following the same procedure, the yield stress values of all type of sludges, raw sludge and settled sludge, were obtained. The results are shown in Table 6.4, Table 6.5, Table 6.6, Table 6.7, and Table 6.8.

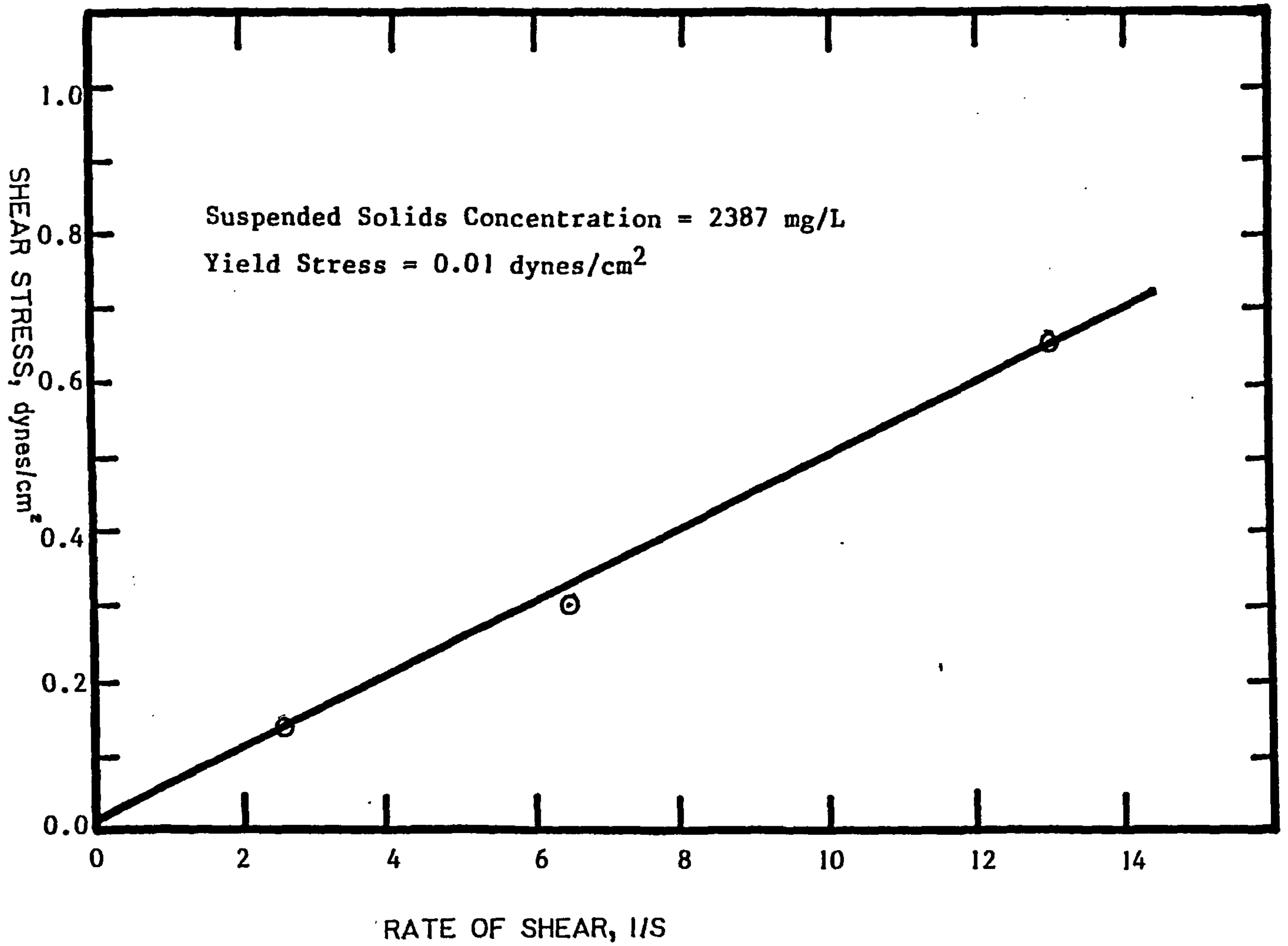
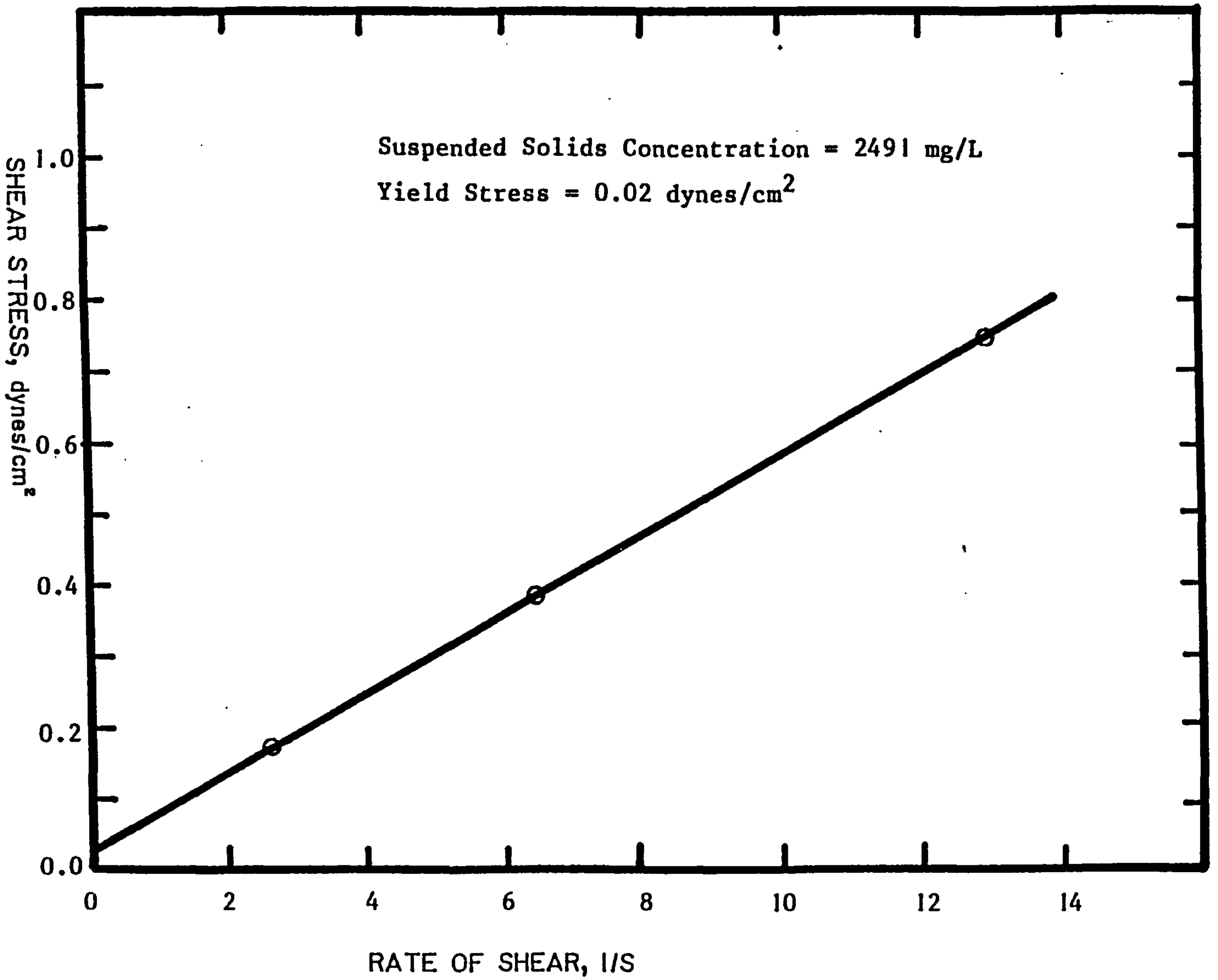


Figure 6.7: Observed Flow Curve for Biological Sludge (Mixed Liquor)



<u>Figure 6.8</u>: Observed Flow Curve for Biological Sludge (Mixed Liquor)

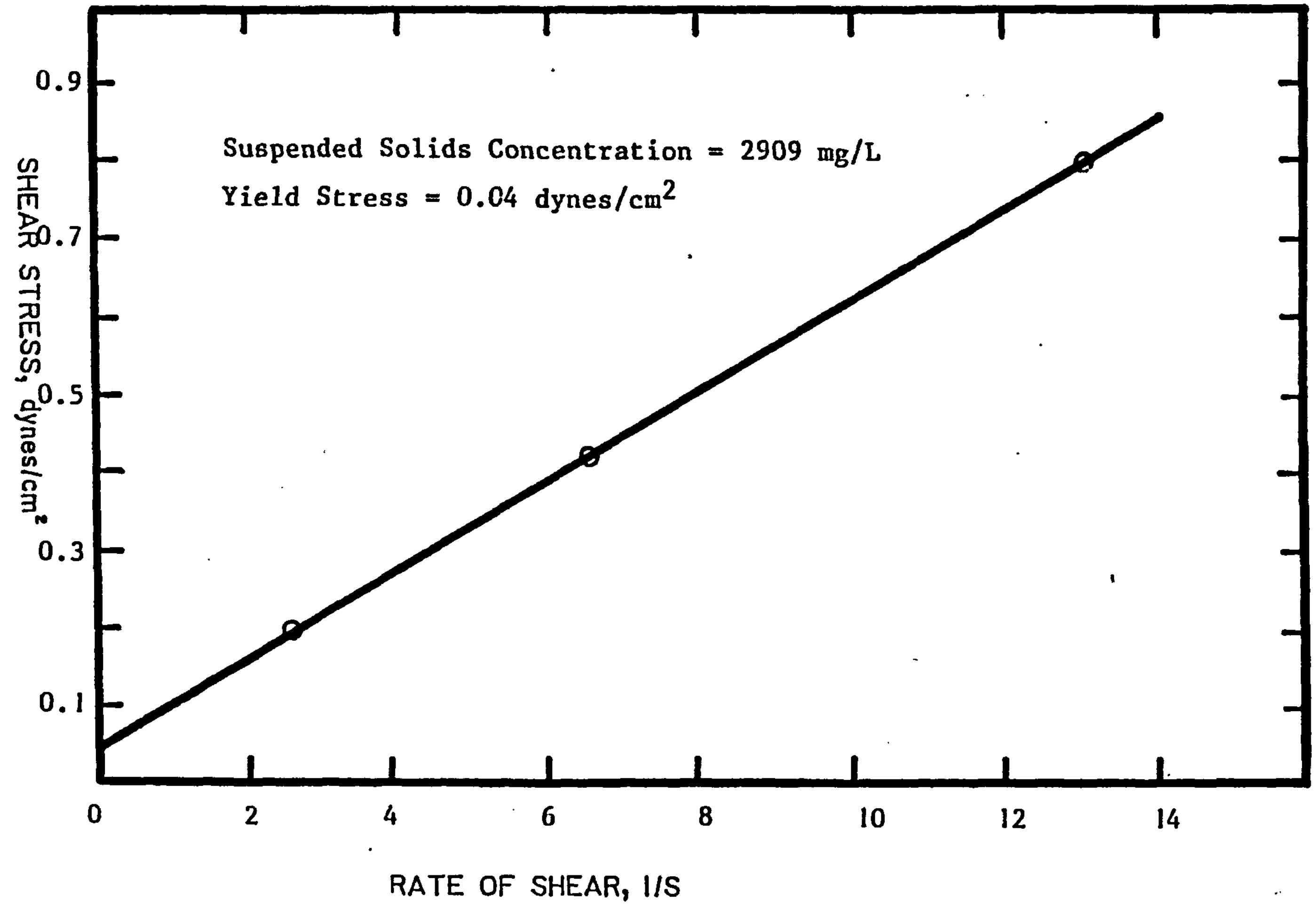


Figure 6.9: Observed Flow Curve for Biological Sludge (Mixed Liquor)

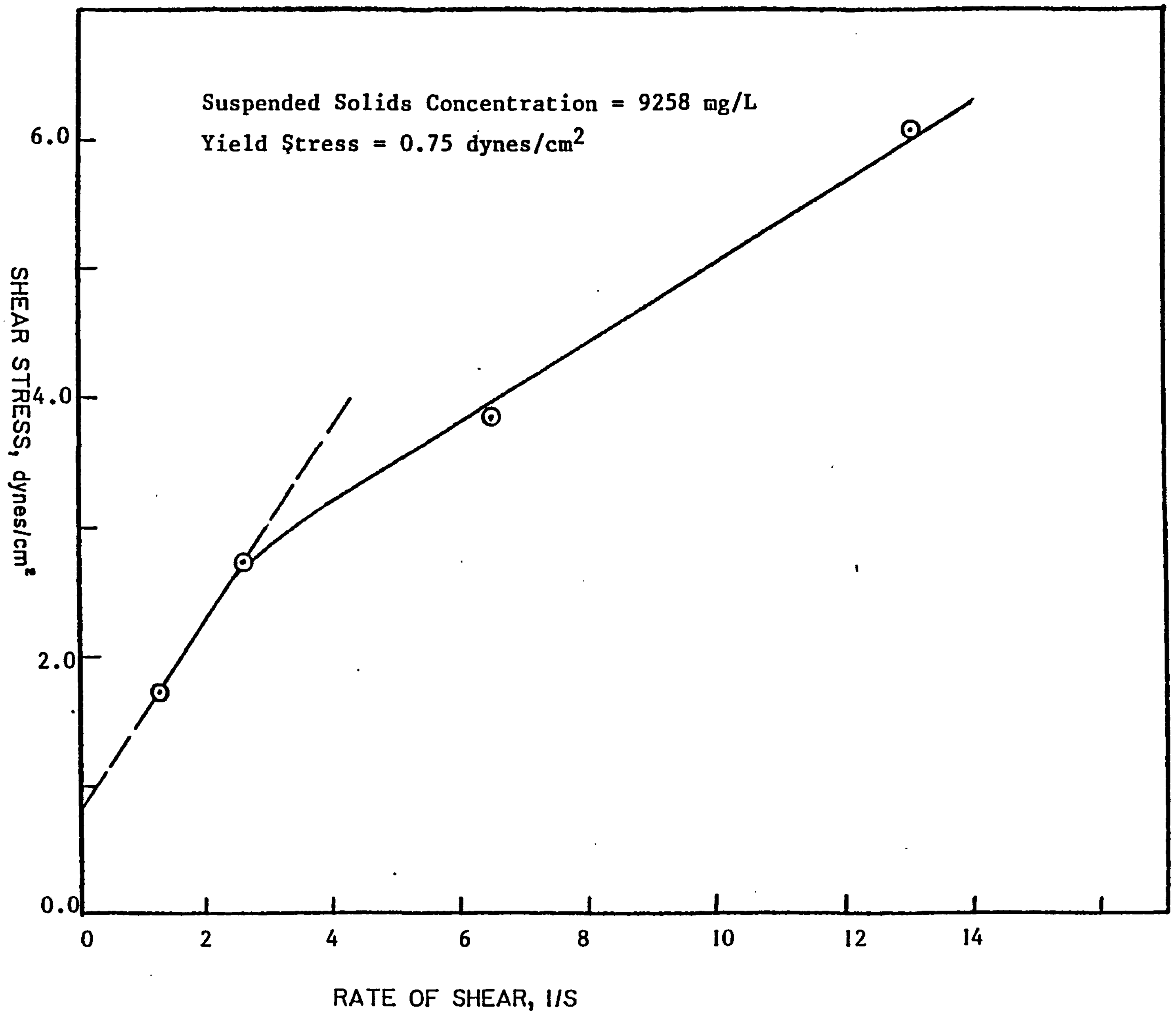


Figure 6.10: Observed Flow Curve for Biological Sludge (Settled Mixed Liquor)

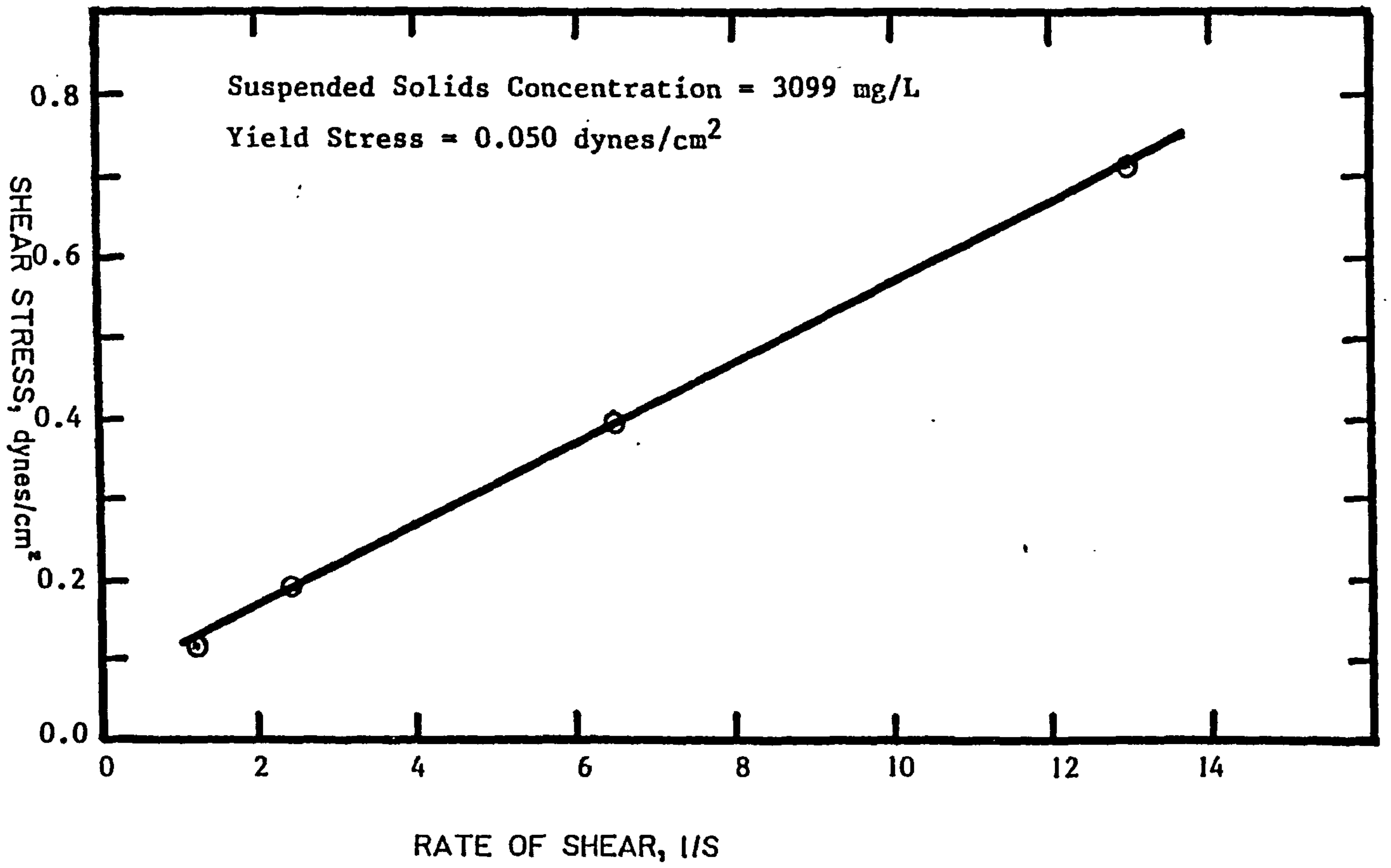


Figure 6.11: Observed Flow Curve for Alum Sludge (Unsettled)

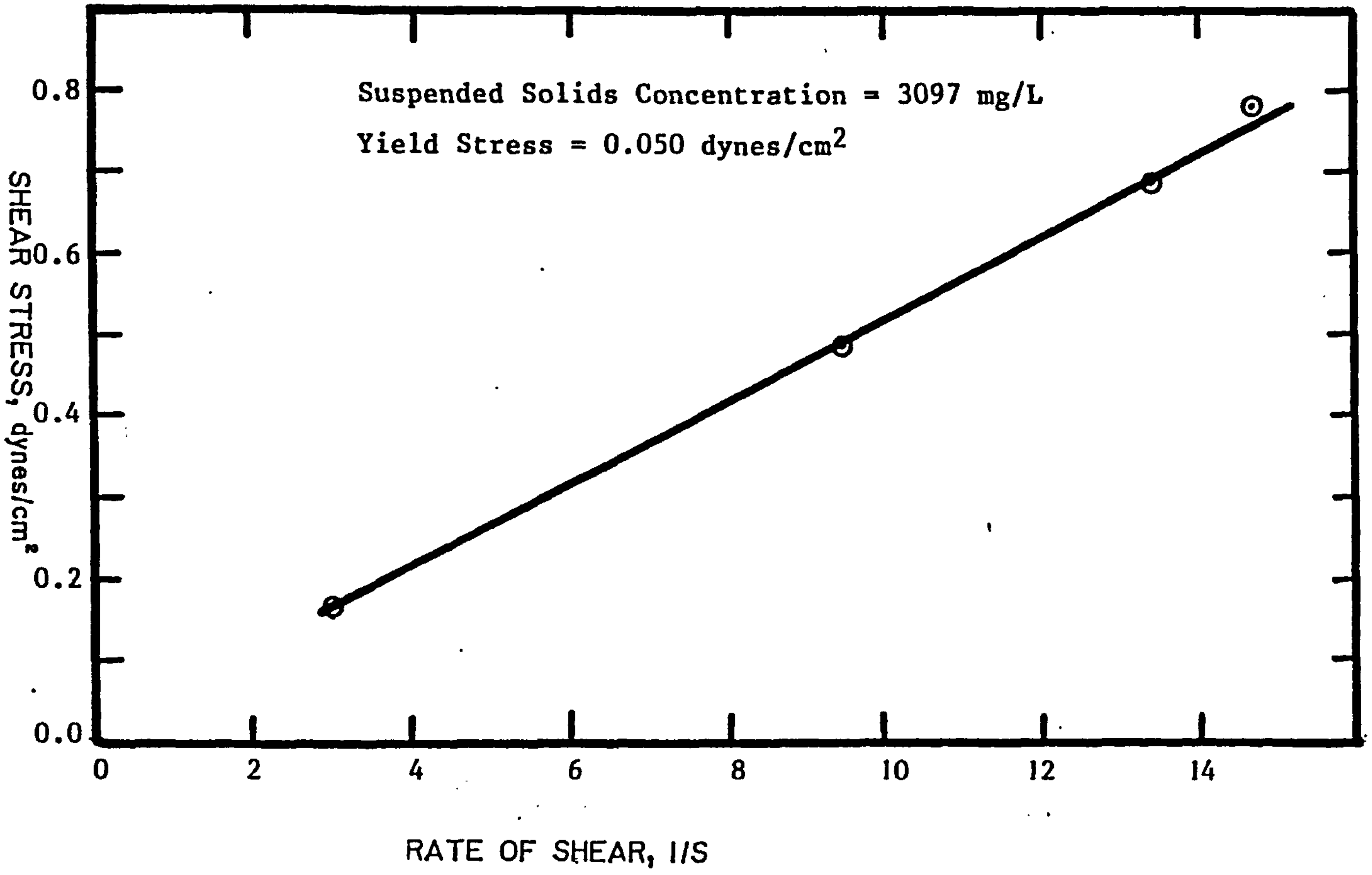


Figure 6.12: Observed Flow Curve for Alum Sludge (Unsettled)

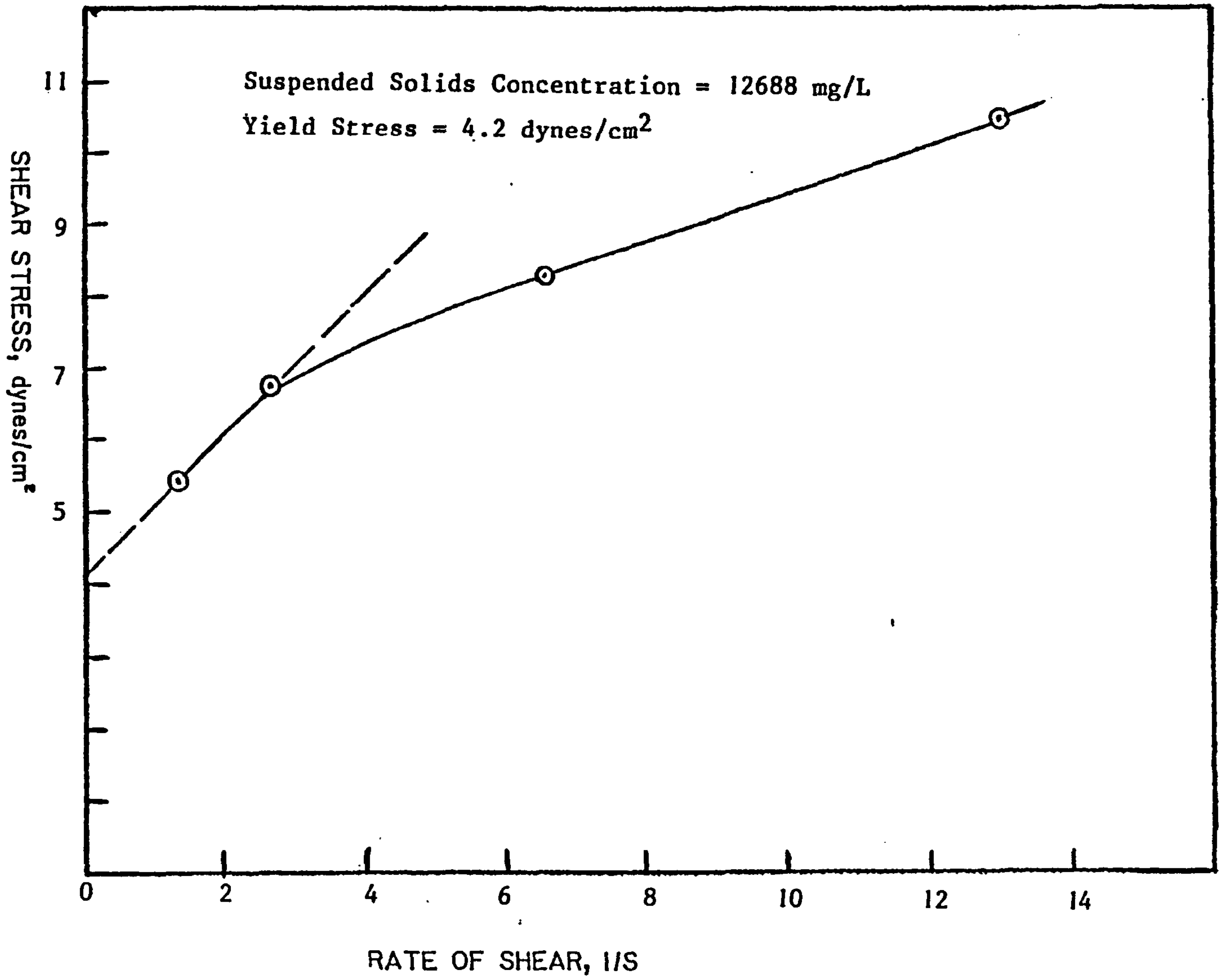


Figure 6.13: Observed Flow Curve for Alum Sludge (Settled)

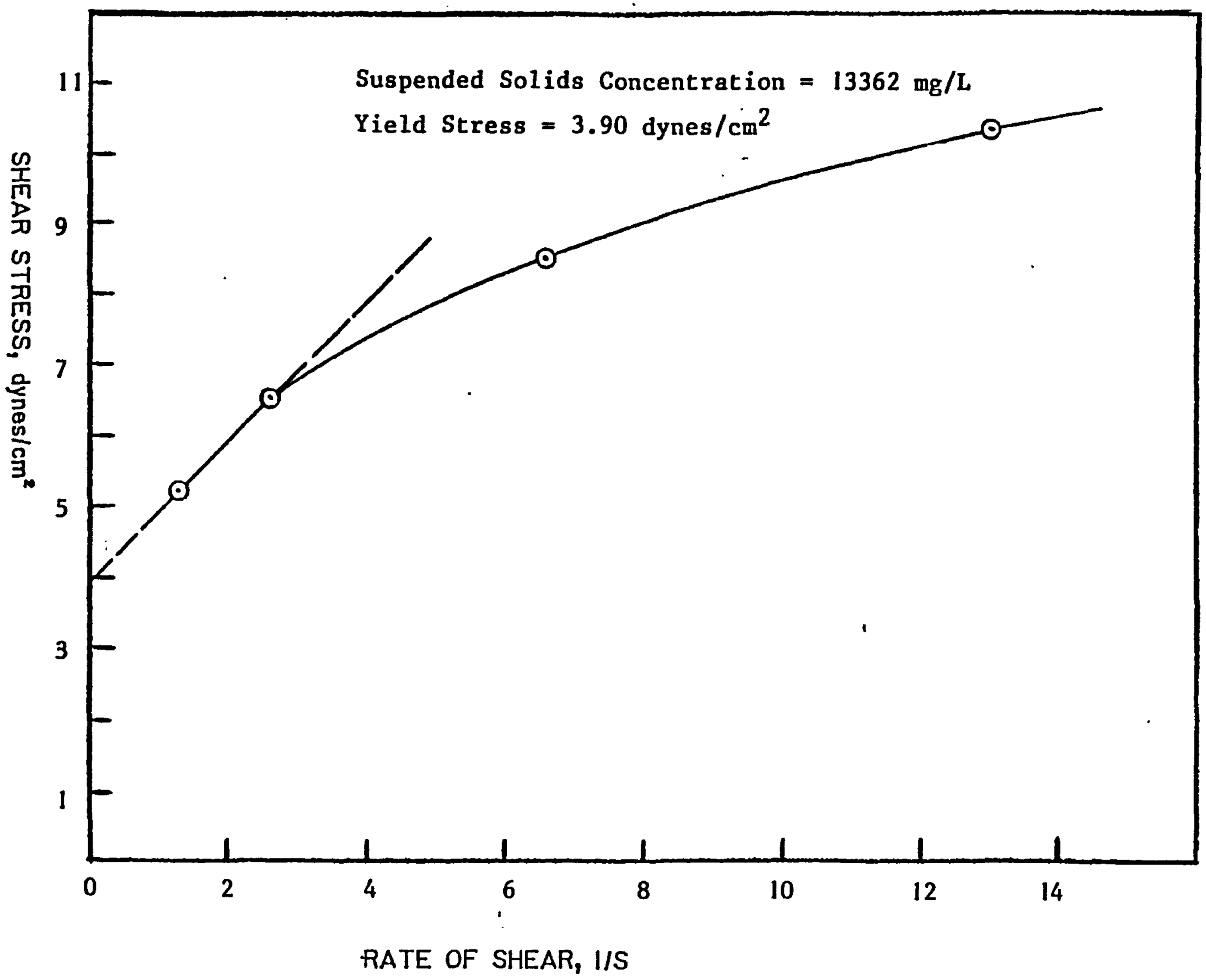


Figure 6.14: Observed Flow Curve for Alum Sludge (Settled)

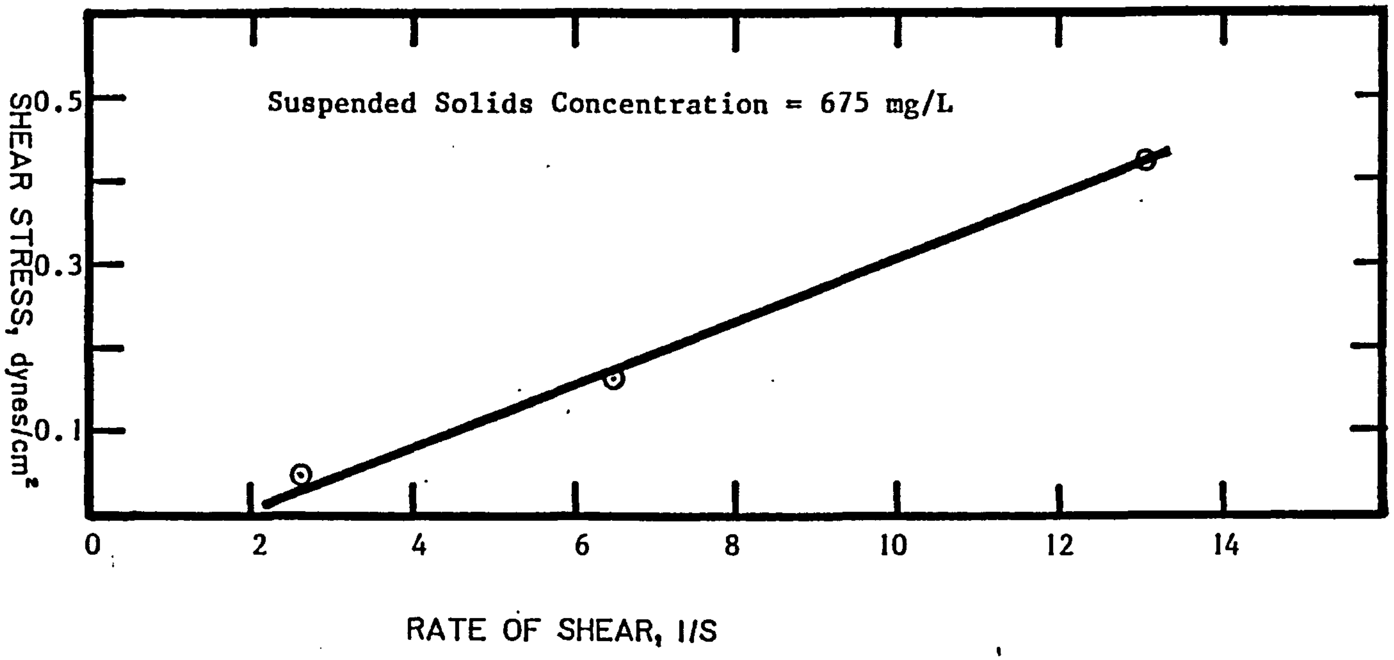


Figure 6.15: Observed Flow Curve for Physico-Chemical Sludge (Unsettled)

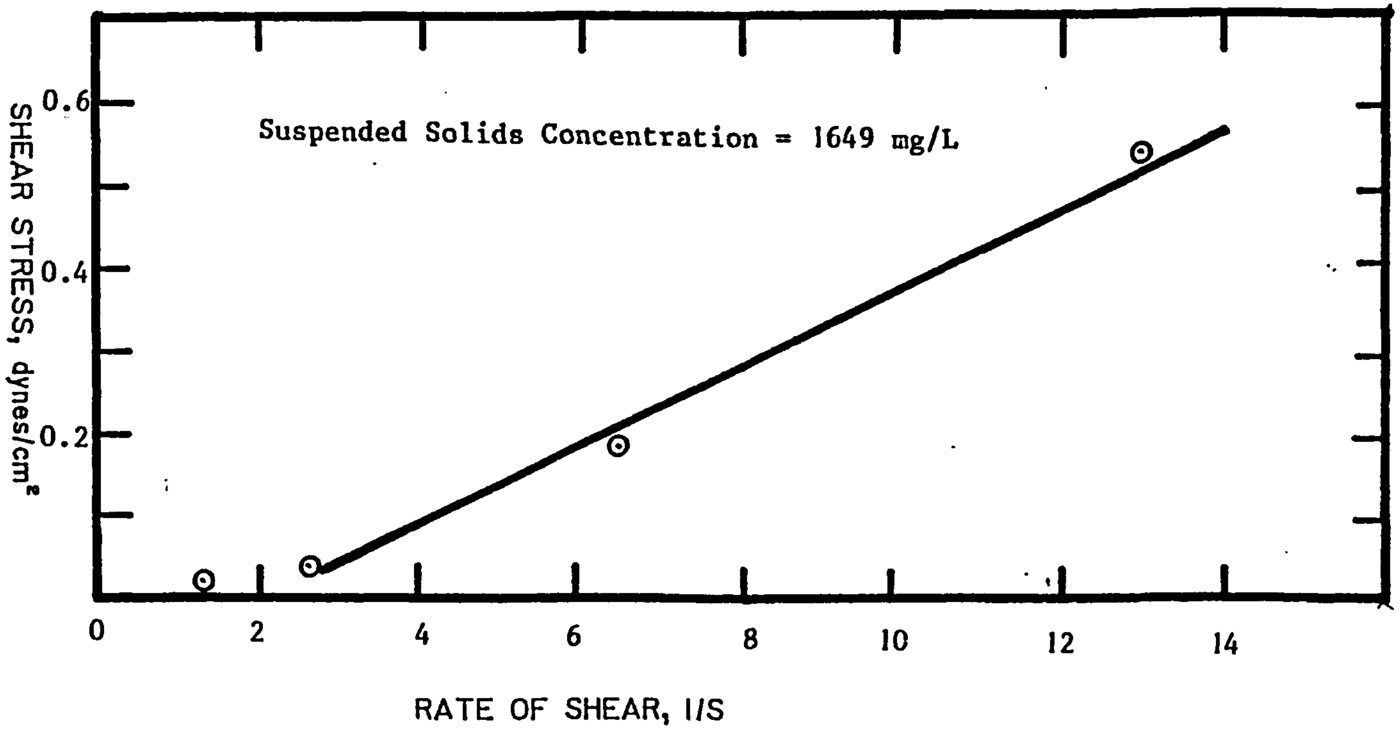


Figure 6.16: Observed Flow Curve for Physico-Chemical Sludge (Unsettled)

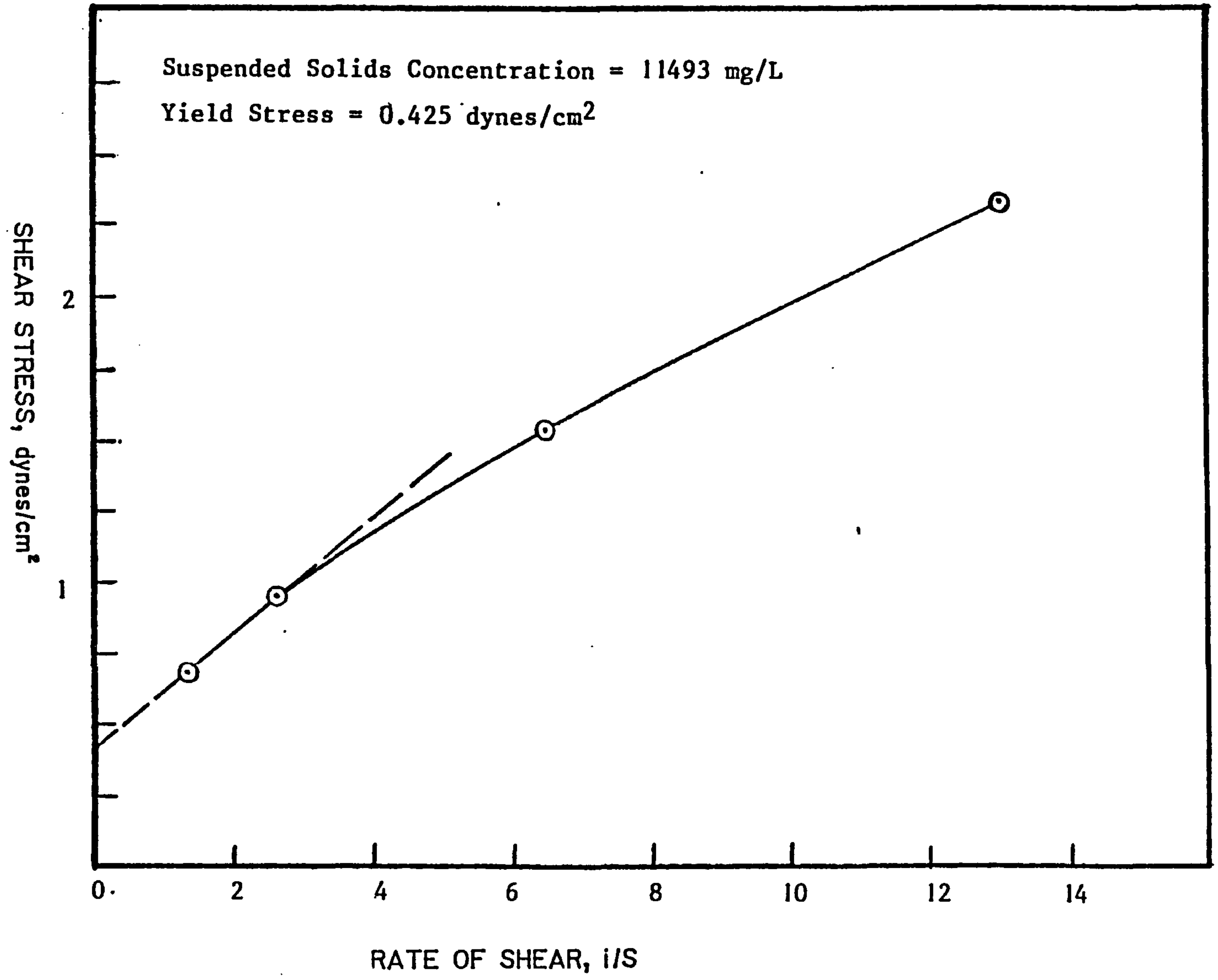


Figure 6.17: Observed Flow Curve for Physico-Chemical Sludge (Settled)

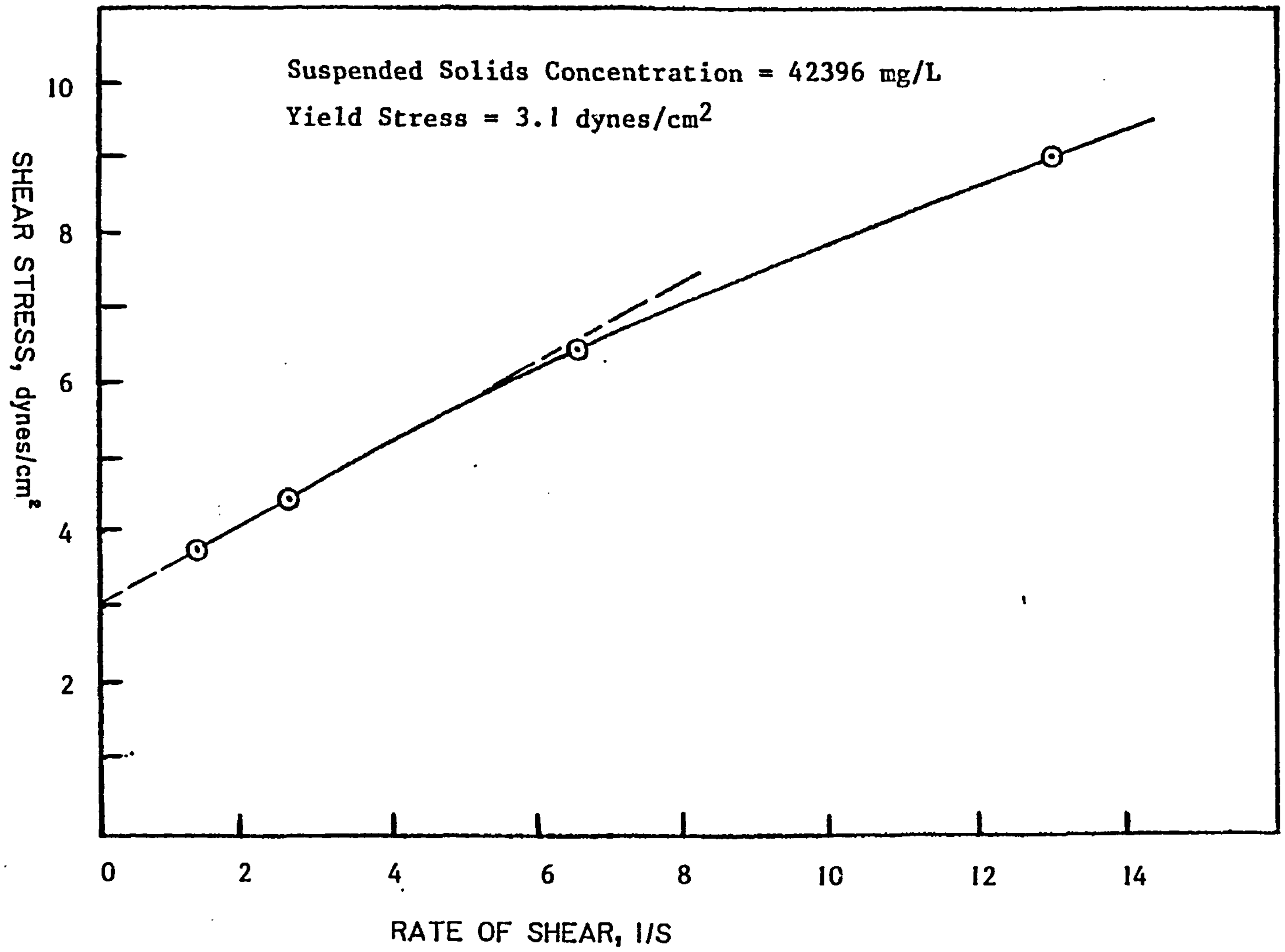


Figure 6.18: Observed Flow Curve for Physico-Chemical Sludge (Settled)

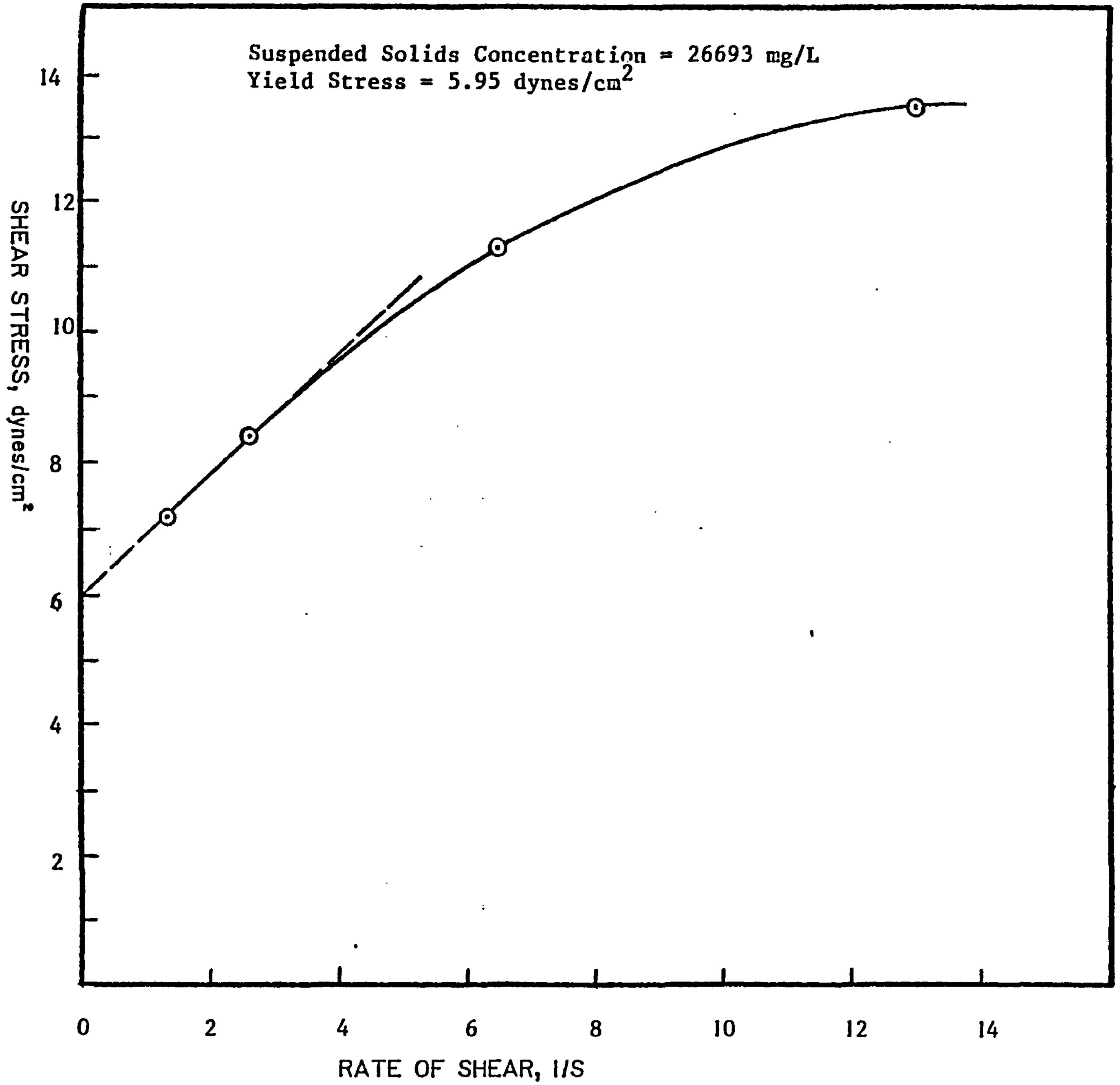
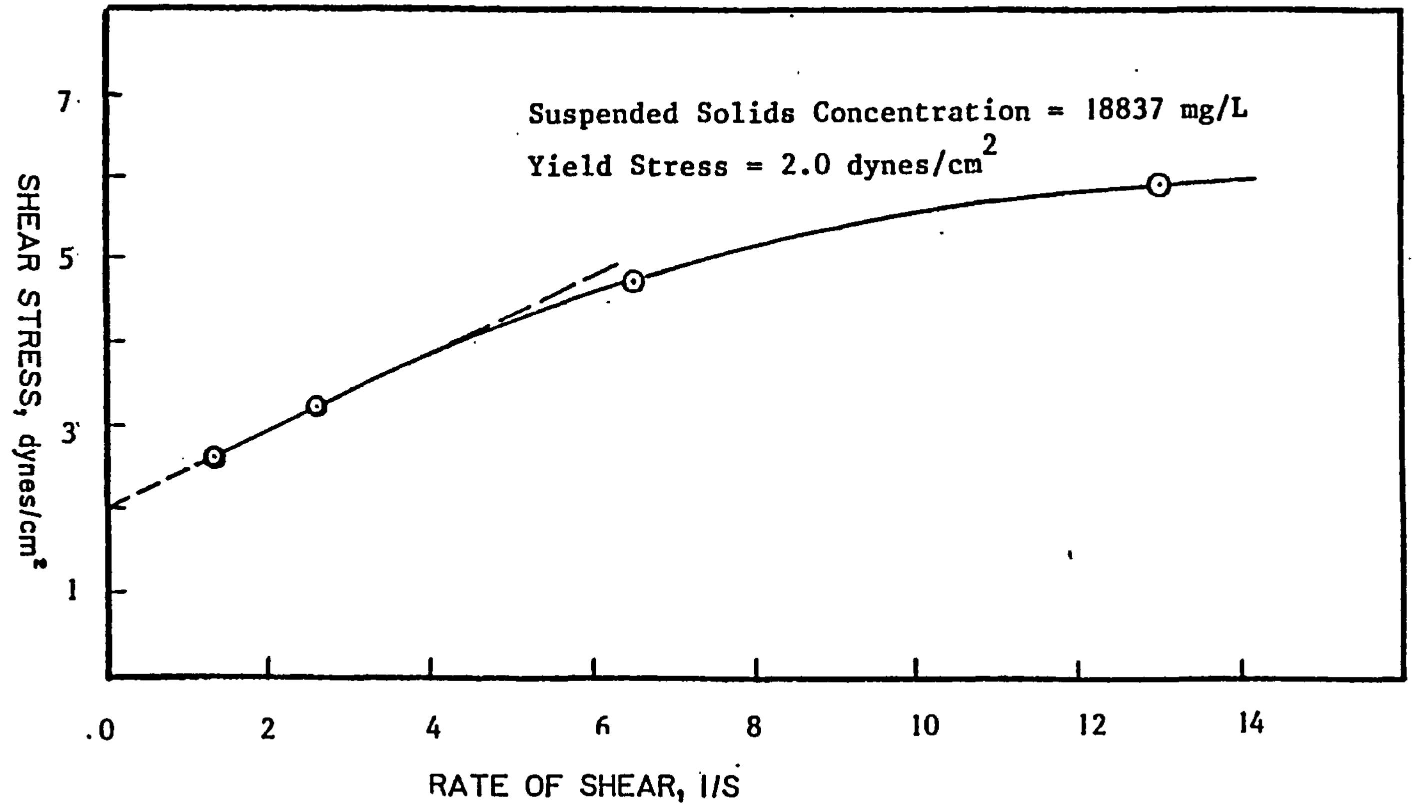


Figure 6.19: Observed Flow Curve for Secondary Digested



<u>Figure 6.20</u>: Observed Flow Curve for Secondary Digested Sludge (Diluted)

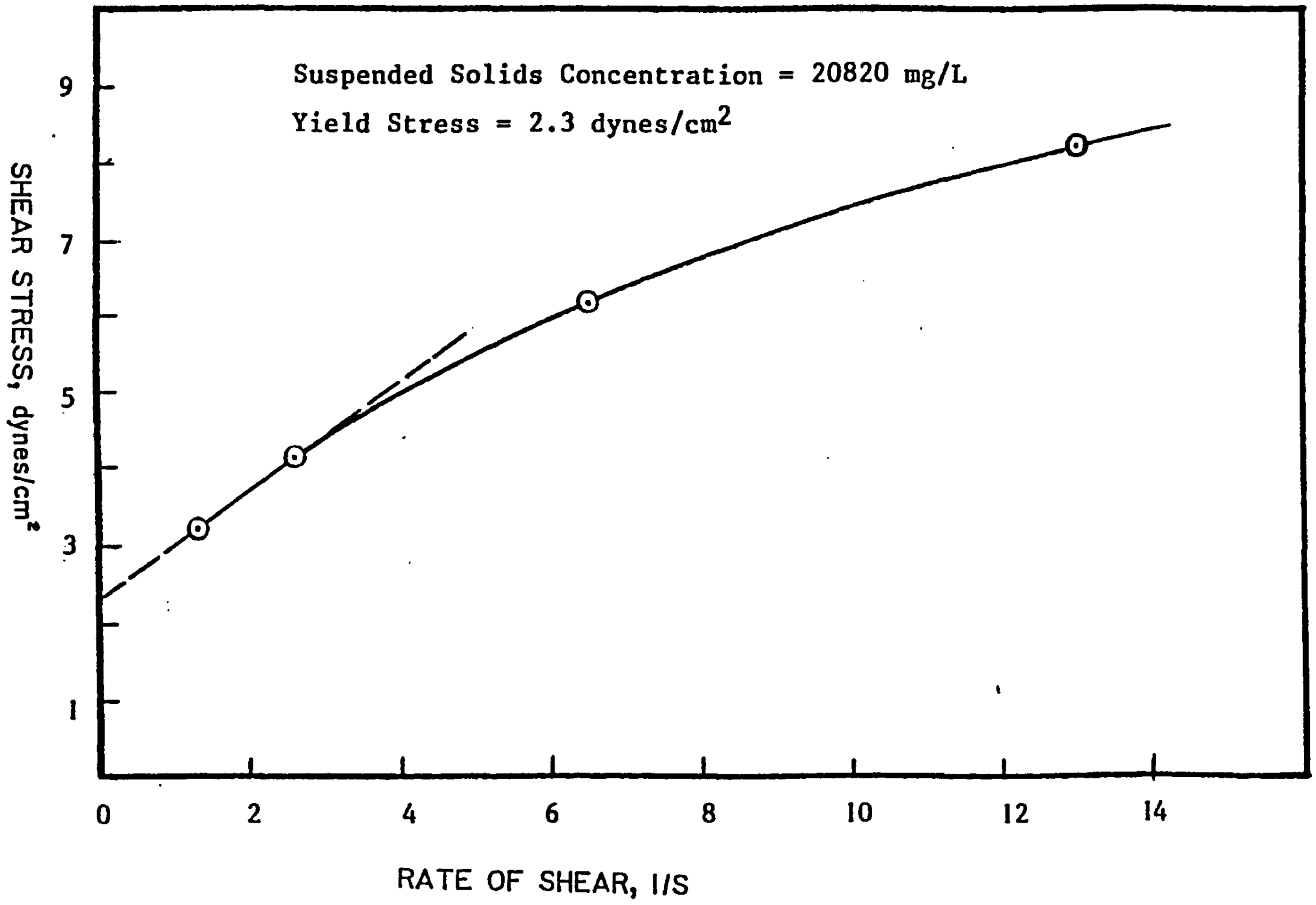


Figure 6.21: Observed Flow Curve for Mixture of Primary and Secondary Sludge (Diluted)

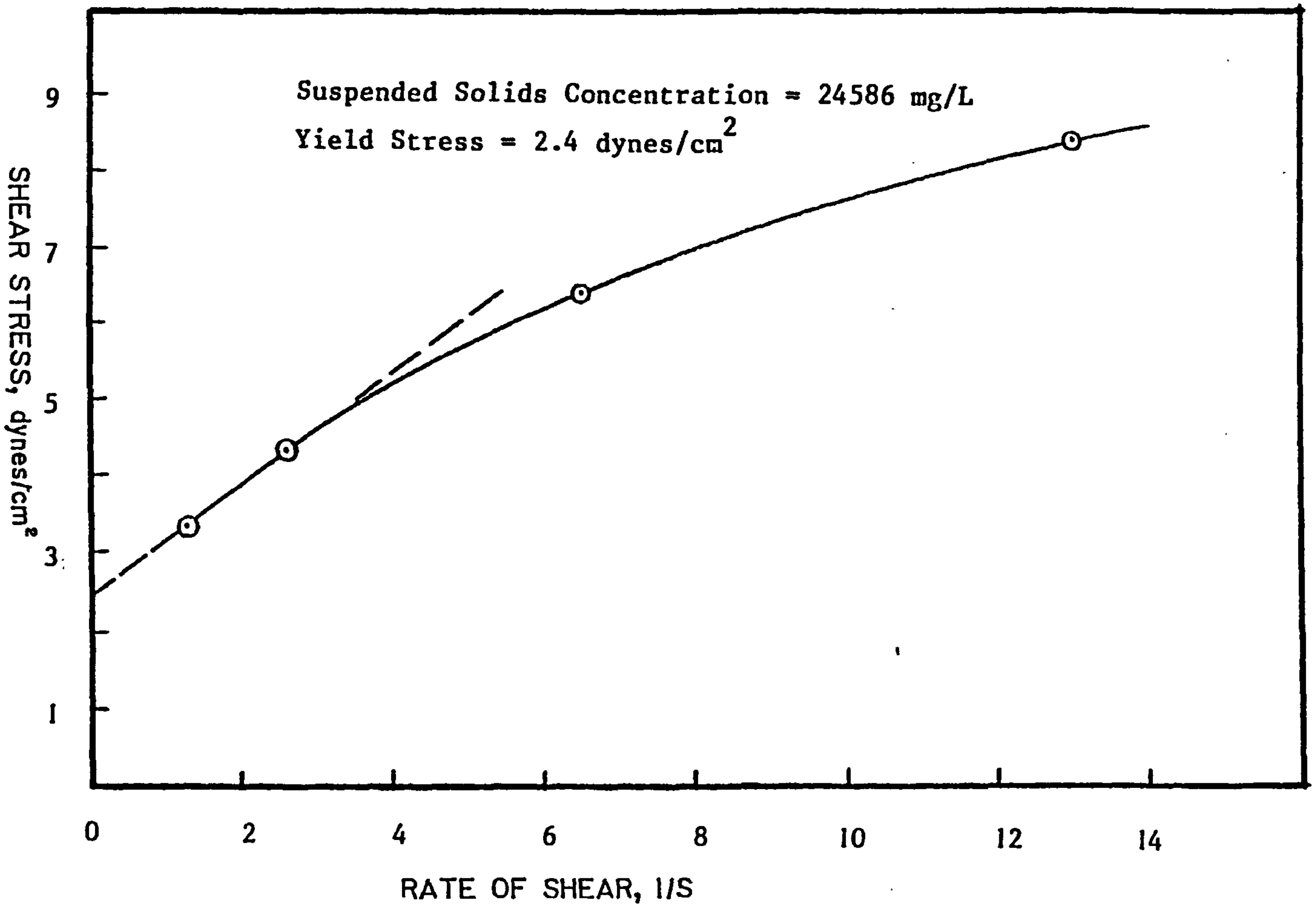


Figure 6.22: Observed Flow Curve for Mixture of Primary and Secondary Sludge (Diluted)

Table 6.4 - SUMMARY OF YIELD STRESS VALUES FOR BIOLOGICAL SLUDGES (GRAPHICAL METHOD)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_Y	
		dynes/cm^2	N/m^2
Mixed Liquor (Biological)	2,491	0.0200	0.0020
Mixed Liquor (Biological)	2,909	0.0400	0.0040
Mixed Liquor (Biological)	2,387	0.0100	0.0010
Settled Mixed Liquor (Activated Sludge)	9,258	0.7500	0.0750
Mixed Liquor (Biological)	1,908	0.0175	0.00175
Mixed Liquor (Biological)	2,708	0.0500	0.0050
Settled Mixed Liquor (Activated Sludge)	8,531	1.300	0.1300
Settled Mixed Liquor (Activated Sludge)	8,538	1.1000	0.1100
Mixed Liquor (Biological)	3,787	0.13	0.0130
Mixed Liquor (Biological)	3,851	0.14	0.0140
Settled Mixed Liquor (Activated Sludge)	11,969	2.30	0.230
Settled Mixed Liquor (Activated Sludge)	11,967	2.95	0.295

Table 6.5 - SUMMARY OF YIELD STRESS VALUES FOR ALUM SLUDGES FROM WATER TREATMENT PLANT (GRAPHICAL METHOD)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Alum Sludge	3,099	0.070	0.0070
Alum Sludge	3,097	0.075	0.0075
Settled Alum Sludge	12,688	4.200	0.4200
Settled Alum Sludge	13,362	3.900	0.3900
Alum Sludge	2,985	0.075	0.0075
Alum Sludge	3,128	0.070	0.0070
Settled Alum Sludge	11,447	3.400	0.3400
Settled Alum Sludge	11,613	3.250	0.3250
Alum Sludge	2,732	0.030	0.0030
Alum Sludge	2,697	0.040	0.0040
Settled Alum Sludge	11,573	3.700	0.3700
Settled Alum Sludge	11,493	4.300	0.4300

Table 6.6 - SUMMARY OF YIELD STRESS VALUES FOR PHYSICO-CHEMICAL WASTEWATER SLUDGES (GRAPHICAL METHOD)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y dynes/cm^2	N/m^2
Diluted Physico-Chemical Sludge from Underdrain	3,557	negligible	------
Diluted Physico-Chemical Sludge from Underdrain	1,640	negligible	------
Physico-Chemical Sludge from Underdrain	42,309	2.9	0.2900
Physico-Chemical Sludge from Underdrain	42,396	3.1	0.3100
Physico-Chemical Sludge from Clarifier	675	negligible	------
Physoci-Chemical Sludge from Clarifier	784	negligible	------
Settled Physico-Chemical Sludge from Clarifier	13,818	0.625	0.0625
Settled Physico-Chemical Sludge from Clarifier	11,493	0.425	0.0425
Physico-Chemical Sludge from Clarifier	5,255	negligible	------
Physico-Chemical Sludge from Clarifier	5,897	negligible	------
Settled Physico-Chemical Sludge from Clarifier	14,766	0.7750	0.0775
Settled Physico-Chemical Sludge from Clarifier	12,596	0.25	0.025

Table 6.7 - SUMMARY OF YIELD STRESS VALUES FOR SECONDARY DIGESTED SLUDGES (GRAPHICAL METHOD)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Diluted Secondary Digested Sludge	24,537	5.2	0.520
Diluted Secondary Digested Sludge	26,693	5.95	0.595
Diluted Secondary Digested Sludge	18,837	2.00	0.200
Diluted Secondary Digested Sludge	22,040	3.60	0.360

Table 6.8 - SUMMARY OF YIELD STRESS VALUES FOR MIXTURES OF PRIMARY AND SECONDARY SLUDGES (GRAPHICAL METHOD)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Mixture of Primary and Secondary Sludge	20,586	2.4	0.240
Mixture of Primary and Secondary Sludge	20,820	2.3	0.230

2.Dekee Model: The values of yield stress for different types of sludges were determined by applying the Dekee model with the help of a non-linear regression technique using a SAS statistical package called NLIN. The initial values of different parameters in Dekee model were obtained using various approaches as discussed in the next paragraph and the final values or the corrected values of parameters including yield stress were obtained by using the non-linear regression technique.

The initial values of yield stress for all types of sludge samples were obtained using the Casson Equation as discussed in Chapter 5. The square root of shear stress and square root of rate of shear were plotted on a regular graph paper. For pseudoplastic fluids with a defined yield stress, this plot gave a straight line. By extending this straight line to Y axis at zero rate of shear and this intercept was considered as initial value of the yield stress. Some of the typical plots used for obtaining the initial value of yield stress are shown in Figure 6.23, Figure 6.24, Figure 6.25, Figure 6.26, and Figure 6.27. The initial values of yield stress for different types of sludges are presented in Table 6.9.

The initial values of time parameter and viscosity parameter were obtained using the method discussed in

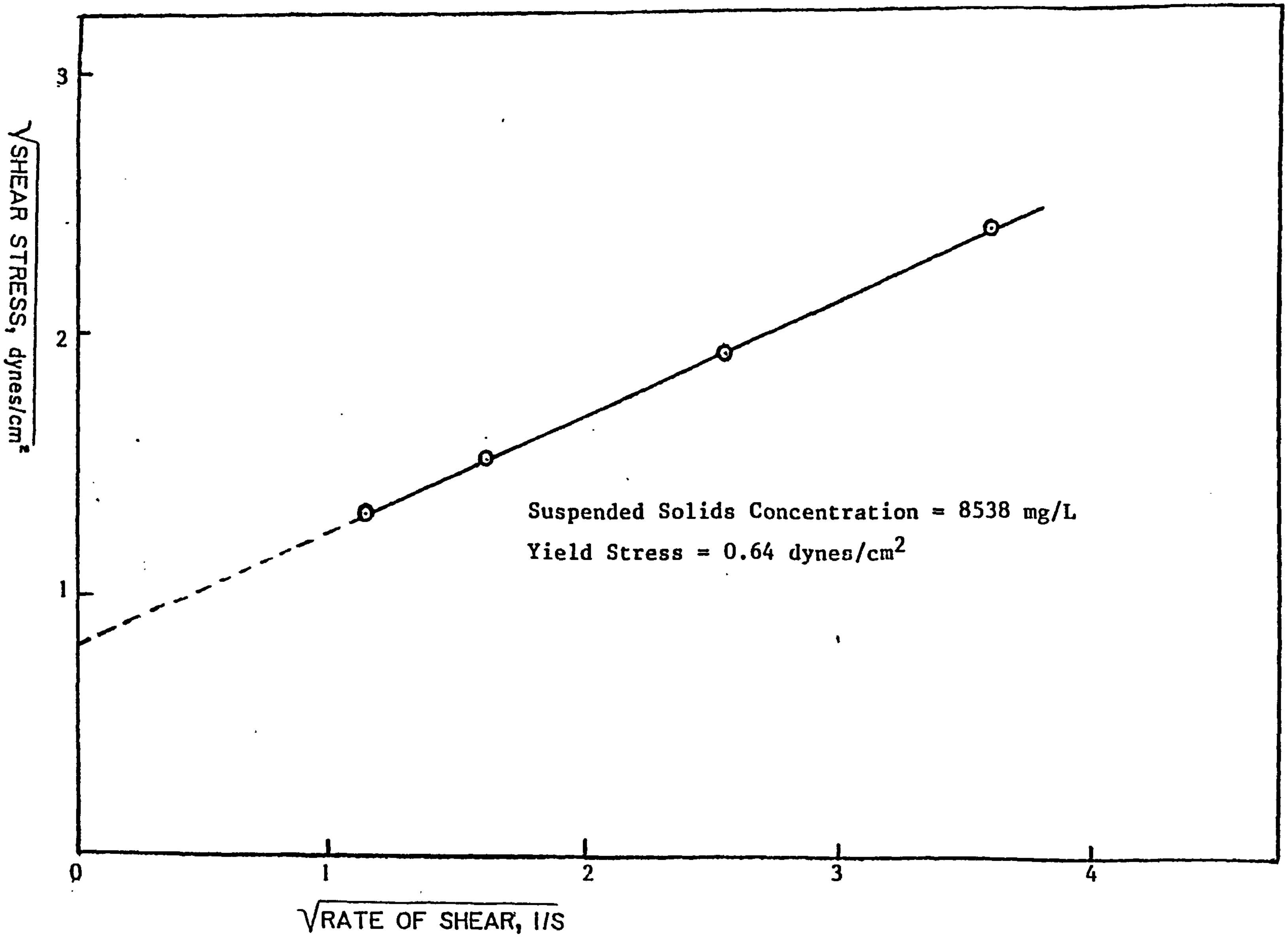


Figure 6.23: Plot to Estimate Initial Value of Yield Stress in Dekee Model for Biological Sludges

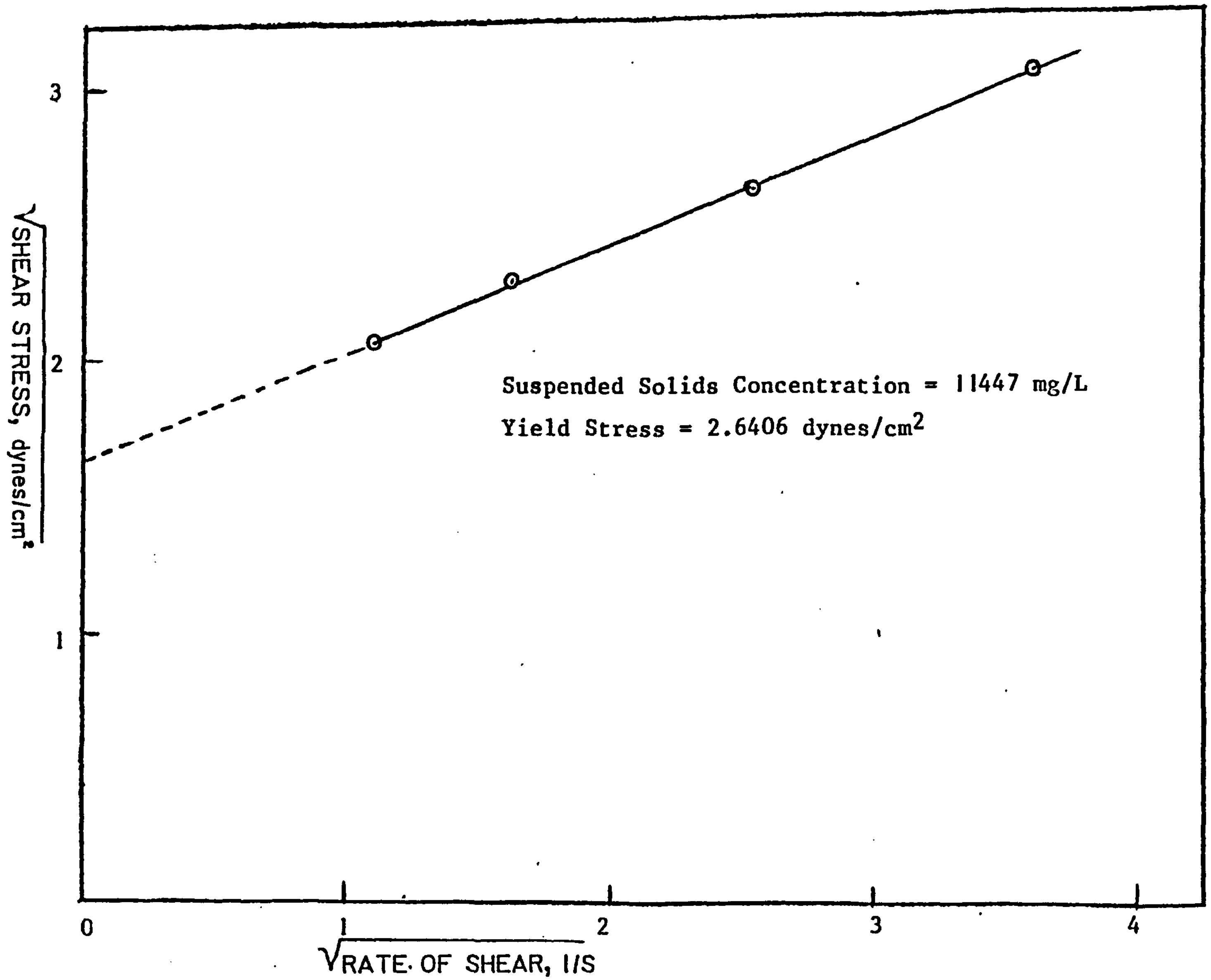


Figure 6.24: Plot to Estimate Initial Value of Yield Stress in Dekee Model for Alum Sludges

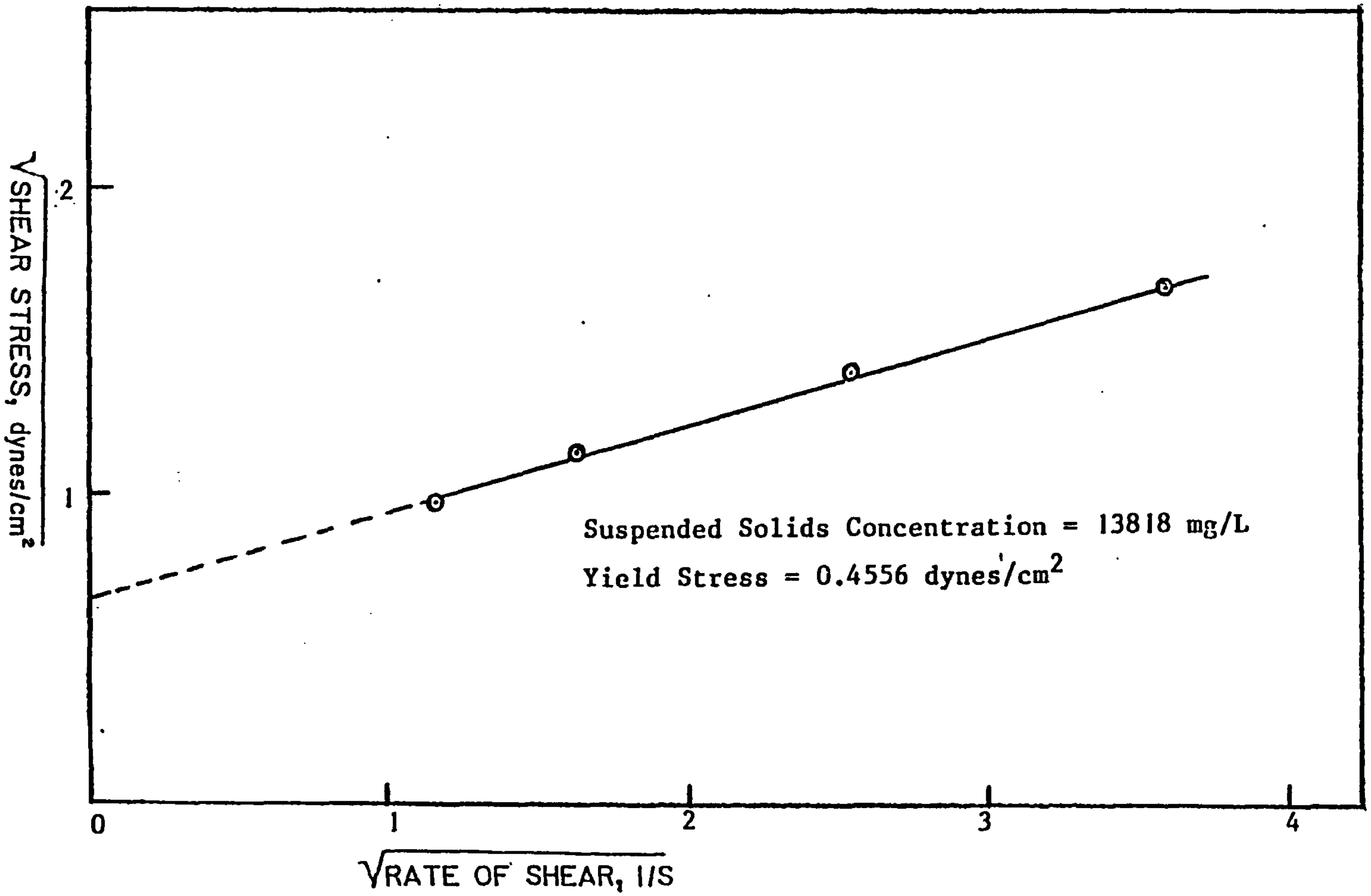


Figure 6.25: Plot to Estimate Initial Value of Yield Stress in Dekee Model for Physico-Chemical Sludges

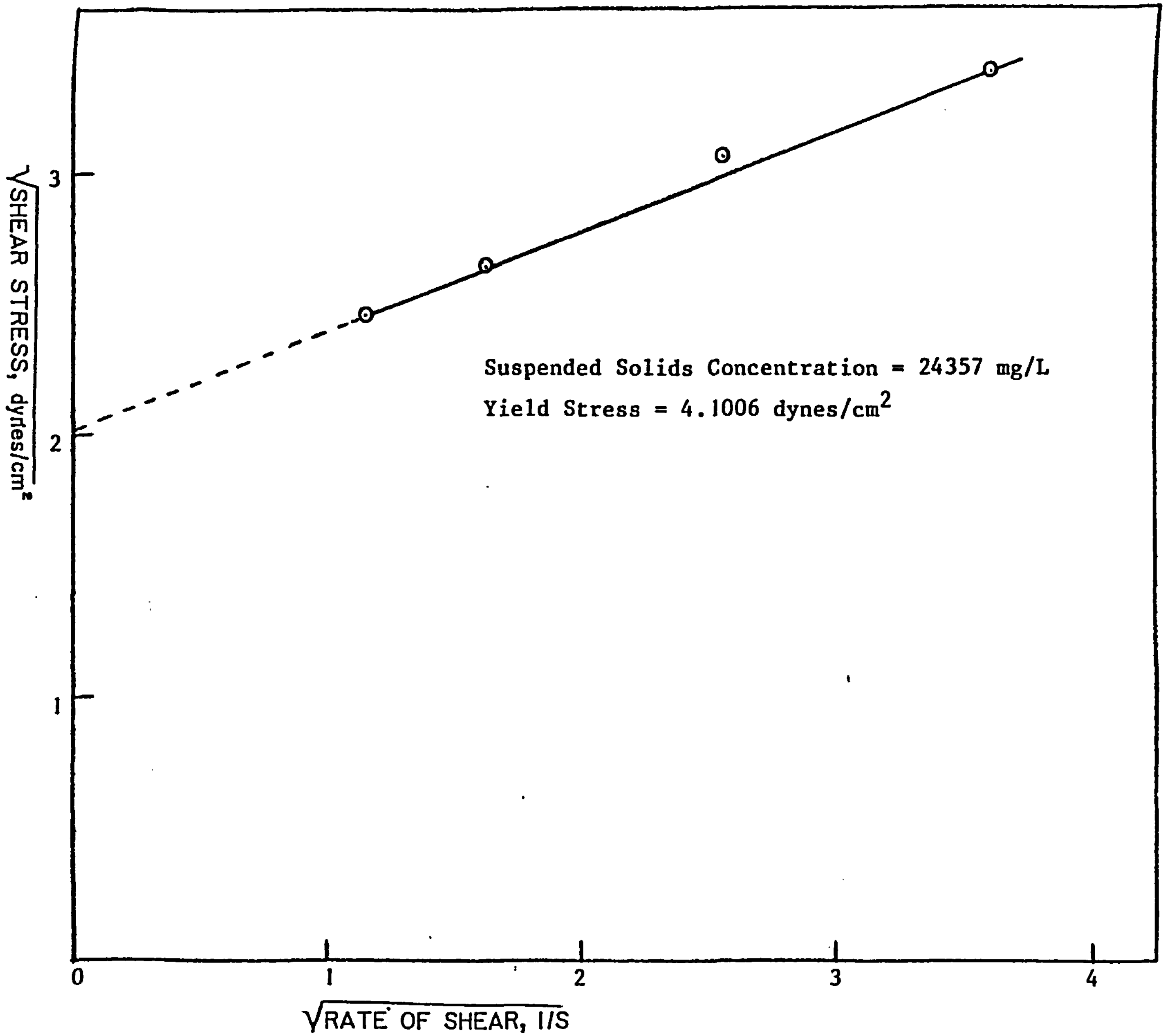


Figure 6.26: Plot to Estimate Initial Value of Yield Stress in Dekee Model for Secondary Digested Sludges

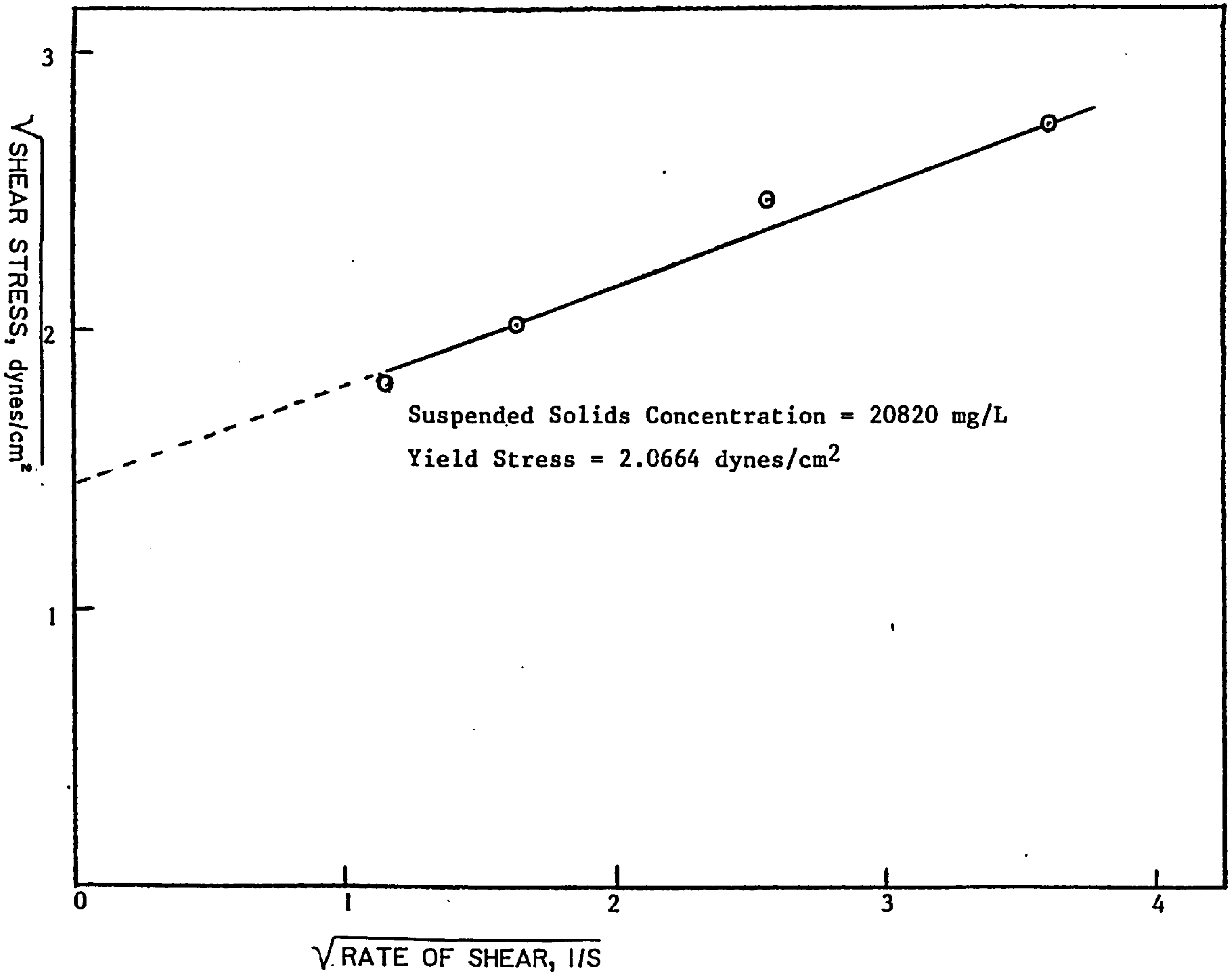


Figure 6.27: Plot to Estimate Initial Value of Yield Stress in Dekee Model for Mixture of Primary and Secondary Sludges

Table 6.9 - INITIAL VALUES OF PARAMETERS FOR DEKEE MODEL FOR DIFFERENT TYPES OF SLUDGES

TYPE OF SLUDGE	SUSPENDED SOLIDS CONCENTRATION mg/L	INITIAL VALUE		
		YIELD STRESS τ_y, dynes/cm^2	VISCOSITY PARAMETER μ_1', poise	TIME PARAMETER t_1, S
Biological Sludge	9,258	0.6006	0.77	0.0380
	8,538	0.6400	0.70	0.0340
	11,969	1.5625	1.30	0.0465
	11,967	2.0306	1.50	0.0586
Alum Sludge	12,688	4.0000	2.15	0.0760
	13,362	4.1006	2.25	0.0805
	11,447	2.6406	1.65	0.0617
	11,573	2.8900	1.80	0.0673
	11,613	2.7225	1.50	0.0554
	11,493	3.5156	1.85	0.0726
Physico-Chemical Sludge	42,309	2.0306	1.45	0.0560
	42,396	2.2500	1.45	0.0571
	13,818	0.4556	0.42	0.0533
	11,493	0.2627	0.30	0.0393
	14,766	0.5439	0.48	0.0472
	12,596	0.2500	0.34	0.0740
Secondary Digested Sludge	24,537	4.1006	2.40	0.0763
	26,693	4.9506	3.00	0.0822
	22,040	2.9327	1.78	0.0729
	18,837	1.5625	1.17	0.0718
Mixture of Primary and Secondary Sludge	20,820	2.0664	1.40	0.0613
	20,586	2.1025	1.52	0.0669

Chapter 5. The rate of shear and non-Newtonian viscosity values were plotted on a semi-log graph paper. For pseudoplastic fluids, this curve became a straight line at a high rate of shear. By extending this straight line part of the curve to the viscosity, Y, axis at zero rate of shear, the value of viscosity parameter was obtained. The slope of this straight line portion of the curve was used as the initial value of the time parameter. The same procedure was repeated for all sludge samples. The typical plots are shown in Figure 6.28, Figure 6.29, Figure 6.30, Figure 6.31, and Figure 6.32. The initial value of time and viscosity parameters for different types of sludges are presented in Table 6.9.

The initial values for all 3 parameters along with the experimental viscosity data were fed into the computer program for non-linear regression to fit the Dekee model. The corrected values of yield stress for all types of sludges are shown in Table 6.10, Table 6.11, Table 6.12, Table 6.13, and Table 6.14. The Dekee model was applied to only those sludge samples which exhibited a pseudoplastic behaviour with a yield stress, and not to those samples which showed a behaviour of Bingham plastic fluids.

The observed behaviour for different types of sludges is presented in Table 6.15.

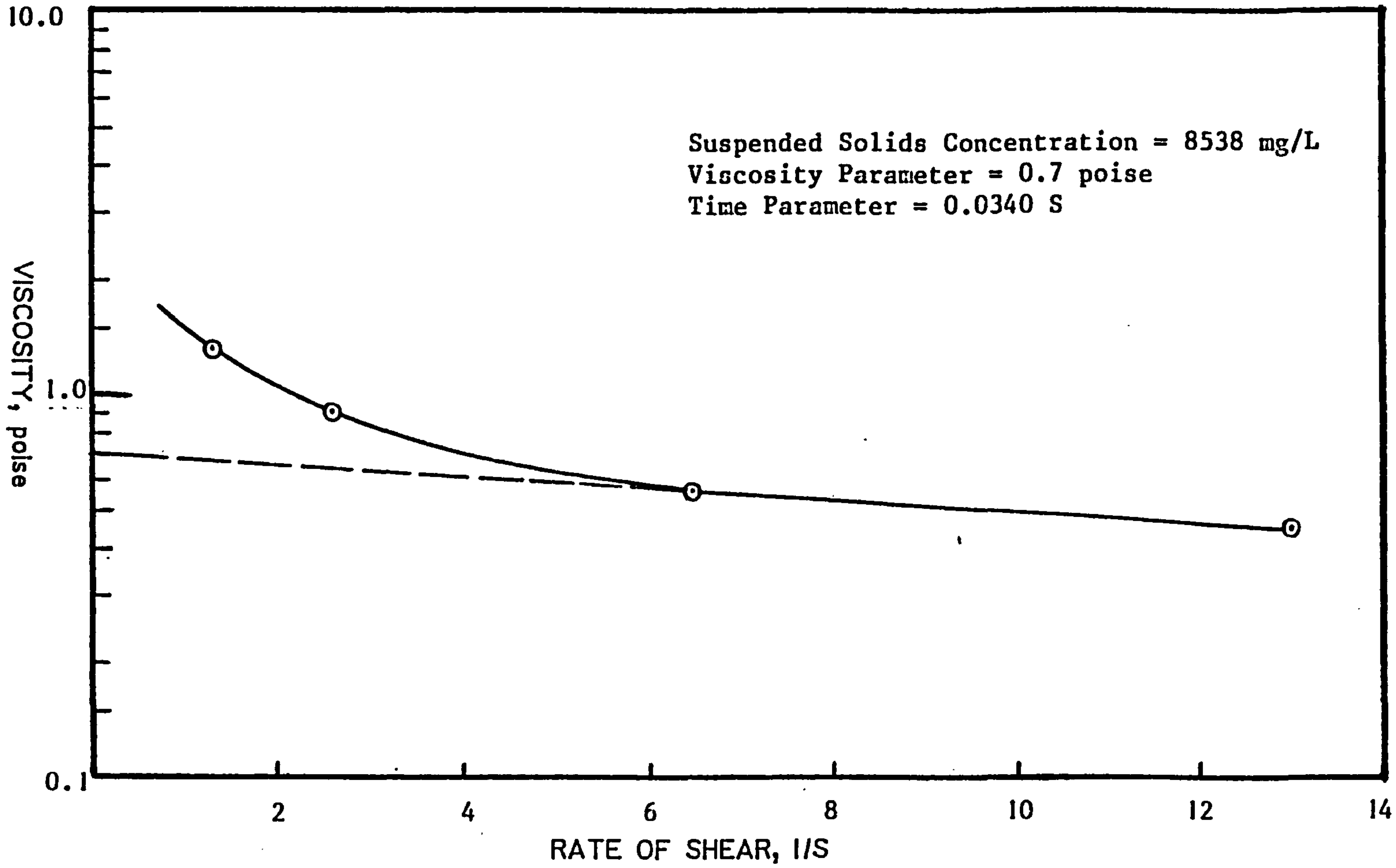


Figure 6.28: Plot to Estimate Initial Values of Time and Viscosity Parameters in Dekee Model for Biological Sludges

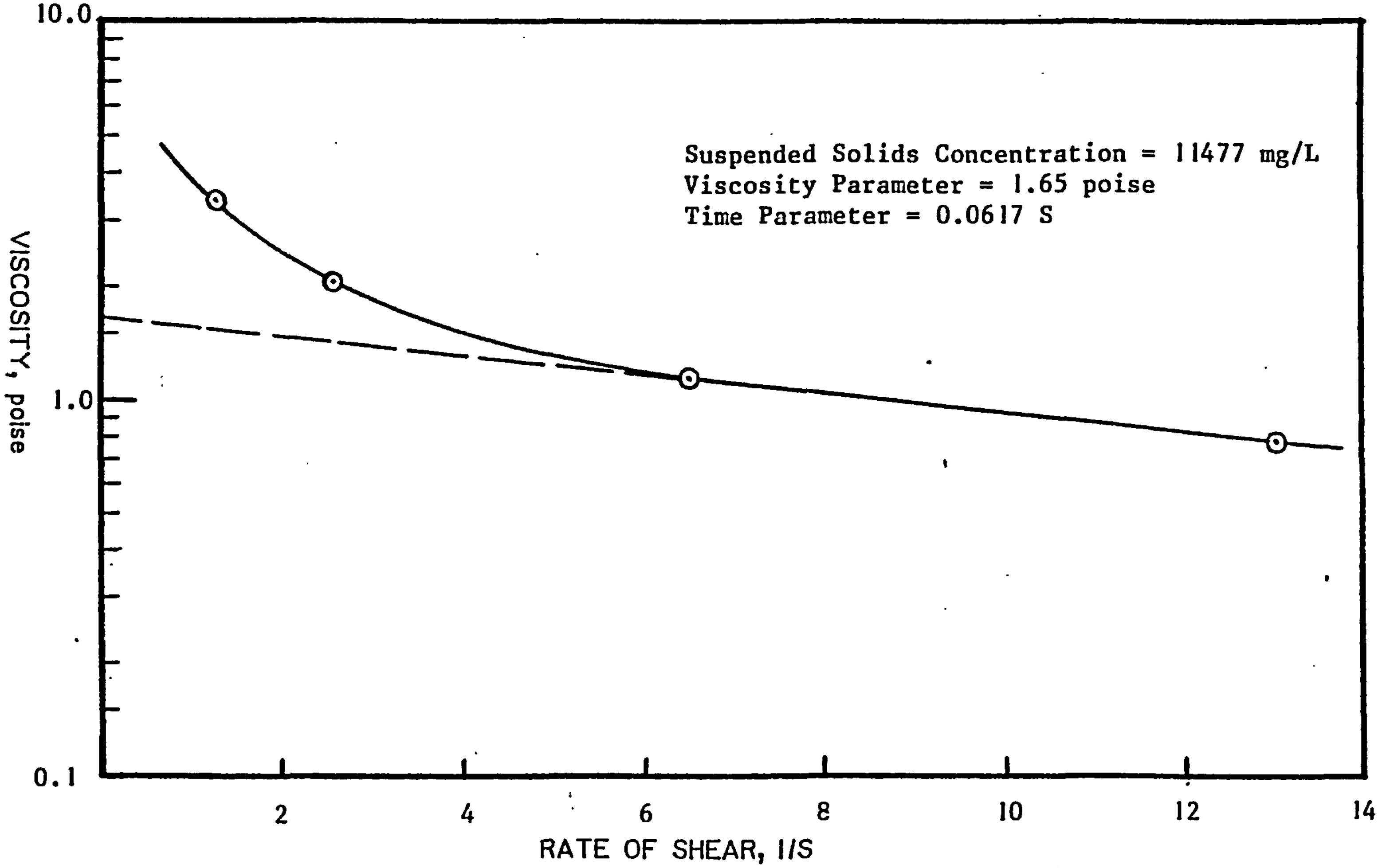


Figure 6.29: Plot to Estimate Initial Values of Time and Viscosity Parameters in Dekee Model for Alum Sludges

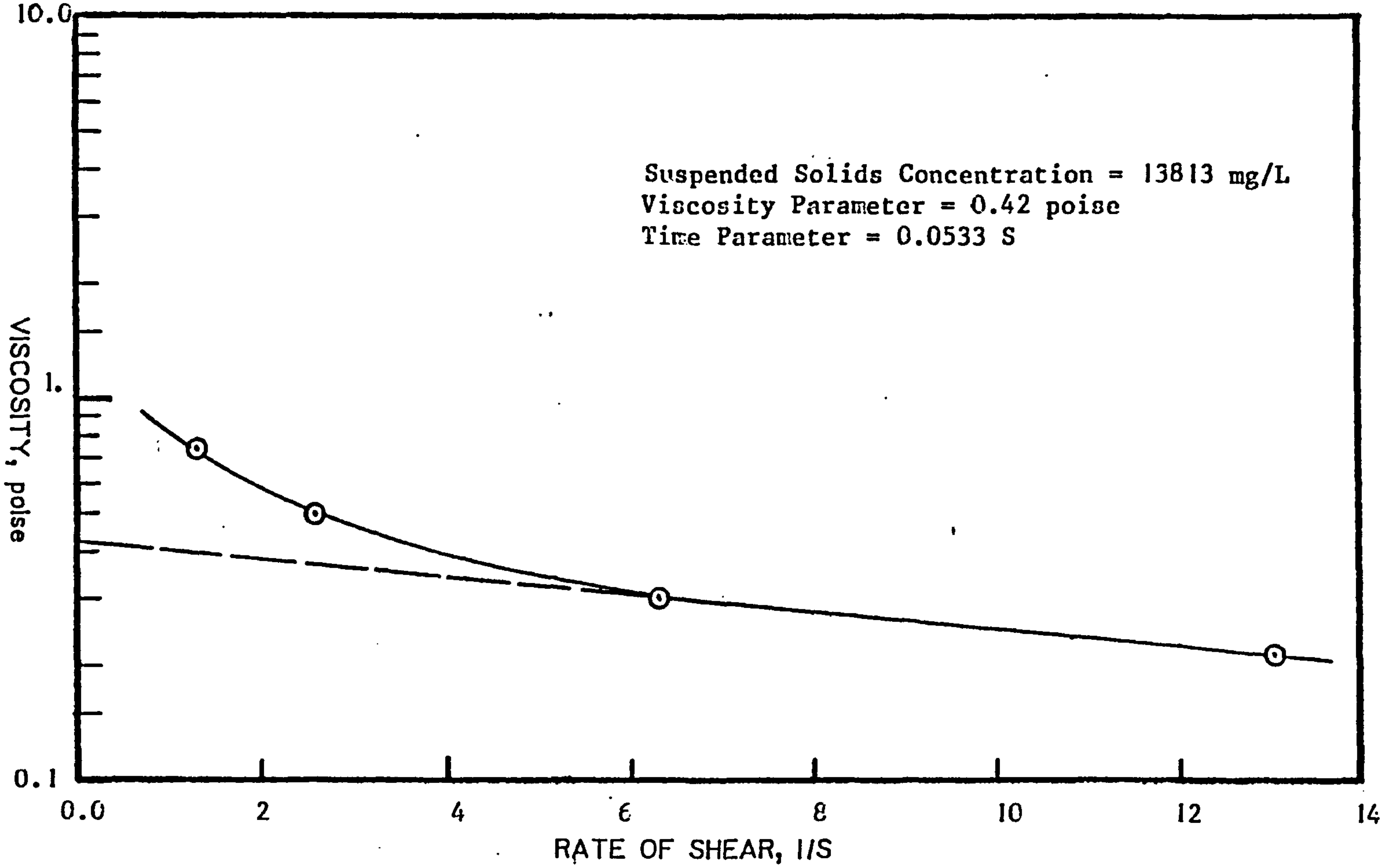


Figure 6.30: Plot to Estimate Initial Values of Time and Viscosity Parameters in Dekee Model for Physico-Chemical Sludges

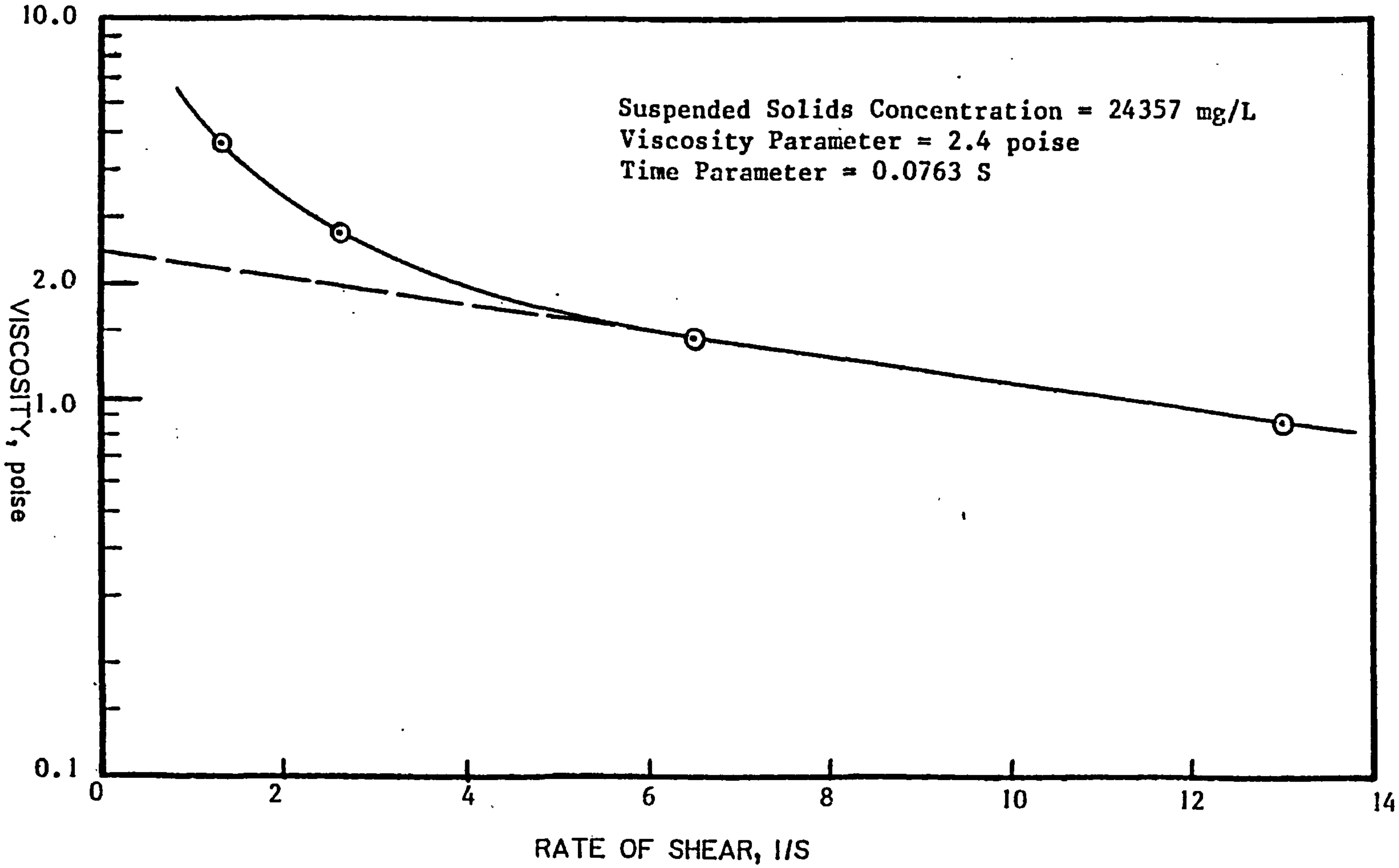


Figure 6.31: Plot to Estimate Initial Values of Time and Viscosity Parameters in Dekee Model for Secondary Digested Sludges

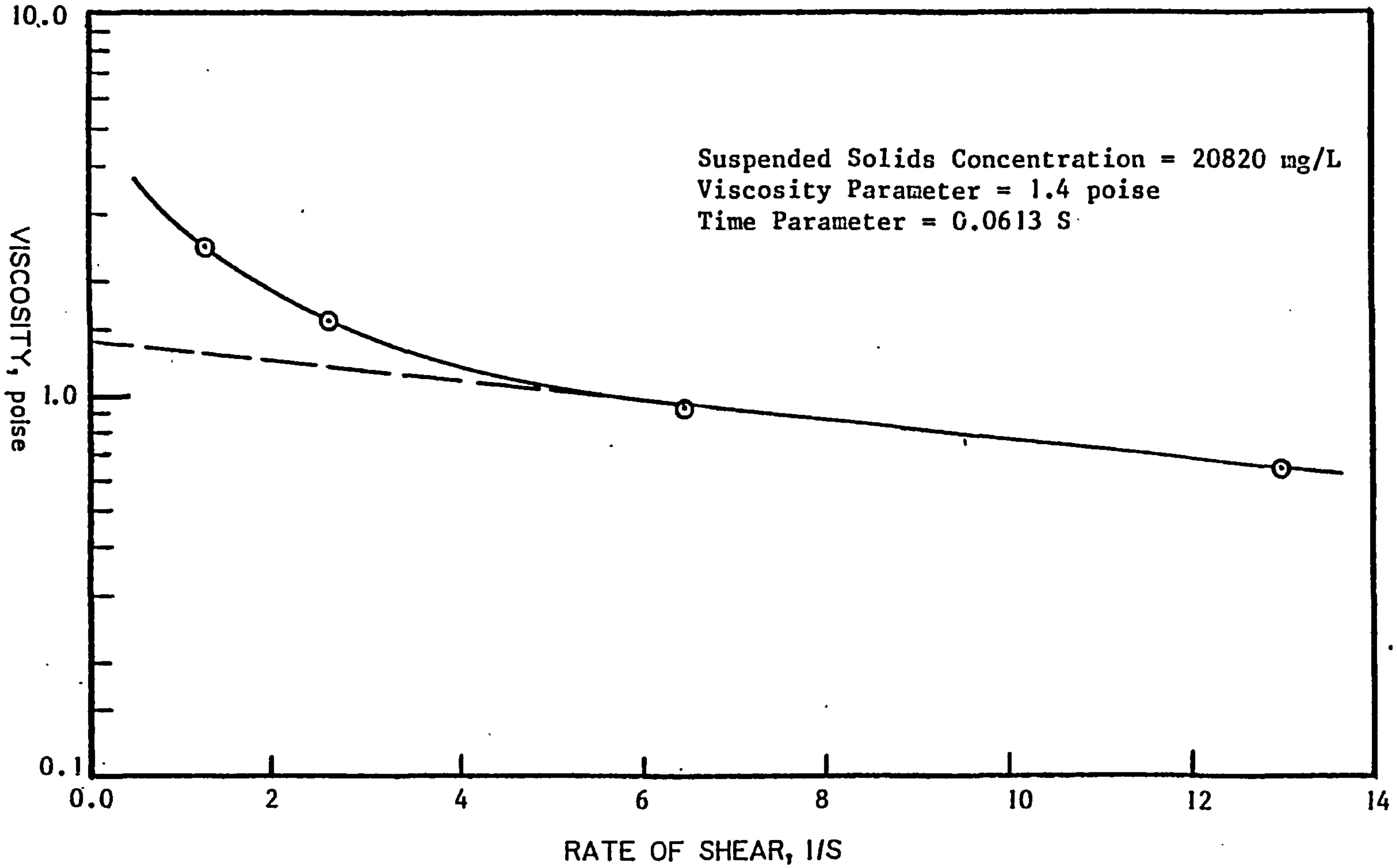


Figure 6.32: Plot to Estimate Initial Values of Time and Viscosity Parameters in Dekee Model for Mixture of Primary and Secondary Sludges

Table 6.10 - SUMMARY OF YIELD STRESS VALUES FOR BIOLOGICAL SLUDGES (DEKEE MODEL)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Mixed Liquor (Biological)	2,491	0.0200	0.0020
Mixed Liquor (Biological)	2,909	0.0400	0.0040
Mixed Liquor (Biological)	2,387	0.0100	0.0010
Settled Mixed Liquor (Activated Sludge)	9,258	0.7688*	0.0767
Mixed Liquor (Biological)	1,908	0.0175	0.00175
Mixed Liquor (Biological)	2,708	0.0500	0.0050
Settled Mixed Liquor (Activated Sludge)	8,538	1.0330*	0.1033
Mixed Liquor (Biological)	3,787	0.13	0.0130
Mixed Liquor (Biological)	3,851	0.14	0.0140
Settled Mixed Liquor (Activated Sludge)	11,969	2.3144*	0.2314
Settled Mixed Liquor (Activated Sludge)	11,967	2.9370*	0.2937

*Only these values were estimated using the Dekee Model; the rest were from the graphical method.

Table 6.11 - SUMMARY OF YIELD STRESS VALUES FOR ALUM SLUDGES FROM WATER TREATMENT PLANT (DEKEE MODEL)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Alum Sludge	3,099	0.0700	0.0070
Alum Sludge	3,097	0.0750	0.0075
Settled Alum Sludge	12,688	4.0090*	0.4000*
Settled Alum Sludge	13,362	3.7100*	0.3710*
Alum Sludge	2,985	0.0750	0.0075
Alum Sludge	3,128	0.0700	0.0070
Settled Alum Sludge	11,447	3.3553*	0.3355*
Settled Alum Sludge	11,613	3.0881*	0.3088*
Alum Sludge	2,732	0.0300	0.0030
Alum Sludge	2,697	0.0400	0.0040
Settled Alum Sludge	11,573	3.6175*	0.3618*
Settled Alum Sludge	11,493	4.3261*	0.4326*

*Only these values were estimated using the Dekee Model; the rest were from the graphical method.

Table 6.12 - SUMMARY OF YIELD STRESS VALUES FOR PHYSICO-CHEMICAL WASTEWATER SLUDGES (DEKEE MODEL)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Diluted Physico-Chemical Sludge from Underdrain	3,557	negligible	------
Diluted Physico-Chemical Sludge from Underdrain	1,649	negligible	------
Physico-Chemical Sludge from Underdrain	42,309	2.7466	0.2747
Physico-Chemical Sludge from Underdrain	42,396	3.0903	0.3090
Physico-Chemical Sludge from Clarifier	675	negligible	------
Physico-Chemical Sludge from Clarifier	784	negligible	------
Settled Physico-Chemical Sludge from Clarifier	13,818	0.5940	0.0594
Settled Physico-Chemical Sludge from Clarifier	11,493	0.4247	0.0425
Physico-Chemical Sludge from Clarifier	5,255	negligible	------
Physoci-Chemical Sludge from Clarifier	5,897	negligible	------
Settled Physico-Chemical Sludge from Clarifier	14,766	0.7818	0.0782
Settled Physico-Chemical Sludge from Clarifier	12,596	0.2116	0.0212

Table 6.13 - SUMMARY OF YIELD STRESS VALUES FOR SECONDARY DIGESTED SLUDGES (DEKEE MODEL)

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y dynes/cm^2	YIELD STRESS, τ_y N/m^2
Diluted Secondary Digested Sludge	24,537	5.0701	0.5070
Diluted Secondary Digested Sludge	26,693	5.8247	0.5825
Diluted Secondary Digested Sludge	18,837	1.9707	0.1971
Diluted Secondary Digested Sludge	22,040	3.5574	0.3557

Table 6.14 - SUMMARY OF YIELD STRESS VALUES FOR MIXTURE OF PRIMARY AND SECONDARY SETTLED SLUDGES

SLUDGE TYPE	SUSPENDED SOLIDS CONCENTRATION mg/L	YIELD STRESS, τ_y	
		dynes/cm^2	N/m^2
Mixture of Primary and Secondary Settled Sludge	20,586	2.2232	0.2223
Mixture of Primary and Secondary Settled Sludge	20,820	2.2017	0.2202

Table 6.15 - OBSERVED BEHAVIOUR OF DIFFERENT SLUDGES

SLUDGE TYPE	BEHAVIOUR
Mixed Liquor	Bingham Plastic
Settled Mixed Liquor	Pseudoplastic with Yield Stress
Alum Sludge	Bingham Plastic
Settled Alum Sludge	Pseudoplastic with Yield Stress
Diluted Physico-Chemical Sludge (from Underdrains)	Close to Dilatant Fluid
Physico-Chemical Sludge (from Underdrains)	Pseudoplastic with Yield Stress
Physico Chemical Sludge (from Clarifiers)	Close to Dilatant Fluid
Settled Physico-Chemical Sludge (from Clarifiers)	Pseudoplastic with Yield Stress
Diluted Secondary Digested Sludge	Pseudoplastic with Yield Stress
Mixture of Primary and Secondary Sludge	Pseudoplastic with Yield Stress

6.3.2.2 Relationship Between Yield Stress and Suspended Solids Concentration

When the suspended solids concentration and corresponding yield stress value for each type of sludge sample was plotted on a logarithmic graph paper, it was noticed that a straight line relationship between suspended solids concentration and yield stress existed. Plots between 'log of suspended solids concentration and log of yield stress' for different types of sludges are shown in Figure 6.33, Figure 6.34, Figure 6.35, Figure 6.36, and Figure 6.37 for results obtained using graphical method and in Figure 6.38, Figure 6.39, Figure 6.40, Figure 6.41, and Figure 6.42 for results obtained using the Dekee Model. A correlation between these two parameters was developed using a linear regression analysis as discussed in section 6.1. Therefore, two sets of equations for each type of sample have been developed. One set of equations correlates the values of yield stress obtained using the graphical method, and the other set of equations correlates the values estimated using the Dekee model. Since the Dekee model was not applied to those sludge samples which exhibited Bingham plastic flow characteristics, the same yield stress values obtained using the graphical method were also used in developing the second set of equations using values estimated by the Dekee model. All these equations developed for the respective sludge samples to estimate the yield stress for different types of sludges by knowing their suspended solids concentration are shown in Table 6.16. Plots overlapping the obtained values of yield stress from graphical method and estimated value of yield stress from the least square equation for different types of sludges are shown in Figure 6.43, Figure 6.44, Figure 6.45, Figure 6.46. Similarly plots of calculated values of yield stress from Dekee model and estimated values from least square equation are shown in Figure 6.47, Figure 6.48, Figure 6.49, and Figure 6.50.

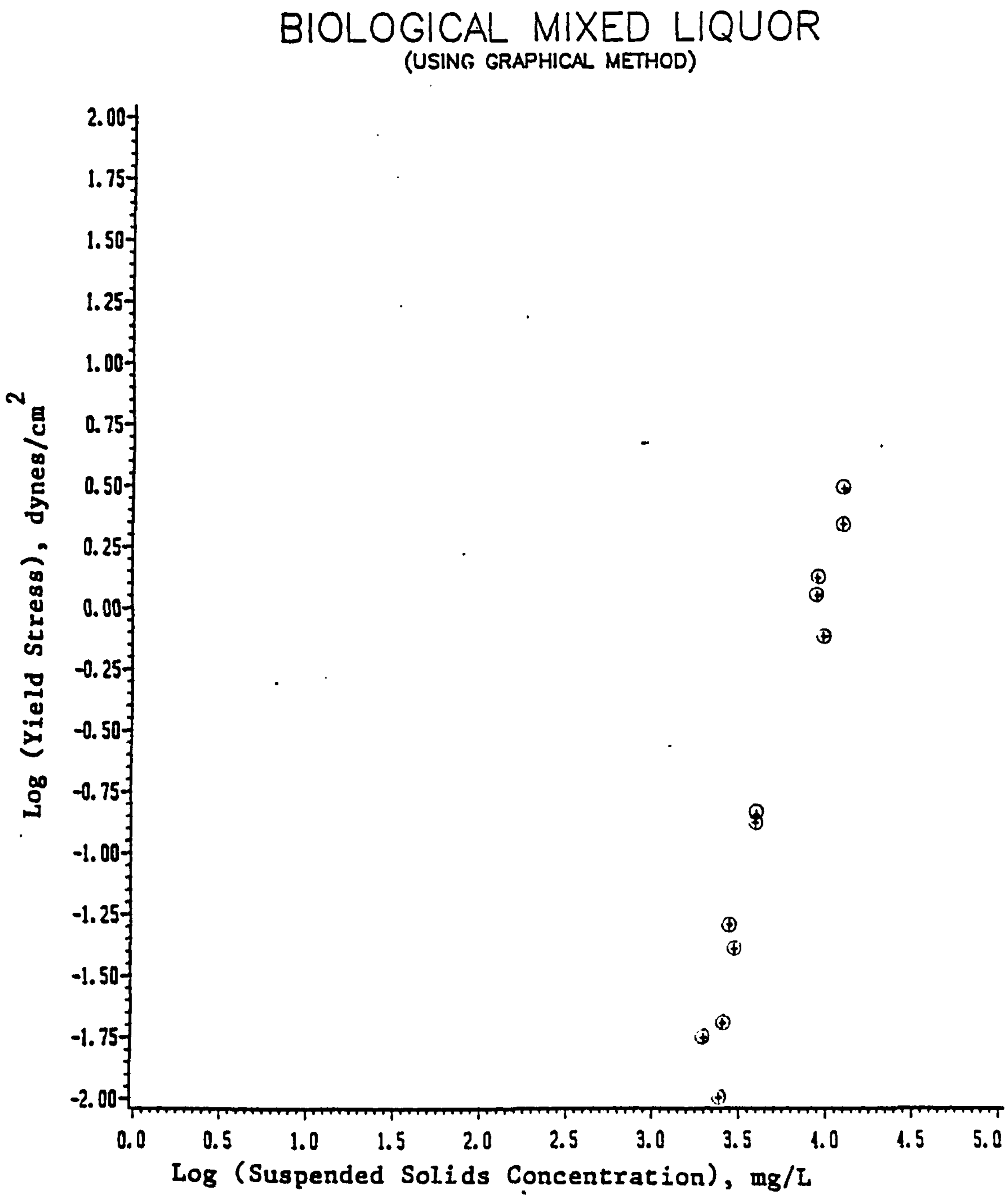


Figure 6.33: Relationship Between Yield Stress and Suspended Solids Concentration for Biological Sludges (Graphical Method)

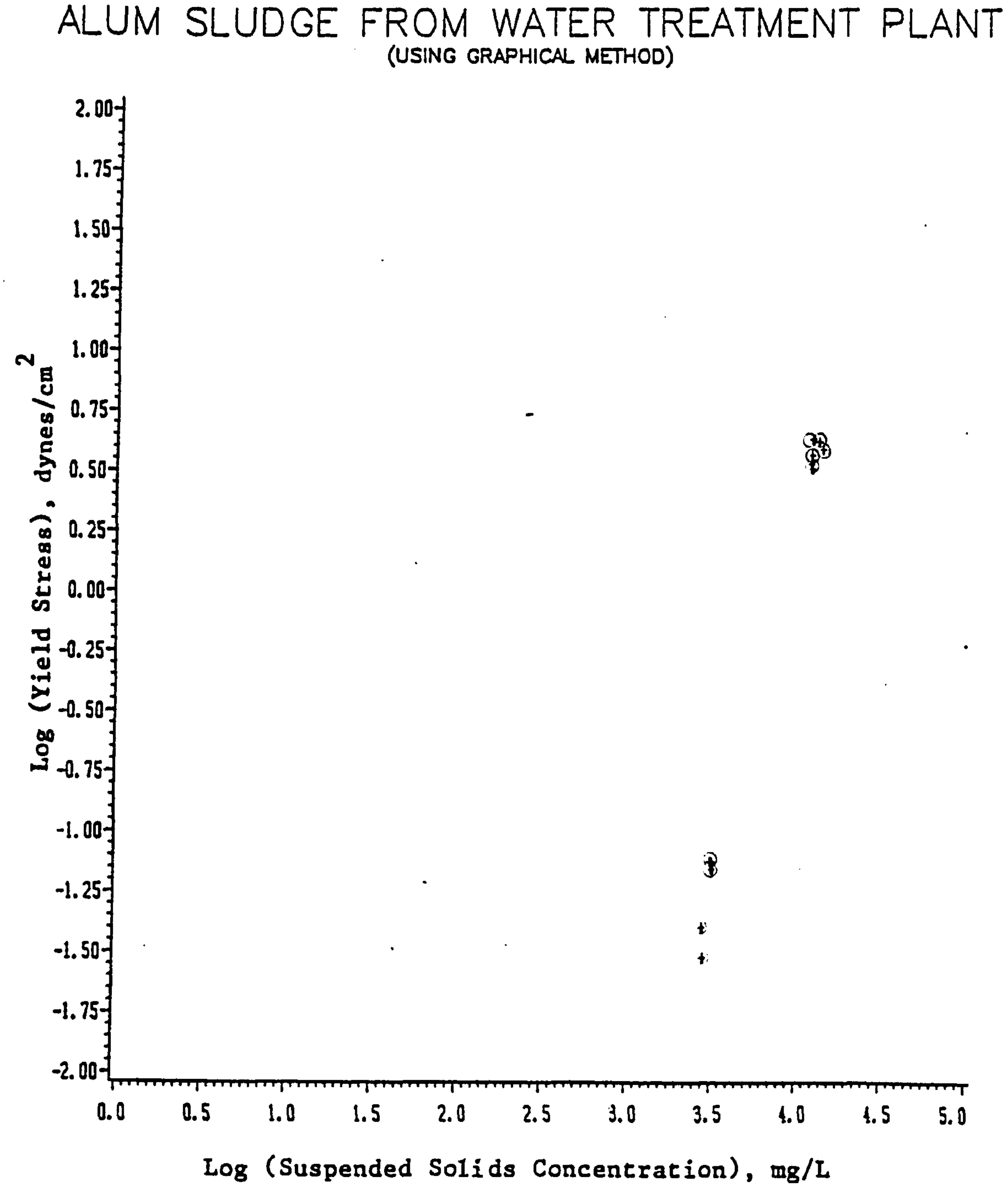


Figure 6.34: Relationship Between Yield Stress and Suspended Solids Concentration for Alum Sludges (Graphical Method)

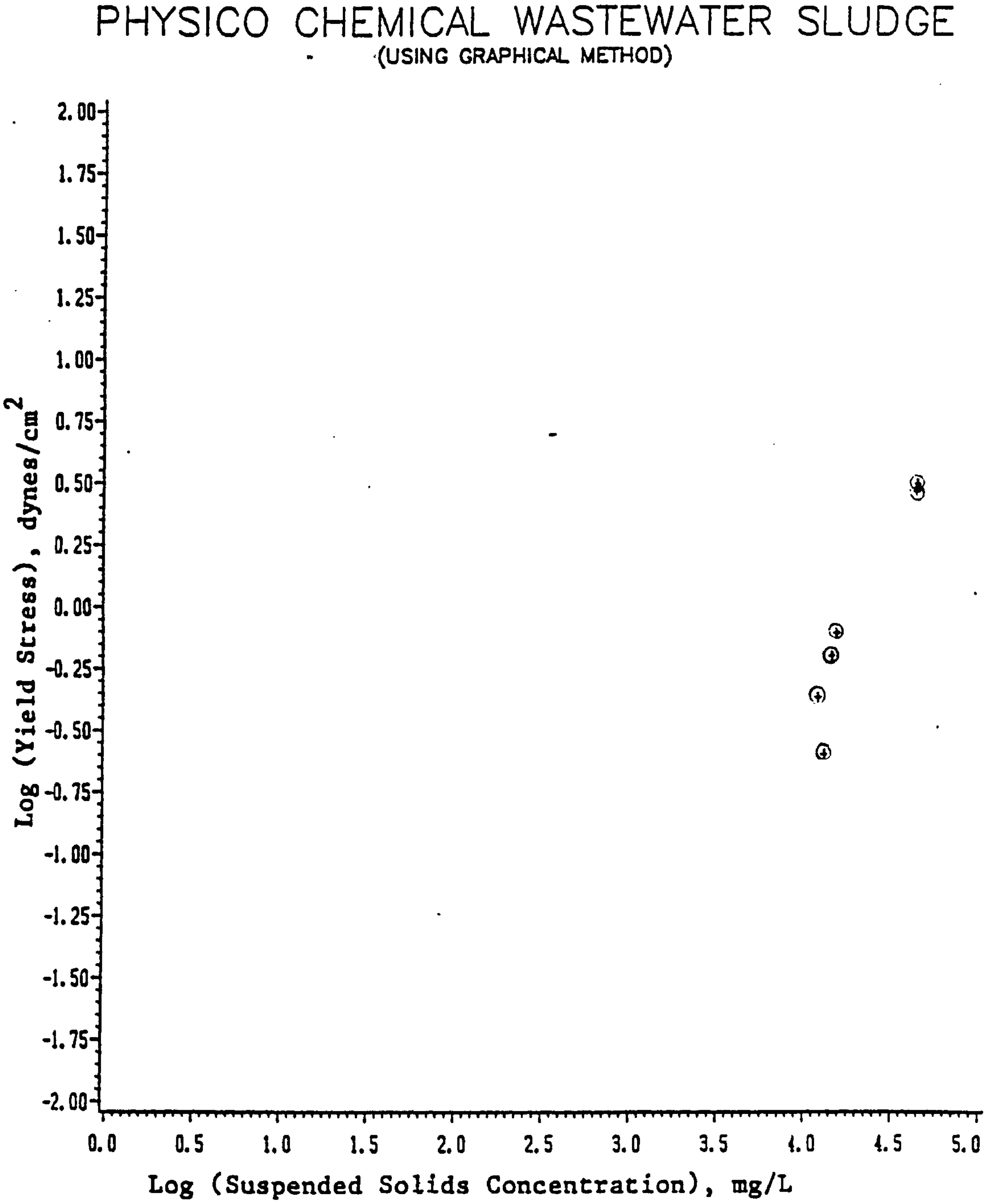


Figure 6.35: Relationship Between Yield Stress and Suspended Solids Concentration for Physico-Chemical Sludges (Graphical Method)

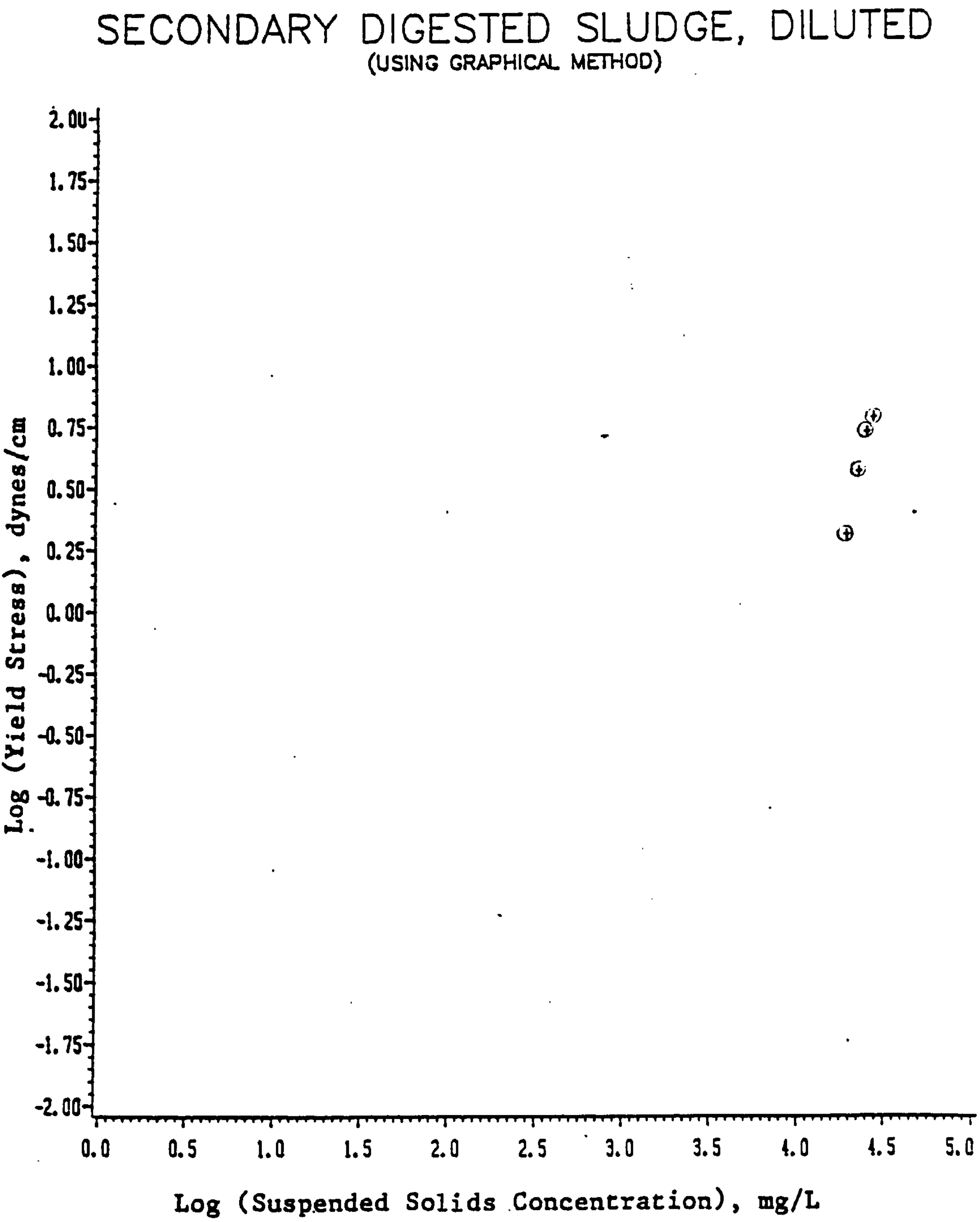


Figure 6.36: Relationship Between Yield Stress and Suspended Solids Concentration for Secondary Digested Sludges (Graphical Method)

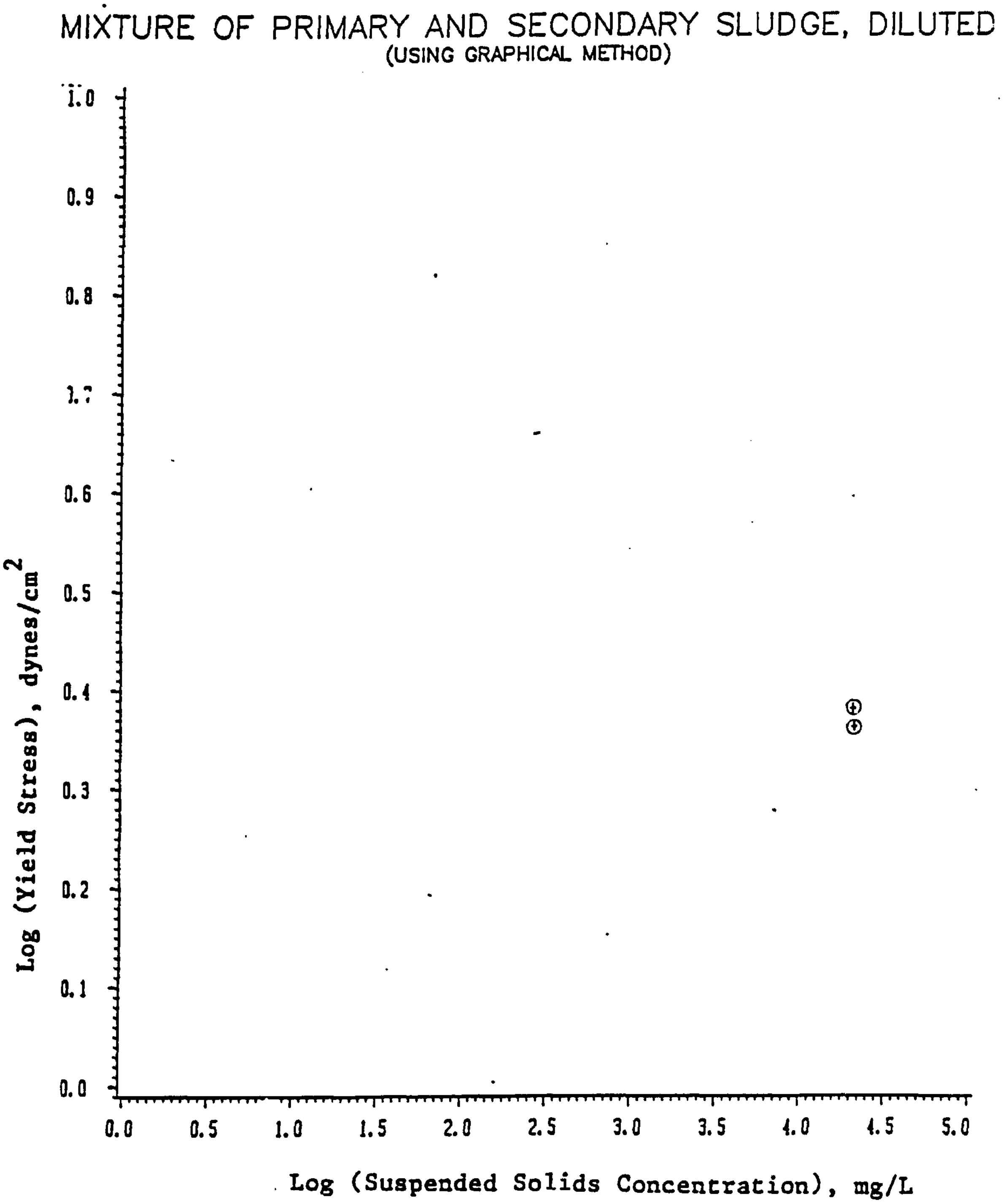


Figure 6.37: Relationship Between Yield Stress and Suspended Solids Concentration for Mixture of Primary and Secondary Sludges (Graphical Method)

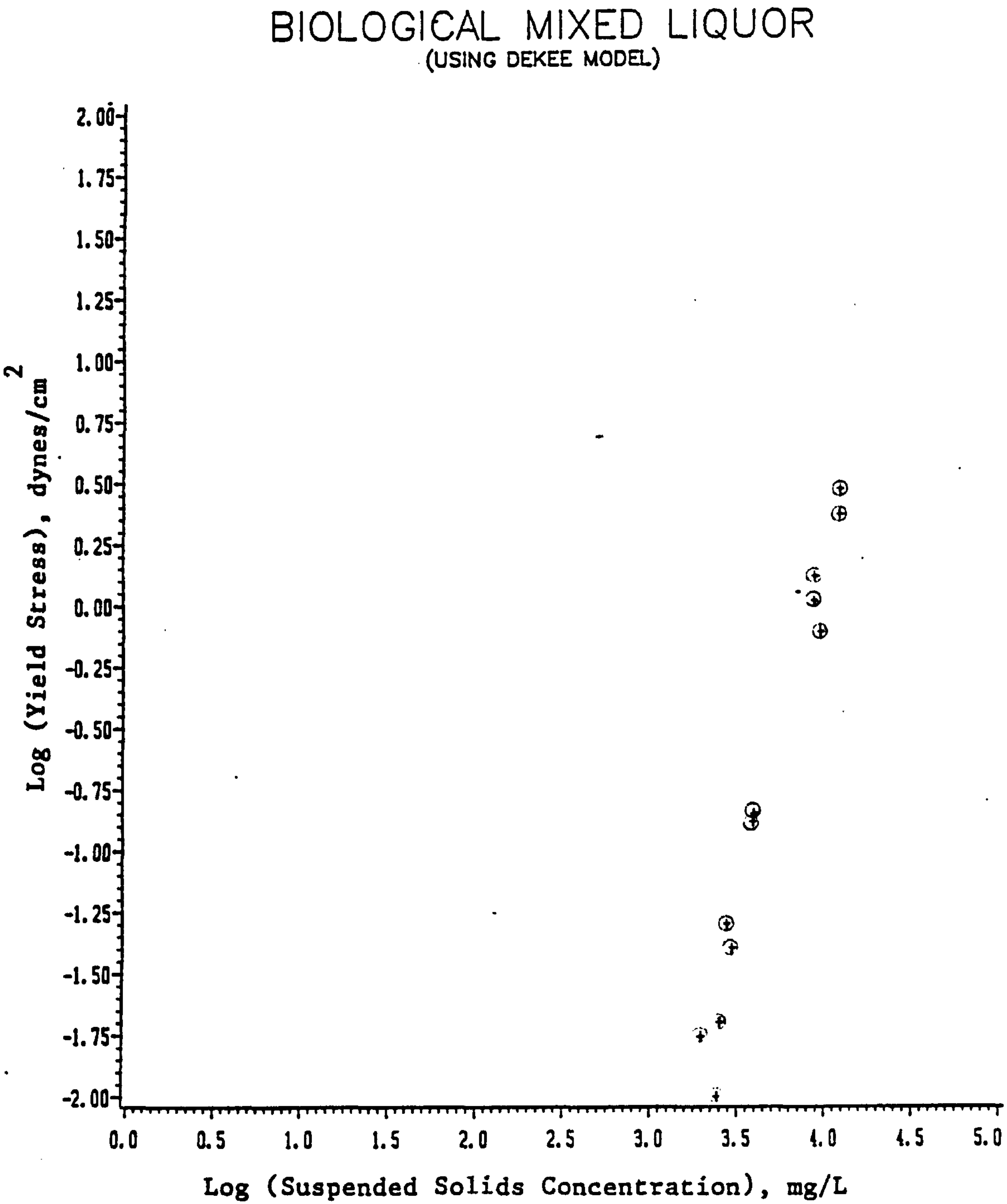


Figure 6.38: Relationship Between Yield Stress and Suspended Solids Concentration for Biological Sludges (Dekee Model)

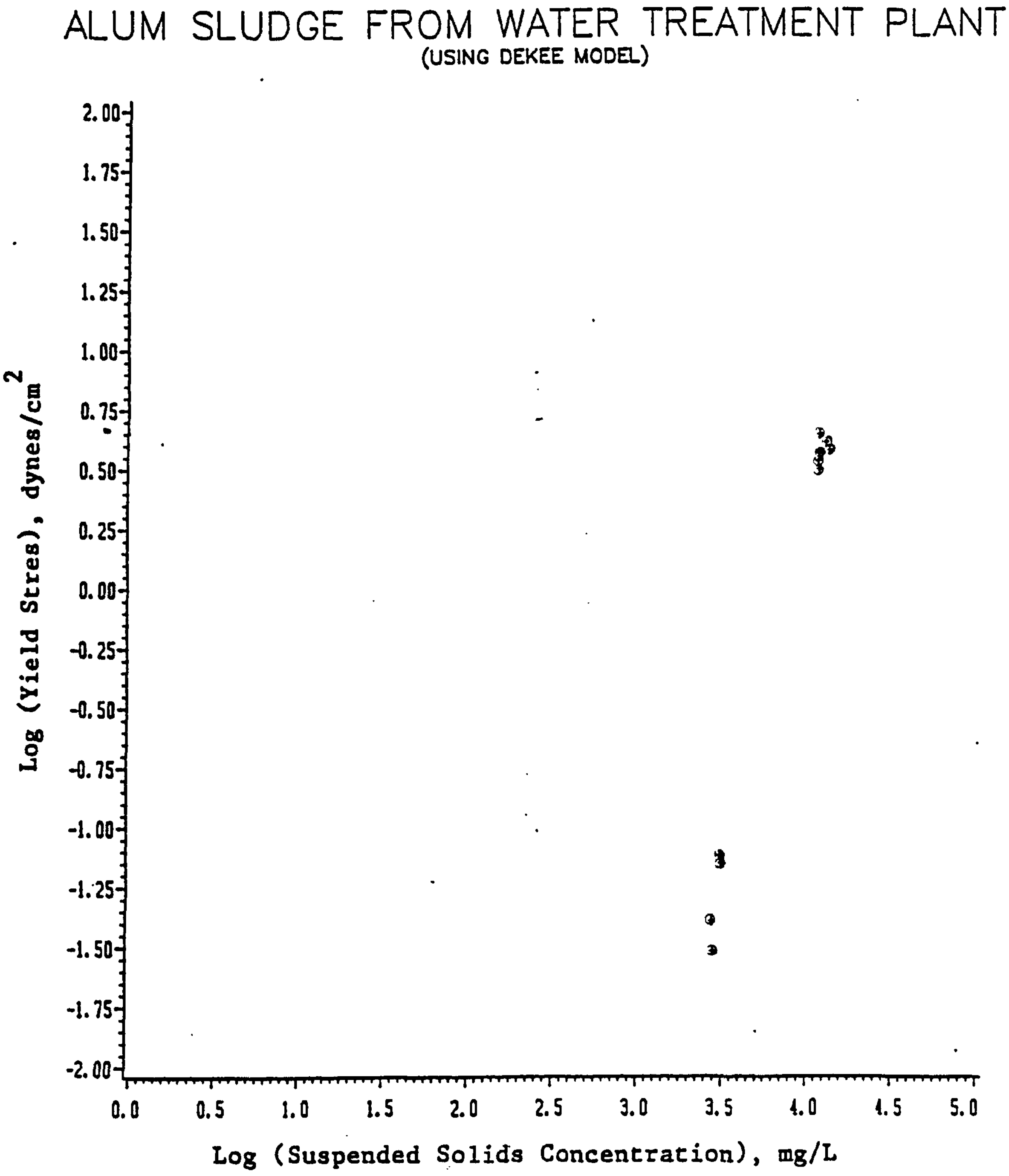


Figure 6.39: Relationship Between Yield Stress and Suspended Solids Concentration for Alum Sludges (Dekee Model)

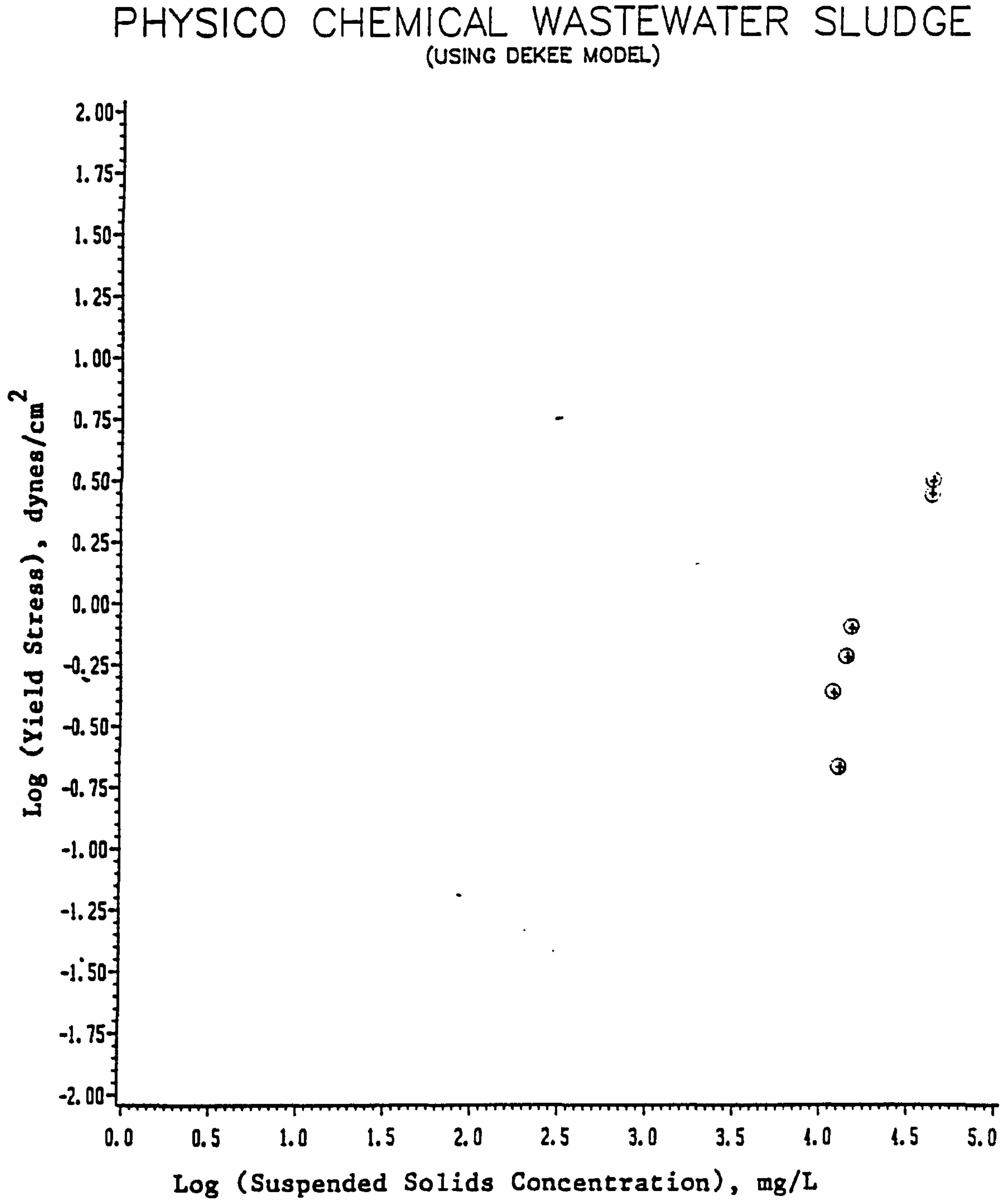


Figure 6.40: Relationship Between Yield Stress and Suspended Solids Concentration for Physico-Chemical Sludges (Dekee Model)

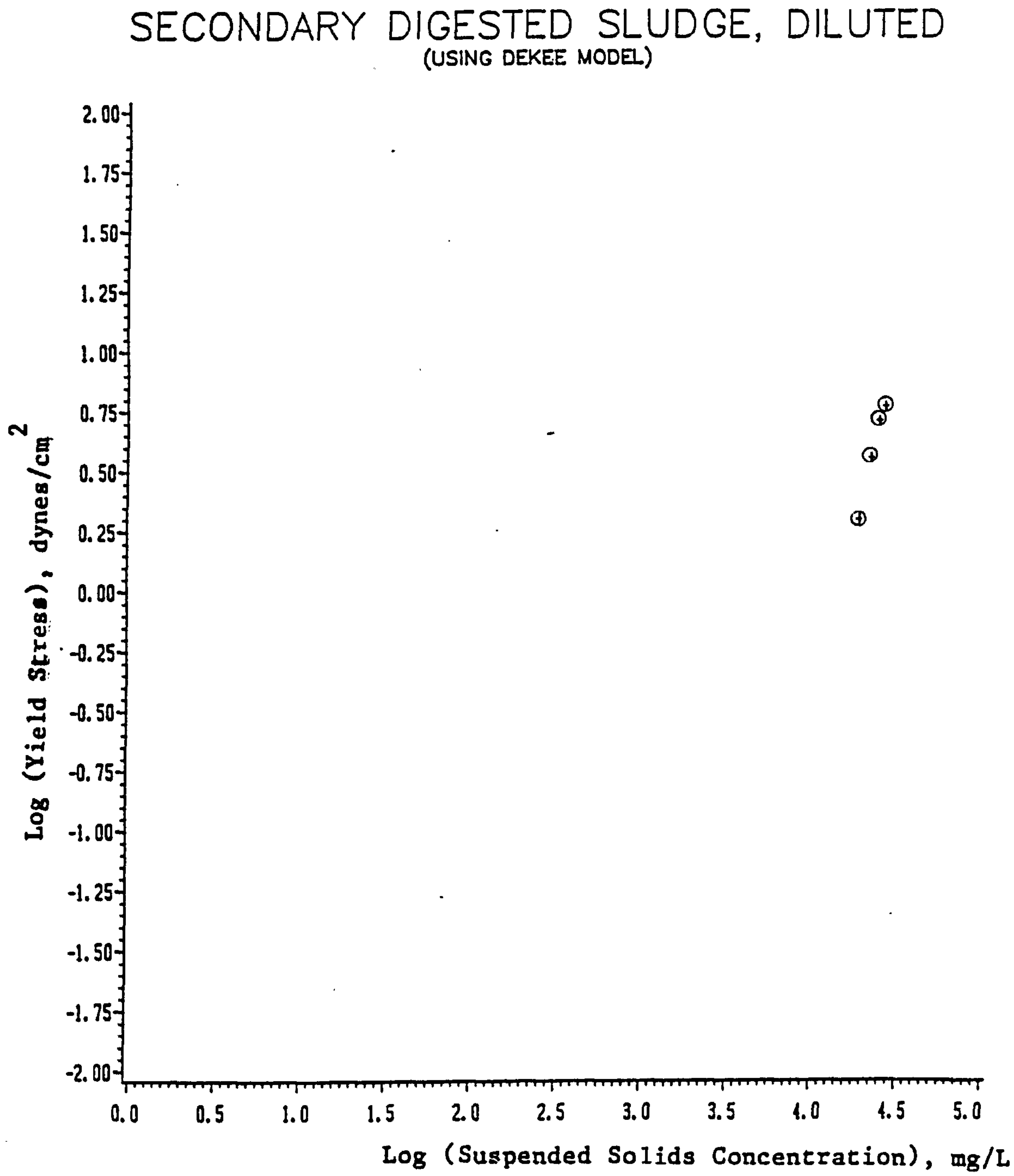


Figure 6.41: Relationship Between Yield Stress and Suspended Solids Concentration for Secondary Digested Sludges (Dekee Model)

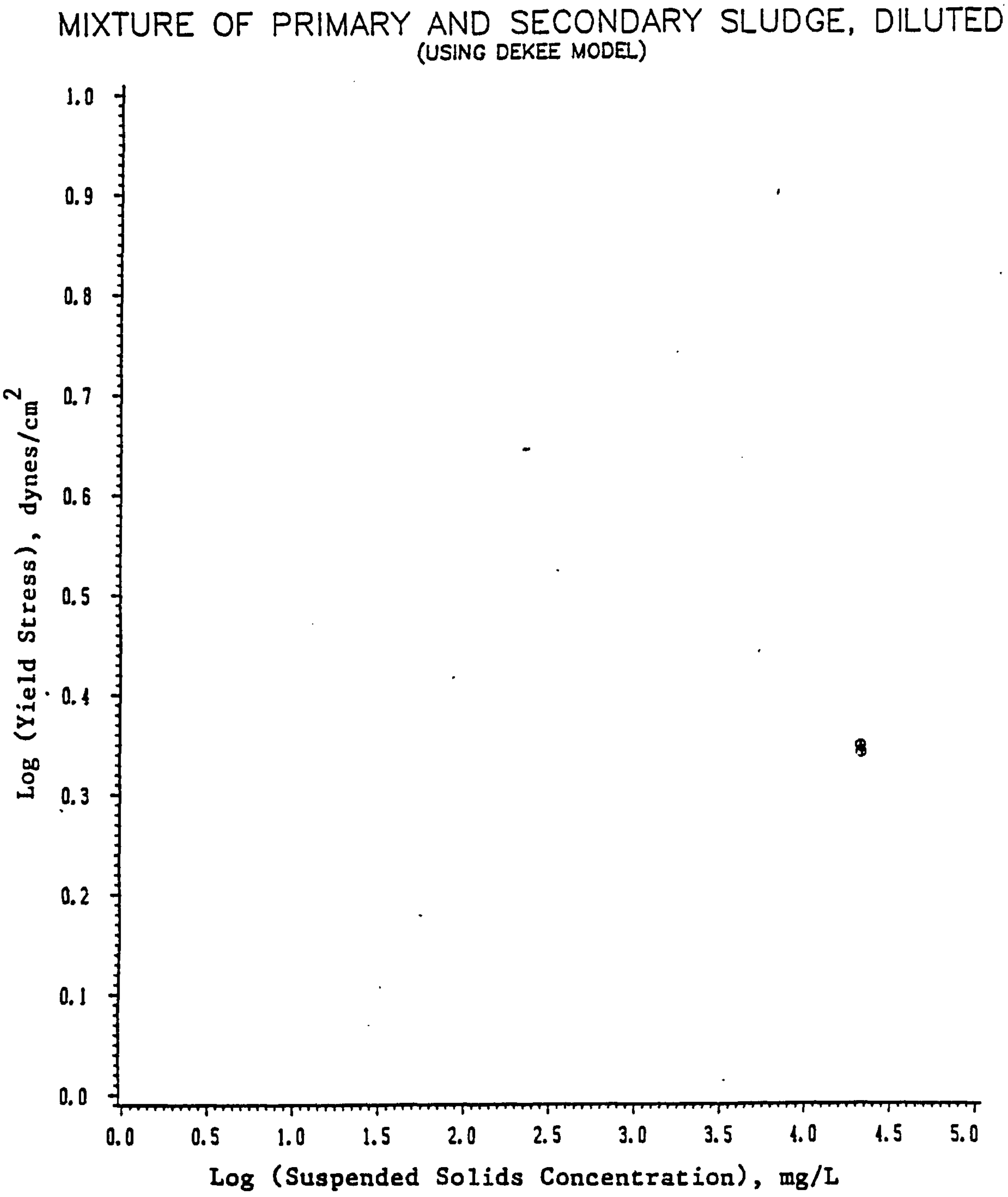


Figure 6.42: Relationship Between Yield Stress and Suspended Solids Concentration for Mixture of Primary and Secondary Sludges (Dekee Model)

Table 6.16. EQUATIONS CORRELATING YIELD STRESS AND SUSPENDED SOLIDS CONCENTRATION

No.	SLUDGE TYPE	GRAPHICAL METHOD	DEKEE MODEL
1	Biological Mixed Liquor	Log (Yield Stress) = 2.9116 Log (SS) - 11.4546	Log (Yield Stress) = 2.9170 Log (SS) - 11.4739
2	Alum Sludge from Water Treatment Plant	Log (Yield Stress) = 2.9922 Log (SS) - 11.6296	Log (Yield Stress) = 2.9704 Log (SS) - 11.5540
3	Physico-Chemical Wastewater Sludge	Log (Yield Stress) = 1.5992 Log (SS) - 6.9124	Log (Yield Stress) = 1.6218 Log (SS) - 7.0284
4	Secondary Digested Sludge	Log (Yield Stress) = 3.2135 Log (SS) - 13.4194	Log (Yield Stress) = 3.1855 Log (SS) - 13.3055
5	Mixture of Primary and Secondary Sludge	Insufficient Data	Insufficient Data

Note: SS = Suspended solid concentration, mg/L
Yield Stress, dynes/cm^2

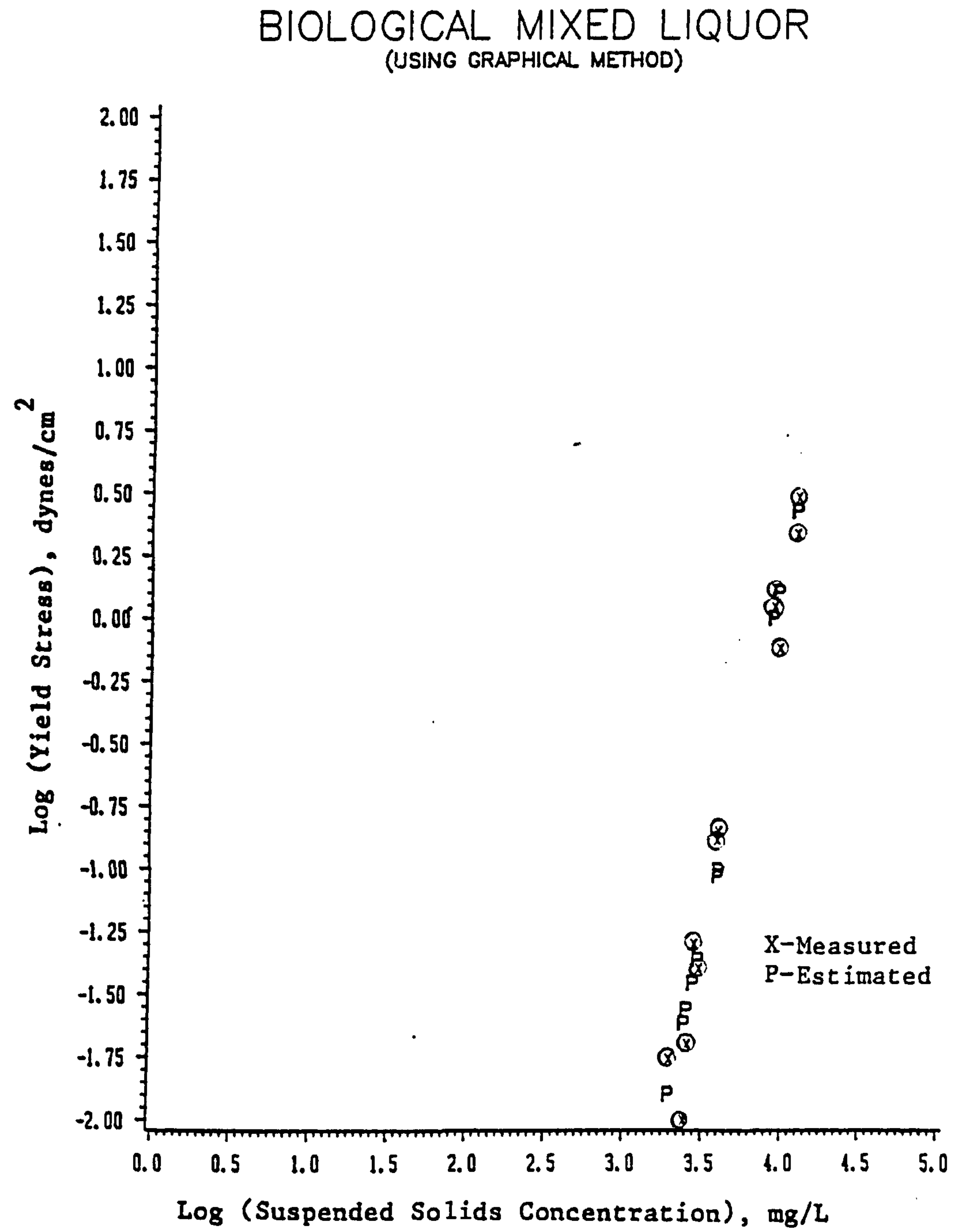


Figure 6.43: Observed Values of Yield Stress By Graphical Method and Estimated Values By Developed Equation for Biological Sludges

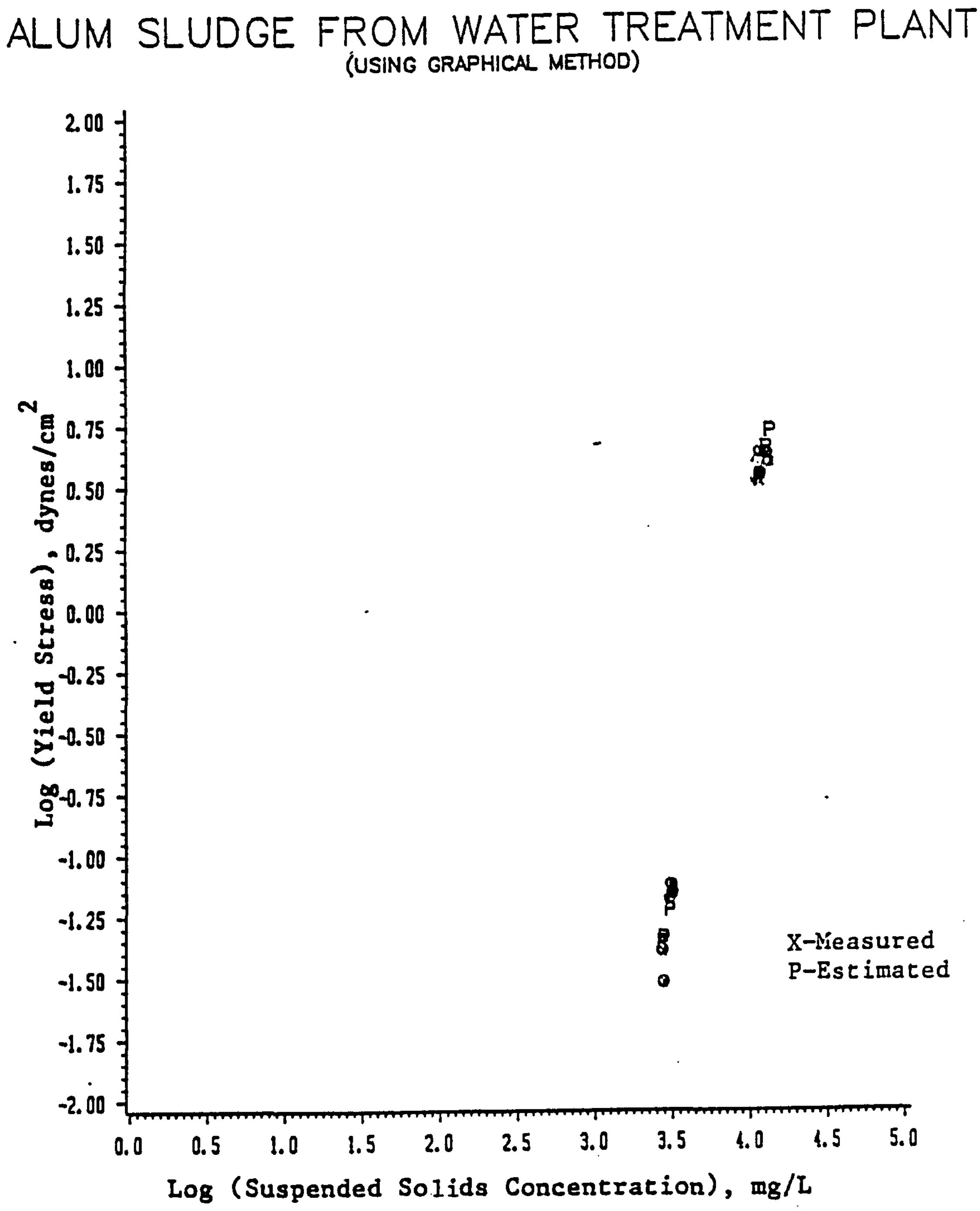


Figure 6.44: Observed Values of Yield Stress By Graphical Method and Estimated Values By Developed Equation for Alum Sludges

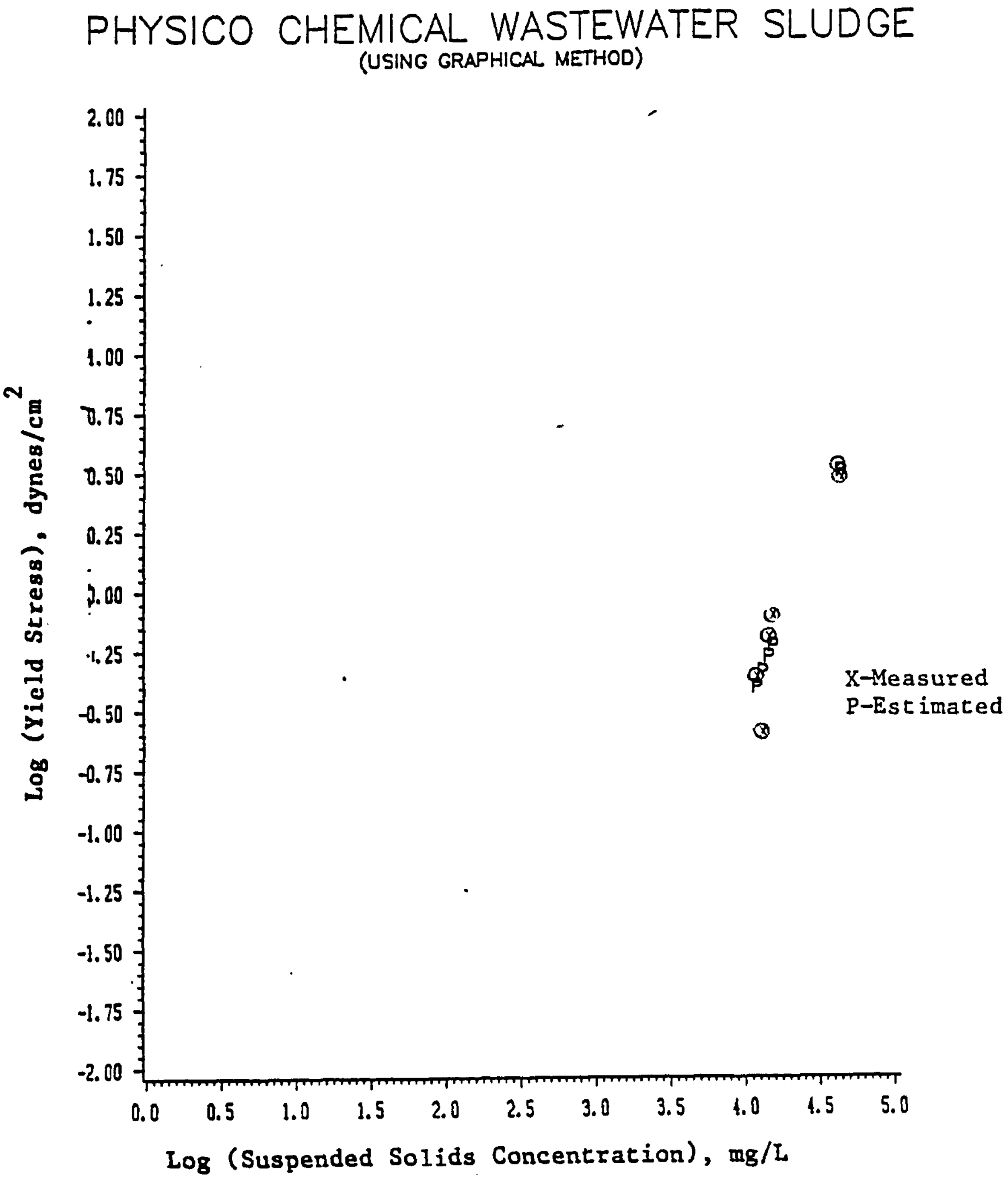


Figure 6.45: Observed Values of Yield Stress By Graphical Method and Estimated Values By Developed Equation for Physico-Chemical Sludges

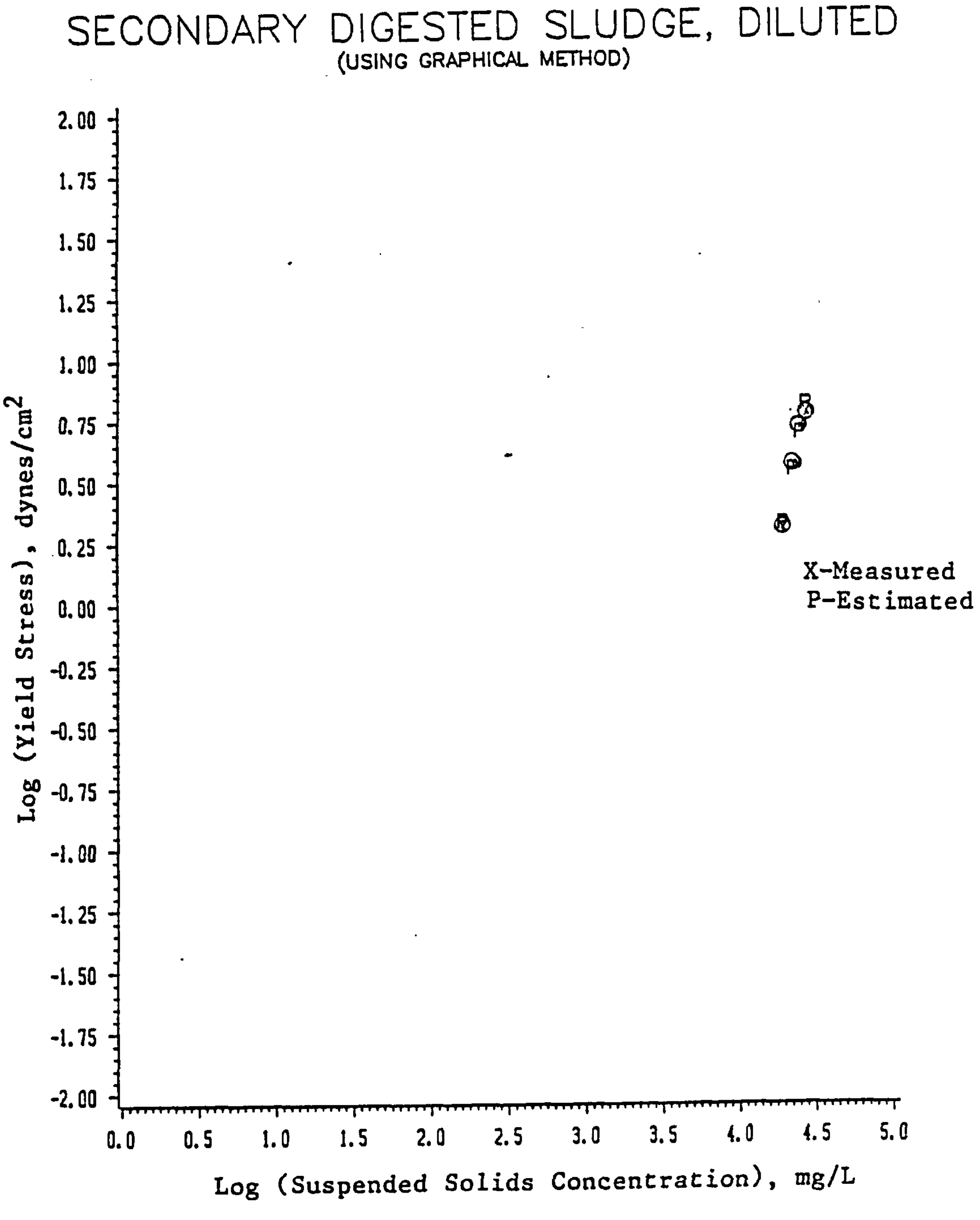


Figure 6.46: Observed Values of Yield Stress By Graphical Method and Estimated Values By Developed Equation for Secondary Digested Sludges

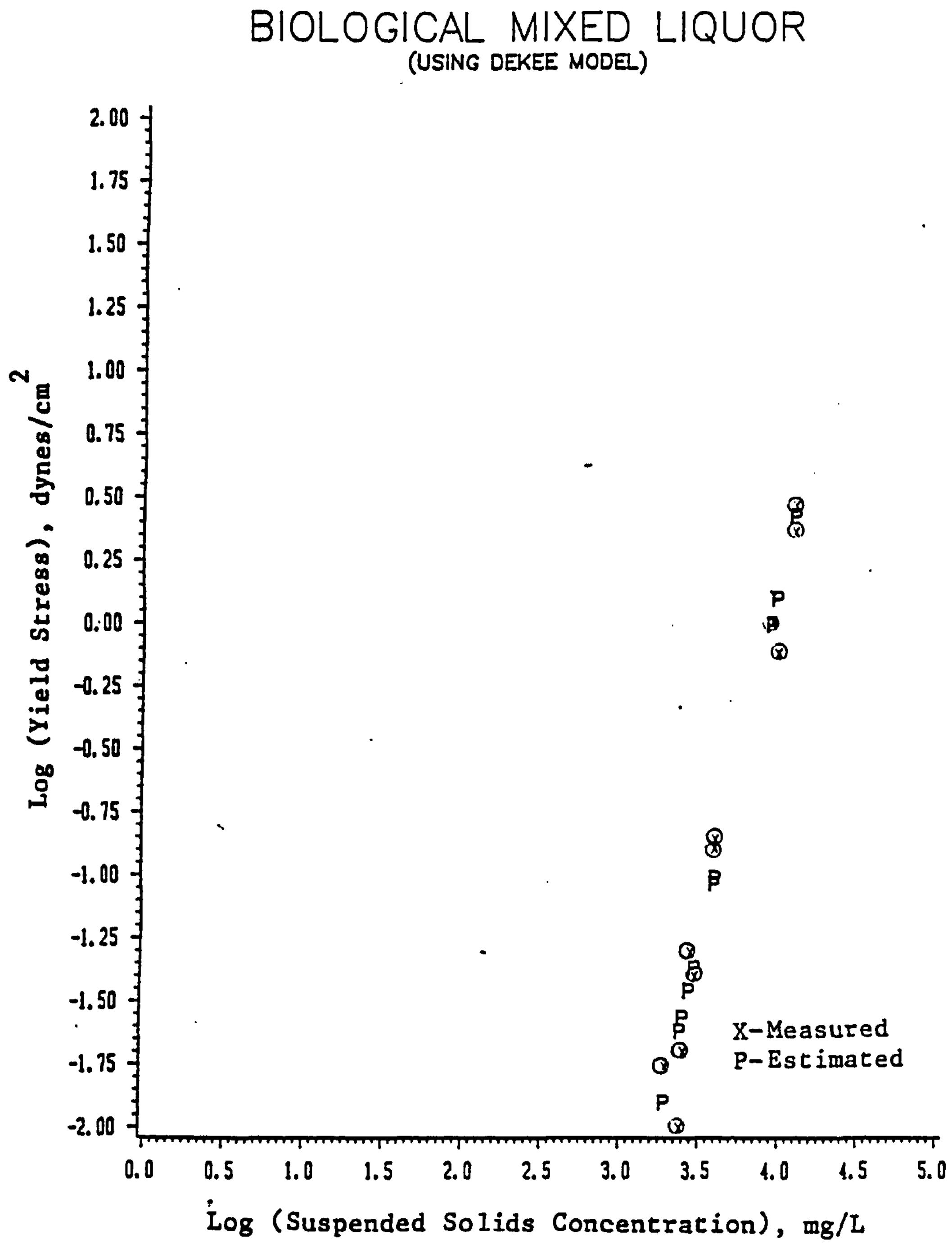


Figure 6.47: Calculated Values of Yield Stress By Dekee Model and Estimated Values By Developed Equation for Biological Sludges

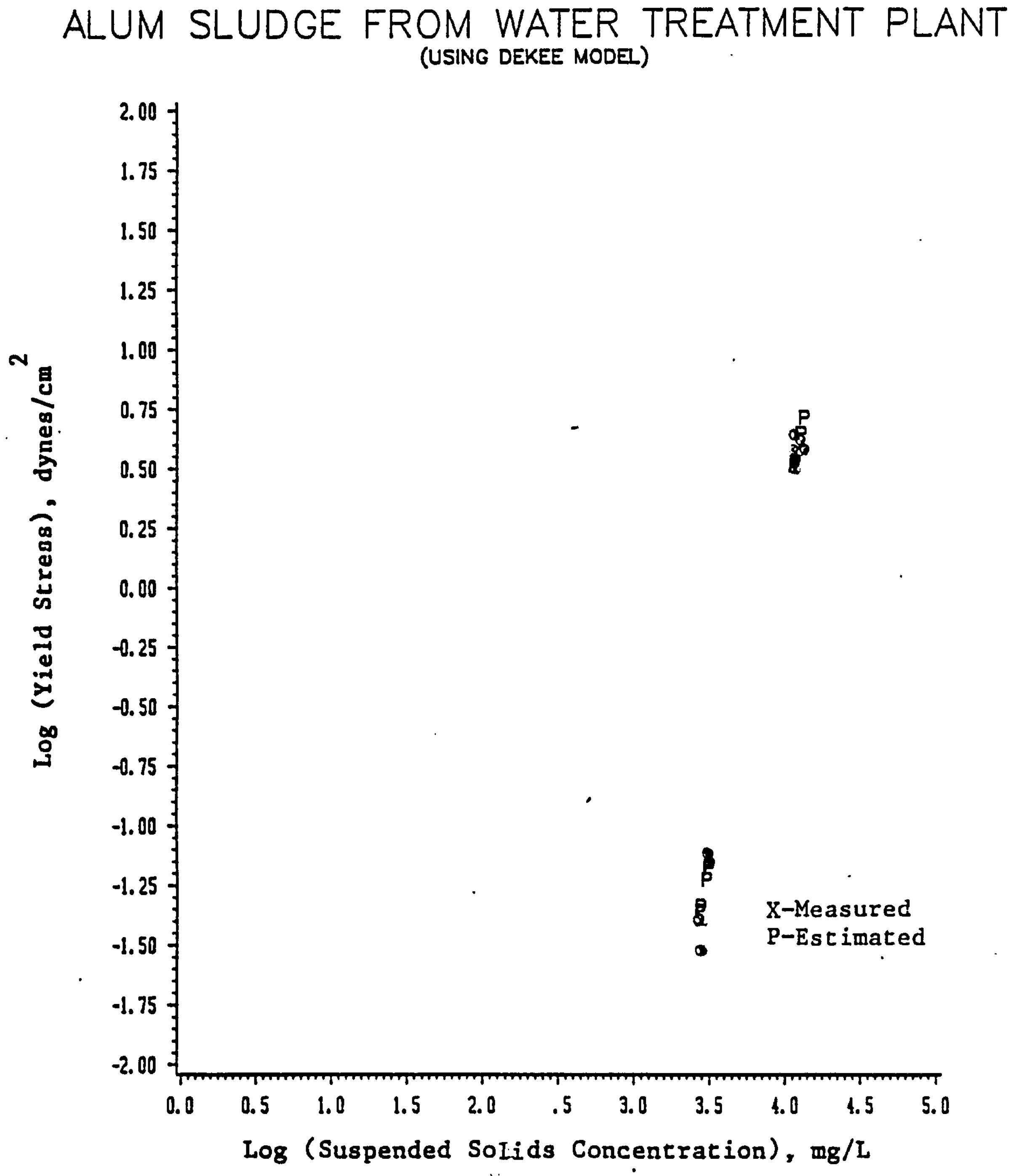


Figure 6.48: Calculated Values of Yield Stress By Dekee Model and Estimated Values By Developed Equation for Alum Sludges

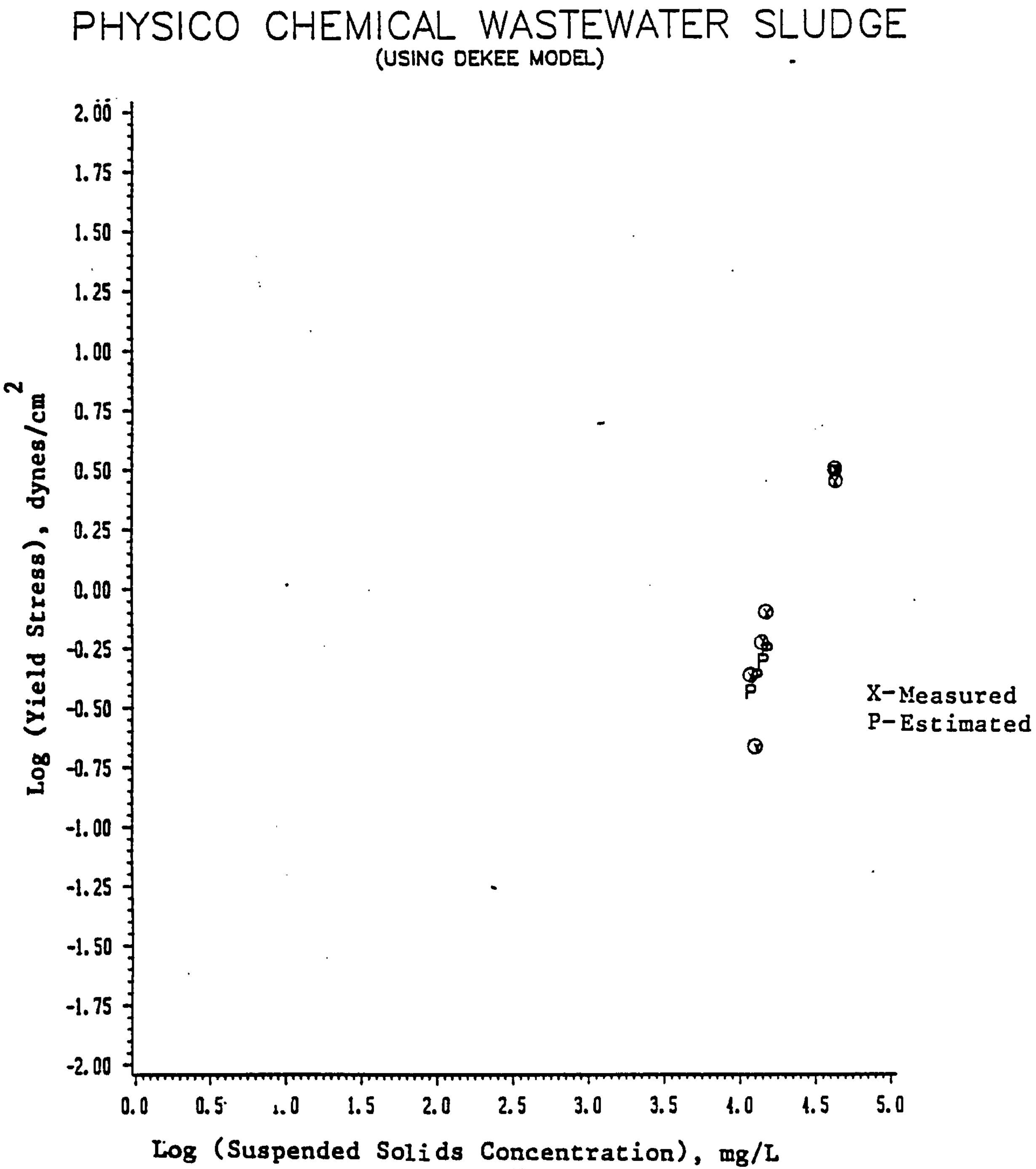


Figure 6.49: Calculated Values of Yield Stress By Dekee Model and Estimated Values By Developed Equation for Physico-Chemical Sludges

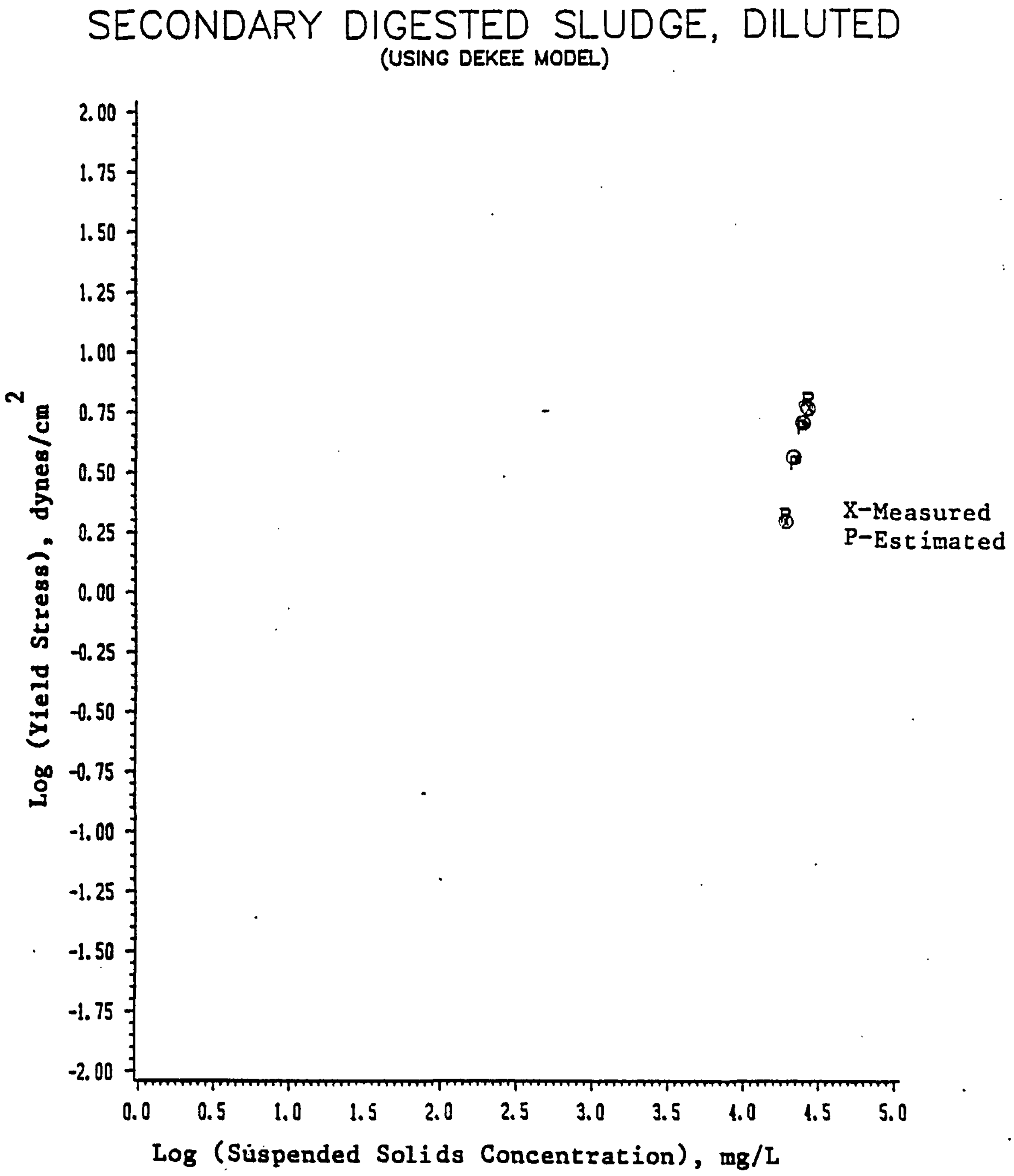


Figure 6.50: Calculated Values of Yield Stress By Dekee Model and Estimated Values By Developed Equation for Secondary Digested Sludges

6.4 Model for Aeration Tank

A model, which optimizes the energy requirement in an aeration tank, was developed by correlating the various parameters which influence the process of mixing and affect the horizontal velocity close to the tank bottom. Experiments were run in a laboratory size aeration tank to identify various parameters. All the experimental data collected during the experiments, calculated parameters and dimensionless factors are shown in the following sections:

6.4.1 Experimental Data

Details of the experimental setup and equipment used to measure different parameters have been provided in the previous chapters.

Experiments were run to measure the horizontal velocities at different points along the water depth during different operating conditions. During the experiment, the length of the tank, L, was kept constant at 0.69 m, whereas the width of the tank, W, was changed to 2.44 m, 2.21 m, 1.98 m, 1.75 m, 1.52 m, 1.29 m and 1.06 m. For each width, the depth of water, H, was changed to 0.50 m, 0.65 m, 0.80 m, 0.95 m and 1.10 m. For each depth of water and each width of the tank, both the submergence of the diffuser and the air flow rate were changed. The velocity profiles obtained for different operating conditions in the aeration tank are tabulated in Appendix C. Since the development of model was based on the horizontal velocity, u, 25 mm above the tank bottom, only these velocity values at different operating conditions are provided in Appendix D.

6.4.2 Rate of Power

The theoretical rate of power, useful rate of power based on isothermal expansion of the air at the outlet or diffuser and useful power based on adiabatic conditions, available at the outlet or diffuser, as described in Chapter 5, were calculated and are summarized in Appendix E. The corresponding air flow rates for standard conditions, STP, and actual operating conditions, are also given in these Tables.

6.4.3 Dimensionless Factors

Different dimensionless factors relating various operating conditions as described in Chapter 5 were calculated for each operating condition separately. The operating conditions for which the dimensionless factors were calculated are summarized in Appendix F, and corresponding dimensionless factors are provided in Appendix G.

6.4.4 Development of Model

In the development of the model the linear regression techniques on were employed as described in Chapter 5. The basic model Eq. 5.58 was in non-linear form; therefore, this equation was linearized first to get the values of the coefficients. The values of different coefficients and constant were obtained using a SAS statistical package called REG. Before the final model was decided to predict the value of horizontal velocity, u, at 25 mm above the aeration tank floor under various operation conditions, different statistical parameters as they are listed below, were considered and then the best model was obtained.

R - SQUARE Value - Coefficient of Determination
F Test Value
PR > F - Significance Probability
T FOR HO: PARAMETER = 0 - Student's t test
PR > |T|

The selected model involving all the five dimensionless factors to predict the horizontal velocity, u, is shown below:

$$F1 = 0.0054 * F2^{0.31} * \left(\frac{F4}{F3}\right)^{2/3} * F5^{1/4} \quad \text{----}[6.2]$$

Chapter VII

DISCUSSION OF RESULTS

The results shown in the previous chapter are discussed in this section.

7.1 Critical Bed Shear

The critical bed shear force on a particle is defined as the minimum shear force necessary for the initiation of particle motion. Since the direct measurement of bed shear force or shear stress is a complex and elaborate procedure, normally it is estimated through other experimental parameters which are simpler to measure. The accuracy of the results depends upon the boundary conditions and the assumptions made during the development of theory. Several procedures have been proposed in the literature to estimate the bed shear stress during critical conditions for the initiation of the motion of particles. In this study, Eqs. 5.6 and 5.7 were used to calculate the critical shear or friction velocity, U_{*c}. After calculating the shear or friction velocity from the laboratory flume data, the critical bed shear stress, τ_{oc}, values were estimated using Eq. 5.5. The point velocity, u, observed close to the bed in the laboratory flume was used as a basic parameter to estimate the values of critical bed shear for different types of particles.

7.1.1 Grit and Gravel Particles

The grit samples were collected from the West Windsor Pollution control Plant, washed several times to remove decomposable organic matter and then dried in an oven. The dried grit was sieved into eight geometric mean sizes, ranging from 0.2121 mm to 2.1817 mm, Table 4.1. In order to widen the scope of this investigation, some larger gravel particles, ranging in size from 3.4 mm to 17.4 mm were also included in these experiments as shown in Table 4.2.

A laboratory flume was used to measure point velocities during critical conditions to initiate the motion of these particles. For these observations, the flow had to be fully developed before any measurements of point velocity were made. The development of flow (boundary layer) was done by covering the bed of the flume by the same size of the particles used for the experiment, except a 0.65 m long stretch at the middle of the flume was left smooth to observe the movement of particles. The accuracy of the critical bed shear stress value depends on how close to the bed is the point velocity measured. Due to the restrictions imposed by the velocity meters, point velocities closer than 7.6 mm above the flume bed were not measured.

A grit chamber resembles closely in shape and hydraulic characteristics to typical channels used in hydraulics engineering. Therefore, the equations developed for open channels can also be applied in the study of grit chambers.

The current design practice of gravity type grit chambers is generally based upon the concept of a discrete particle settling under ideal conditions - assuming that all particles settle in accord with Newton's Law, liquid velocity is the same in all parts of the chamber, and there are no eddies [18]. However, in an actual chamber the velocity is not uniform and there are eddies present due to turbulence which retard settling. An increase in chamber velocity increases the scour of the settled material. Therefore, it is the scouring process and not the settling process which determines the design flow velocity for grit chamber. Using the Shields' findings of the scouring of bed material, Camp [18] came up with a relationship as shown in Eq. 2.1. Camp also proposed the use of parabolic channel. It is apparent from Eq. 2.1 for scour velocity that the depth of flow in the channel has no influence on the critical mean velocity. This is not quite true because, even if the mean velocity of flow in a channel remains the same for different depths of flow, the velocity profile still changes with depth. Consequently, the scouring velocity on the channel bed is influenced by the depth of flow. Therefore, it is not justified to ignore the influence of flow depth in the grit chamber design while calculating the critical scouring velocity. For example, two different channels may have flat beds of identical particles and therefore will require the same bed shear stress to move the particles. Assuming a similar velocity distribution profile, the velocities at any given distance above the bed should also be the same in these two channels. However, since the mean velocity occurs at y equal to a constant fraction of the depth, Eq. 5.17, the deeper flow depth will have a higher mean velocity.

A new approach has been suggested to design a grit chamber using the concept of critical shear stress rather than a critical mean velocity. The advantage of using shear stress to specify the critical scouring conditions is that only one quantity is enough, whereas if mean velocity is used, one must also consider the depth of flow and location along the depth at which the mean velocity is observed or computed.

The observed mean values of point velocity, u, at 7.6 mm above the bed for critical conditions are shown in Table 6.1 These values are the average of data obtained at two locations in the flume, A and B, as shown in Figure 3.1. The calculated critical shear velocities, U_{*c}, and corresponding particle Reynolds number, regime of flow for different sizes of grit and gravel particles are also shown in Table 6.1. The particle sizes and corresponding values of critical bed shear stress are shown in Table 6.2. The particle sizes and the corresponding values of shear stress are plotted on Log-Log scale in Figure 6.4. This plot shows that in the hydraulically smooth flow regime, particle Reynolds number, $U_{*}k_{s}/\nu \leqq 5$ the influence of fluid viscosity is predominant and the curve is a straight line. It means that the particles of sizes 0.4 mm or smaller will keep the flow hydraulically smooth. However, for rough turbulent flow conditions, particle Reynolds number, $U_{*}k_{s}/\nu \geqq 70$, the influence of bed roughness becomes more significant. During this regime of flow, the plot between particle sizes and corresponding shear stress values becomes curvilinear, and the influence of viscosity on the value of critical shear stress is negligible. The shape factor for the grit and gravel particles also had an effect on the nature of relationship in the turbulent region. It has been reported [10] that the influence of shape factor on the drag coefficient increases with an increasing Reynolds number. In the transitional state, $5 \leqq U_{*}k_{s}/\nu \leqq 70$, the influence of both viscosity and roughness are dominating the shear stress and the plot changes from a straight line to a curve. This plot can be used directly in finding the critical bed shear stress required to initiate the motion of any size of grit particle within specified conditions. This will also indicate the regime of flow in a channel whose bed is made up of uniform size of grit or gravel particles.

The best fit equation, Eq. 6.1, developed for the plot between particle sizes and corresponding values of shear stress was tested for different statistical parameters as discussed in Section 6.1. The value of most important statistical parameter, i.e. coefficient of determination for this equation was 0.994. This implies that 99.4% of the variation in critical shear stress is accounted by the model. The values of the other statistical parameters as discussed in Chapter 6 were also favourable.

Substantial amount of work on the relationship between particle size and critical shear has been done in the field of hydraulics engineering, but most of the work is applicable to river channels [55,91] and packed bed laboratory flumes [81]. The two popular curves for critical bed shear were given by U.S.B.R. [91] and Shields [81]. The critical bed shear values obtained from these curves are higher than those obtained in this investigation. The data reported in Table 6.2 and Figure 6.4 are for the operating conditions normally encountered in grit chambers i.e., a bed made up of scattered grit particles. In a typical grit chamber, the accumulation of grit particles is not permitted. Therefore, the grit chamber bed can neither be considered as a packed bed as used by Shields nor as a river channel or canal with a higher content of fine sediment as used by U.S.B.R. and Lane [54,55].

7.1.2 Sludge Particles

Some units in the treatment of water and wastewaters are designed to keep all the particles in suspension, whereas some other units are designed to allow the settling of these particles. For example, aeration tanks, flocculation chambers and mixing chambers are designed to keep all the particles in suspension all the time. On the other hand, settling tanks are designed to allow the settling of all settleable particles. Similarly grit chambers are designed to allow the removal of heavy inert particles keeping all the decomposable organic particles in suspension.

The experiments with sludge particles were conducted to determine the critical bed shear stress, τ_{oc}, required to initiate the motion of settled particles in treatment units. Different types of sludge samples were collected both from water and wastewater treatment plants as shown in Table 4.3. Those sludge samples, which were not settled when collected, were allowed to settle for 3 to 4 hours and the settled sludge was used in the flume to run the scouring experiments. The settled sludge was more representative of the actual field conditions, because it is the settled sludge particles that have to be moved in a treatment unit or mixing chamber.

With a very low velocity of flow in the flume, the sludge flocs were poured and uniformly spreaded over the flume bed. Then the velocity of flow was increased slowly till the settled sludge started scouring. During this critical condition of the motion of sludge particles, the velocity profiles were obtained along the depth of flow at two locations, A and B, Figure 3.1, along the length of the flume. The horizontal point velocity, u, 7.6 mm above the bed, was used as the basic parameter to estimate the value of critical bed shear stress for different types of sludge samples. Due to the restrictions imposed by the velocity meters, the point velocity any closer to the bed could not be measured. This point velocity, u, was used in Eq. 5.6 to obtain the critical shear or friction velocity, U_{*c}. Then Eq. 5.5 was used to estimate the critical bed shear stress value. All the estimated critical shear stress values are shown in Table 6.3, for different types of sludge samples analyzed. In most of the treatment units and mixing chambers, except sedimentation tanks, the particles are not allowed to settle, if the units are designed properly. Therefore, it is reasonable to assume that the bed of such treatment unit is smooth.

Once the sludge particles had settled down in the flume, the thickness of the layer on the bed did not seem to make a significant difference in the value of critical bed shear stress. The top layer of the sludge scoured first, followed by the next layer and eventually all the sludge particles were in suspension. The physical characteristics of the sludge particles, such as floc strength, are expected to, but not significantly, influence the critical shear stress.

The critical shear stress value for a given sludge indicates the minimum bed shear stress necessary that must be provided in the treatment unit in which the settling of similar particles is not permitted. The horizontal velocity close to the bed will have to be kept higher than the velocity needed to achieve the critical shear stress.

7.2 Yield Stress of Sludges

It has been long recognized, also confirmed in this investigation, that the sludge samples behave more closely to the non-Newtonian fluid than to the Newtonian. Therefore, all the sludge samples were treated as non-Newtonian fluids.

The yield stress, τ_y, is defined as the stress which must be exceeded before any flow starts. A fluid or suspension at rest contains a three dimensional structure of sufficient rigidity to resist any stress less than the yield stress, τ_y. For Bingham plastic fluids, if this stress is exceeded, the structure completely disintegrates and the system behaves as a Newtonian fluid due to a shear stress, $\tau - \tau_y$. It is therefore suggested that the maximum shear allowed in the aeration tank or in any other unit, where the shearing of the flocs or particles is unwanted, should always be less than yield stress value for that suspension. If the applied shear through diffused aeration, mechanical aeration or other means exceeds the yield stress, then the floc or particles would start shearing. The settling properties of the particles will deteriorate and the removal efficiency of these flocs or particles in settling units will decrease.

Yield stress values for different sludges were obtained with Brookfield Viscometer as described in Chapters 5 and 6 and presented in Tables 6.4 - 6.8. Flow curves for different sludge samples, Figs. 6.7 - 6.22, were found to represent characteristics of different types of sludges. The observed behaviour of different types of sludges are shown in Table 6.15.

Babbitt and Caldwell [12,13], Behn [14], Bokil and Bewtra [15] and Dick [24,25] have shown sludges to behave as Bingham plastic fluid. However the results obtained in this study were different. For mixed liquor and alum sludge (water treatment plant) the flow curves were close to Bingham plastic fluids. But when these samples were allowed to settle and analyzed again, they behaved like pseudoplastic fluids with certain yield stress. The physico chemical sludge (wastewater treatment plant) collected from the secondary clarifier behaved altogether differently. At low concentrations, the flow curves were similar to those for dilatant fluids without any yield stress. When these samples were allowed to settle and settled sludge was analyzed, the flow curves became similar to those for pseudoplastic fluids with certain yield stress. When the physico-chemical sludge was collected from the underdrains which take the sludge to the dewatering facility for the same plant and diluted, it also behaved close to dilatant fluid without any yield stress, whereas the same sludge in concentrated form behaved as pseudoplastic fluid with a yield stress value. Other sludges such as secondary digested sludge, mixture of primary and secondary sludges, also behaved as pseudoplastic fluids with yield stress values. Therefore, it can be said that the behaviour of sludges changes with the concentration of suspended solids and the physical state of the sample, suspended or settled. Suspended sludge samples do behave more closely to the Bingham plastic fluids as found by other researchers also, but the behaviour of settled sludge changes to pseudoplastic fluid with a certain yield stress.

The change in the behaviour of sludge samples with suspended solids concentration may be due to the flocculent nature of the solid particles. Dilute concentrations of sludge particles disrupt fluid stream lines and increase the viscosity without imparting non-Newtonian behaviour. As the concentration of the solid phase increases, an opportunity for more complex rheological behaviour exists. Not only do particle-liquid interactions exist, but also, particle-particle interactions and particle deformation can occur. A pronounced change in rheological behaviour takes place when the volumetric concentration of solids increases to the extent that a continuous solid phase can exist. Now instead of deforming continuously in response to an applied stress, the suspension can resist deformation until sufficient stress is applied to exceed the yield strength of the solid phase. Then the suspension assumes properties more like a fluid. In case of lower concentration of suspended solids, a weak continuous solid phase did seem to exist, which resulted in Bingham plastic type fluid behaviour. However, in higher concentration of suspended solids in different sludges, particle-particle interaction resulted in a pronounced change in behaviour of sludge samples and they exihibited pseudoplastic behaviour with a yield stress value. However, the behaviour of sludge makes no difference in the value of yield stress, which is the most important design parameter for different treatment units.

7.2.1 Relationship Between Yield Stress and Suspended Solids Concentration

When log(suspended solids concentration) and corresponding log(yield stress) values were plotted, they showed a straight line relationship, Figs. 6.33 - 6.37 . This relationship was true with all types of sludge samples analyzed. Therefore, these plots can be used directly to obtain the value of yield stress at different suspended solids concentration. It is shown in Figs. 6.7 - 6.22, the behaviour and flow curve of sludges may be different at different suspended solids concentrations, but the yield stress values do not change with the behaviour.

Equations correlating the log(yield stress) and log(suspended solids concentration) also have been developed using linear regression technique, Table 6.16. These equations were tested for different statistical parameters for reliability of the model. The most important parameter during the evaluation of the model was the R-SQUARE, the coefficient of determination. For all the correlations, this value varied between 0.88 and 0.99, i.e., 88% to 99% of variations in yield stress are accounted by the selected models. Other statistical parameters as mentioned in Chapter 6 also had favourable values.

Yield stress values were obtained using both graphical method and Dekee model as discussed in Chapters 5 and 6. The set of equations developed using graphical method was considered more reliable than the set of equations developed using the yield stress values obtained by Dekee model. The reason is that the yield stress obtained with Dekee model would be only as good as the basic experimental data used in the model, whereas in the graphical method, one can see the change in the behaviour of fluids and any experimental error can be visualised. However, when only limited data are available and a good flow curve is difficult to obtain, then the use of Dekee model may be appropriate. It is recommended to check the values of yield stress obtained using graphical method with Dekee model.

The plots between log(yield stress) and log(suspended solids concentration) also give the critical suspended solids concentration at which the yield stress value can be considered as negligible, below the accuracy of measurement.

7.3 Model for Aeration Tank

It is a common practice in the operation of aeration tanks to maintain a certain minimum dissolved oxygen all the time. However, the minimum velocity requirements in the aeration tank to keep the biological flocs in suspension have not been given much consideration. The operating parameters which influence the velocity profiles in the aeration tanks have also not been fully investigated.

In this study, the important controlling parameters in the operation of aeration tanks to maintain a required horizontal velocity were investigated. Experiments were run in the laboratory size aeration tank under different operating conditions and the data were used to develop a dimensionless model using a linear regression technique. Statistical analysis was carried out to select the best model to predict the horizontal velocity close to the tank's floor under different operating conditions.

The details about the experimental setup, instrumentation, operating parameters, raw data and the dimensionless factors have been provided in Chapters 3, 4, 5 and 6. The parameters which can influence the velocity, u, in the tank are shown below:

a. rate of power consumption
b. tank length (along the diffusers)
c. tank width
d. water depth in the tank
e. depth of water above the diffusers (submergence)
f. distance of the diffusers from the side wall of the tank

The above mentioned parameters, except the length of the tank, were varied during the experiments and the horizontal point velocity, u, along the depth of water in the tank at mid-width was measured for each operating condition. The rate of power consumption was varied by changing the air flow rate and diffuser submergence. The processed data are shown in Appendix B. These data were converted into dimensionless factors as explained in Chapter 5. A dimensional analysis was performed to establish a relationship between different dimensionless factors, Eq. 5.51. The dimensionless factor involving the horizontal velocity, u, was considered as a dependent variable and other factors which influence the velocity were considered as independent variables.

Surface tension played an insignificant role in the experimental aeration tank due to its size. Surface tension is important in the formation and movement of bubbles in liquid. However, in this dimensional analysis , the details of air bubbles in the aeration tank was not considered. Therefore, the effect of surface tension on this analysis was neglected.

During the process of analyzing Eq. 5.51 critically, a few modifications were made in Eq. 5.51 to make this model more effective and reliable in predicting the velocities under different operating conditions. The length factor term was dropped from Eq. 5.51, because length of the tank (0.69 m) was not changed during the experiments. Since the diffusers are conventionally placed along the length of the aeration tank, the length of the tank makes no significant difference in the spiral motion of the liquid and the velocity. Also, the dimensionless factor involving the distance of diffusers from the side wall of the tank, X, was dropped from Eq. 5.51, because it was noticed during the analysis of data, that a small change in X made no significant difference in the velocity, u. Statistical analysis also showed that this factor made no significant contribution to the model for predicting velocity. In order to determine the effect of water depth, H, directly, this term was changed in the form of H instead of H% in depth factor. The final equation, Eq. 5.52, after making above modifications contains five instead of seven factors.

7.3.1 Calculation of Dimensionless Factors

The calculations for all dimensionless factors except the power factor, are straight forward. In calculating the power factor, values for rate of power. were obtained by using different assumptions. These power factor values are summarized in Appendix E.

When the compressed air is discharged into the tank through the diffusers, the frictional losses in the pipes, fittings, instrumentation, compressor etc. add to the power requirement. This loss of power is variable and depends on individual layout. In order to neglect the effect of these variable power losses in delivery system and compressor, the actual power available at the outlet was used for further calculations. The values of power obtained using Eqs. 5.54 and 5.55 are very close to each other, Appendix E. The small difference in their values is due to different assumptions made in deriving these equations. Eq. 5.54 was derived based on the assumption of isothermal expansion of the air whereas Eq. 5.55 was derived on the assumption of adiabatic conditions.

For the calculation of useful power available at the outlet or diffusers, the actual air flow rate was used to obtain the air flow rate under standard conditions, Eqs. 5.56 and 5.57.. This air flow rate takes into account the change in the density of air in the rotameter and piping due to outlet conditions.

7.3.2 Determination of Coefficients for Model Equation

The derived model, Eq. 5.52, is in non-linear form and it was linearized by taking log of both sides, Eq. 5.59. The values of unknown coefficients such as f, A, B, D and J were determined by applying a linear regression technique [41]. Various possible combinations were evaluated to obtain the best fit model for predicting the horizontal velocity, u, at 25 mm above the tank floor, under different operating conditions. These analyses included the independent variables individually or their different combinations. The evaluation was done in terms of various statistical parameters shown in Chapter 6. The selected best fit model is shown in Eq. 6.2. The values of test statistical parameters and their importance in predicting the horizontal velocity, u, close to the bed are discussed below:

R SQUARE: This statistical parameter predicts how well a multiple regression model fits a set of data. The value of R% for the selected model was 0.96. This implies that 96% of the variations in velocity, u, about their mean are accounted for by the model. The value of R^2 can range between 0 and 1 and the larger the value the better the model fit.

Sometimes R^2 is not considered a dependable test for the adequacy of the model. For example, R^2 will be equal to 1 when the number of terms in the model is equal to the number of data points or observations.

F Test: The F test value predicts how well the model contributed information in predicting horizontal velocity, u, i.e it tests how well the model as a whole accounts for the dependent variable's behaviour.

The computed F value of the model is compared with statistical $F_{0.05}$ value

Rejection region for null hypothesis (L = 0.05),

$F > F_{0.05}$

Total number of data, n = 819

Degree of freedom, $k = v_1 = 3$

$v_2 = n-(k+1) = 815$

For L = 0.05, $F_{0.05} = 2.60$

F value of model = 6052.97

Therefore, $F >> F_{0.05}$

It indicates that the null hypothesis has been rejected and at least one of the coefficient is nonzero. It means that the selected model did contribute significantly in predicting the horizontal velocity, u. F test is considered to be a more reliable test for evaluating the adequacy of the model. In final selection of the model the use of both tests is recommended.

PR > F: The significance probability labelled as PR > F was 0.0001 for the selected model, which is a very small number. It signified that the probability of getting a greater F statistic than that observed in the model was very low. In other words it indicats that the contribution of the model in predicting the value of independent variable was significant.

T FOR HO: PARAMETER=0: After confirming that the model was useful in predicting the value of dependent variable, F1, it was decided to make inferences about particular independent variables that have practical significance. A test of this hypothesis was performed using a Student's t test. The 't' statistic for testing the null hypothesis that the true coefficients are equal to zero appear under column headed 'T FOR HO: PARAMETER=0'. The 't' values for various terms in the model were compared with the values obtained in the rejection region for a two tailed test with L=0.05.

Rejection Region

$$t < -t_{L/2,\ n-(k+1)}$$

$$t > t_{L/2,\ n-(k+1)}$$

Where $n = 819$ = number of observations

$k = 3$ = number of coefficients in the model, excluding intercept

Values of 't' obtained for the selected model are listed below:

Term	't' Value	't' for Rejection
Intercept	-25.302	-1.960
F2	52.387	1.960
F4/F3	88.446	1.960
F5	14.667	1.960

All the 't' values obtained for the model are outside the 't' values for the rejection of hypothesis. Therefore, it s concluded that all the parameters are contributing significantly in predicting the dependent parameter F1.

PROB > |T|: The two tailed significance levels for each 't' values are listed under the column headed PR > |T|. The values of this parameter express the probability that a 't' statistic would obtain a greater absolute value than that observed in the model, given that the true parameter is zero. Thus a very small value of this probability indicates that the value of the parameter is not likely to equal zero and therefore the independent variable contributes significantly to the model. In the selected model, it was found for all the independent variables PR > |T| values were 0.0001. Therefore it is concluded that all the independent variables used in the model contributed significantly to the model.

The model was also tested after including dimensionless factor, X/H, Eq. 5.51. It was found that the value of PR > |T| was very high. Therefore, it reinforces the reason of elimination of this factor from the model.

7.3.3 Physical Evaluation of the Model

In this section the critical analysis of the model, Eq. 6.2, has been carried out to determine the physical justification of the equation, i.e. if the relationship between the dependent variable and the independent variables is acceptable in actual opertion of the aeration tank.

Eq. 6.2 shows that the dependent dimensionless factor, F1, increases when the independent dimensionless factor, F2 increases. Factor F2, is the power factor, and it is quite obvious that when more power is put into the system, keeping all other operating conditions same, the horizontal velocity close to the tank's floor will increase. The power input to the system, aeration tank, can be increased by increasing air flow rate and diffuser submergence.

The dimensionless factor, F1, decreases with an increase in the dimensionless factor, F3, the width factor. The larger the width of the aeration tank, the smaller will be the horizontal velocity. The fluid motion in diffused aeration tanks is spiral, Fig. 2.1. Therefore, the bigger is the size of the spiral loop for the same operating conditions, larger will be the energy losses and lower will be the velocities.

The velocity factor, F1, increases with an increase in the depth factor, F4. In depth factor, only the water depth in the aeration tank was varied and other parameters were kept constant. As the depth of water in the tank increases, the horizontal velocity close to the tank bottom also increases for the same operating conditions. It has been observed that in deeper water, diffused air bubbles tend to stay longer, which allows these air bubbles to transfer more energy to the water. This transfer or dissipation of energy eventually results in higher water velocity. It is also true that longer the air bubbles stay in water, the more will be the oxygen transfer to the liquid content of the tank. Therefore, an optimum depth of liquid to satisfy both the velocity requirements and the oxygen transfer is important in the design of the aeration tank.

The dimensionless factor F1, increases with an increase in the submergence factor F5. Therefore, when the submergence of the diffusers increases, the horizontal velocity close to the bed also increases. In the case of submergence of diffusers, similar observations were made as for liquid depth in the tank. At the higher values of submergence, a better dissipation of energy through diffused air resulting in a better spiral flow and higher horizontal velocities, were observed. With low submergence, when the diffusers were kept close to the surface of water, high superfacial turbulence without or with weak spiral motion, was observed. A stronger and well defined spiral flow always resulted in higher horizontal velocities. Higher submergence will also result in higher oxygen transfer to the liquid content of the aeration tank.

7.3.4 Sensitivity Analysis of the Model

There are always some chances of getting experimental errors associated with the estimation of model parameters. Therefore, a senstivity analysis was conducted to evaluate the sensitivity of the model to these unforseen errors in the experimental and statistical parameters. If a small variation in an input parameter causes a large difference in the model output or the value of dependent variable, the model is said to be sensitive to that parameter. The exponents of the model were obtained through the statistical analysis and if a small change in one of these exponents causes large change in the overall performance of the model, then that exponent and its parameter are considered to be sensitive. The objective of sensitivity analysis is to know and to be careful about the parameters which will affect the model result significantly by small variations. It also helps to put more effort in the collection and analysis of parameters which are very sensitive.

The sensitivity analysis is divided into two parts. In the first part the sensitivity of the variation in the input parameters or independent variables to the output variable or dependent variable are discussed. In the second part the sensitivity of small variation in the exponents of the input parameters on the performance of the model are discussed. The overall analysis helps in reinforcing the validity of the selected model for predicting horizontal point velocity, u, close to the tank bottom.

7.3.4.1 Variation in Input Parameters

The effect of variation in the values of input parameters or independent variables of the model such as F2, F3, F4 and F5 on the output parameter or dependent variable, F1, is studied and discussed below:

a. Power Factor, F2: The power factor is the most important input parameter in the physical sense. However, this parameter is not very sensitive. It is found that by varying the value of F2 by ±10%, the change in the value of F1 is only ±3%. Therefore, in the calculation of power factor, F2, a small error will not change the output parameter, F1, of the model significantly.

b. Depth Factor, F4: The depth factor, F4, has been found to be most sensitive among all the input parameters. A ±10% variation in the value of F4 caused a ±6% change in the value of F1. This change in the value of output parameter is quite significant. Therefore, no major error in the measurement of depth of water can be allowed and this measurement should be done very carefully. Also in the design of the aeration tank, the depth of liquid in the tank should be given a serious consideration.

c. Width Factor, F3: The width factor, F3, has also been found to be equally sensitive as the depth factor, F4, in the model. A variation of ±10% in the value of F3, resulted in a change of ±6% in the value of output parameter F1. Therefore, the width of the tank should also be measured very carefully. In the design of the aeration tank, the width should be selected carefully.

d. Submergence Factor, F5: The submergence factor, F5, has been found to be least sensitive among all the input parameters. However, in this factor, the depth of water, H, in the tank is involved and it is a sensitive term. In the measurement of submergence, h, some error can be allowed without affecting the value of output parameter, F1, drastically. It is noticed that a variation of ±10% in the value of F5, caused a change of only ±1.3% in the value of F1.

7.3.4.2 Variation in Exponents of Different Factors

The sensitivity of the model to the variations in exponent of each input parameter or independent variable is discussed below:

a. Exponent to Power Factor, F2: The exponent to the power factor, F2, determined by the statistical analysis is 0.310. When this exponent value of 0.310 is changed to 0.3116, an increment of 0.5%, there is a corresponding change in the estimated value of F1 using model Eq. 6.2. The number of estimated values of F1 which show an error within ±20%, when the exponent value is changed from 0.310 to 0.3116, changes from 738 to 698 out of total 819 observations. This change from 738 to 698 is -5.4% of 738. When the exponent value is varied ±3.5%, all the estimated values of F1 showed an error of more than ±20%, many exceeding to ±40%. Therefore, this exponent is very sensitive and the rounding off of the value obtained through the statistical analysis should be done very carefully.

This analysis also confirms that the exponent value of 0.310 for parameter F2 is the best value for estimating F1. In this case, 738 estimated values out of total 819 observations showed an error within ± 20% and this was the largest number obtained out of all the exponent values tried in the analysis.

b. Exponent to Width Factor, F3, and Depth Factor, F4: The exponent to the depth factor, F4 and to the width factor, F3, determined statistically, is 2/3 and -2/3 respectively. Since the values of both the exponents are same except their signs, these two factors are grouped together and then analyzed for the sensitivity of the exponent. When this value of exponent is changed by 0.5% to 2.01/3, the variation in the number of estimated values of F1 showing an error within ±20% dropped from 738 to 727 out ot total 819 observations. This value represented a change of 1.5%. When the exponent value is changed by ±5%, almost all the estimated values show an error of more than ±20%, most of them exceed ±40% error. Therefore, it can be concluded that the the model is sensitive to these exponents also, but to a lesser degree as compared to the exponent of power factor, F2.

This analysis also confirms that the exponent value for the ratio of depth factor to width factor, as determined by statistical analysis, is the best value for estimating F1. In this case, 738 estimated values show an error within ±20%, and this was the largest number obtained out of all different exponent value tried in this analysis.

c. Exponent to Submergence Factor, F5: The exponent of the submergence factor, F5, determined by the statistical analysis is 1/4. When this value of exponent is changed by 10% to 1.1/4, the variation in the number of estimated values showing an error within ±20% is only 1%. Even when the exponent value is changed by 50% to 1.5/4, the variation in number of estimated values showing an error within ±20% is negligible. Therefore, the model is insensitive to this exponent and provides the best estimated values of F1.

Chapter VIII

CONCLUSIONS

This research has given a new dimension to the design of certain water and wastewater treatment units. At present, the suspension and shearing of particles in treatment units is controlled by maintaining certain lower and upper limits on velocities. It is proposed to use critical bed shear stress and yield stress for a more rational design.

The following conclusions are drawn on the basis of the results obtained in this study:

8.1 Experiments on Grit Particles

a. The depth of flow in a conventional grit chamber influences the mean velocity. Therefore, the influence of depth of flow while calculating the critical scouring velocity for grit particles of specific sizes should be taken into consideration.

b. The critical bed shear stress is a more rational parameter for designing a grit chamber as compared to critical mean velocity used as present design parameter.

c. A correlation between the grit particle sizes and corresponding critical bed shear stress values has been established.

d. For fully developed flow conditions and uniform size particles the critical bed shear stress values for a smooth bed are lower than a packed bed.

8.2 Experiments on Sludge Particles

a. Most of the sludges normally encountered in the field of water and wastewater engineering behaved as non-Newtonian fluids, as indicated below:

(a) Unsettled mixed liquor (biological sludge) behaved as Bingham plastic fluid

(b) Settled mixed liquor (biological sludge) behaved as pseudoplastic fluid with a yield stress

(c) Unsettled alum sludge behaved as Bingham plastic fluid

(d) Settled alum sludge behaved as pseudoplastic fluid with a yield stress

(e) Unsettled physico-chemical sludge behaved close to dilatant fluids

(f) Settled physico-chemical sludge behaved close to pseudoplastic fluid with a yield stress

(g) Secondary digested sludge (diluted) behaved as pseudoplastic with a yield stress

(h) Mixure of primary and secondary sludges behaved as pseudoplastic fluid with a yield stress

b. Rheological behaviour of sludges changed with the suspended solids concentration.

c. The yield stress values for different types of unsettled and settled sludges were determined. These are the limiting shear stress values beyond which the suspended particles start disintegrating in water and wastewater treatment units.

d. A relationship between suspended solids concentration and corresponding yield stress value for different types of sludges has been established..

e. The critical bed shear stress values for different types of sludges were obtained. These are the minimum shear stress values required to prevent the settling of suspended particles.

f. It is recommended that various treatment units in water and wastewater field should be designed taking into consideration the critical bed shear stress and the yield stress values.

8.3 Experiments on Aeration Tank Model

a. The important parameters, which affect the design and operation of an aeration tank, are identified. An empirical equation correlating these parameters which significantly affect the spiral motion (mixing) in the aeration tank has been developed. This equation predicts the horizontal velocities close to the tank bottom (25 mm above) under different operating conditions.

b. The physical evaluation of the developed equation revealed that:

(a)Increase in the power input in the system would provide higher velocities in the aeration tank.

(b)Increase in tank width would decrease the velocities.

(c)Increase in water depth would result in increased velocities, and

(d)Incrase in diffuser submergence would yield higher velocities.

c. The sensitivity analysis of the model revealed that the power factor was not a sensitive parameter, wherease the depth factor and width factor were found to be very sensitive. Submergence factor was found to be least sensitive. Therefore, it is recommended to select the values for all sensitive parameters more carefully.

Chapter IX

APPLICATION

This chapter is divided into three major sections and under each section the practical application of the results obtained in this study is discussed.

9.1 Grit and Gravel Particles

The experiments conducted with grit and gravel particles in the laboratory flume have provided valuable data and rational design parameters. for grit chambers and sanitary sewers. This approach can also be used in the design of other units in which the accumulation of inert material is either desirable or undesirable.

9.1.1 Design of Grit Chambers Based on Critical Bed Shear Stress

The application of the proposed method for designing a grit chamber is recommended using the following steps:

a. Select the smallest particle size to be removed completely in the grit chamber.

b. Determine the critical bed shear stress, τ_c, for this particle size, using Figure 6.4 or Eq. 6.1.

c. Calculate the shear or friction velocity, U_{*c}, using Eq. 5.5.

d. Select the total depth of flow of wastewater to be maintained in the grit chamber.

e. Calculate the corresponding value of y using Eq. 5.12 or 5.17, at which the point velocity will be a mean velocity.

f. Obtain the point velocity, u, for the above y using Eqs. 5.6 or 5.7, depending on the flow regime. This point velocity will be the critical mean velocity, u_m.

g. Design the grit chamber, using mean velocity, u_m, depth of flow, and the given flow rate of wastewater.

9.2 Different Sludge Particles

Using data gathered through experimental and theoretical analyses on different types of sludge particles, new methods of designing treatment units and mixing chambers in water and wastewaters treatment are proposed.

9.2.1 Design of Aeration Tank for Activated Sludge Process

The current practice of designing aeration tank is based on maintaining a certain minimum dissolved oxygen, D.O., concentration. in the unit all the time. In this approach of design, the role of mixing and scouring velocities close to the tank floor are often ignored. The scouring velocity in the aeration tank is necessary to keep the activated sludge flocs in suspension without shearing them. It is recommended that the aeration tank using diffused aeration should be designed to satisfy both the mixing and the D.O. requirements.

The application of the proposed method to design an aeration tank where the settling of flocs is undesirable, is illustrated with an example in the following steps:

a. Select the mixed liquor suspended solids, MLSS, concentration to be maintained in the reactor.

b. Determine the yield stress, τ_y , value for biological sludge for the selected MLSS concentration using Equation given in Table 6.16. or using Figs. 6.33 - 6.37.

c. Determine the corresponding critical bed shear stress, τ_{oc} for biological sludge from Table 6.3

d. The level of shear in the reactor should be kept between these two extreme stress values. Select an appropriate intermediate value of shear stress preferably closer to the yield stress, τ_y.

e. This will be the amount of shear needed close to the aeration tank floor to keep the sludge flocs in suspension without shearing them and this shear value can be used to determine the operating parameters.

f. Determine the horizontal velocity, 25 mm above the tank floor, needed to provide the above calculated bed shear by using Eq. 6.2.

g. Follow procedure in Section 8.3 to determine the operating parameters to provide the calculated horizontal velocity at 25 mm above tank floor.

h. These operating conditions may have to be modified to satisfy DO requirments.

9.2.2 Design of Flocculation Basins in Water and Wastewaters Treatment

The flocculation basins are used both in water and wastewater treatment. In water treatment they are used, after rapid mixing of coagulant and coagulant aid, to make the alum flocs bigger and denser. In wastewater treatment, flocculation basins are used in physico chemical treatment. Chemicals are added for various purposes in the raw wastewater and these basins allow the formation of bigger and stronger flocs. The proposed design procedure is given below:

a. Select the type of particles to be flocculated in the basin.

b. Select the suspended solids concentration based on previous experience or given in the literature.

c. Determine the yield stress value, τ_y, for the corresponding sludge and selected suspended solids concentration.

d. Determine the critical bed shear stress, τ_{oc}, for that type of sludge from Table 6.3.

e. Select the extent of shear needed in the basin somewhere between these two stress values. In flocculation basins the value of shear should be above the critical bed shear stress, τ_{oc}, to prevent settling and below yield stress to prevent floc disintegration.

f. Design the basin volume, V, to provide the desired detention time for floc formation.

g. Calculate the power input to provide mixing just enough to maintain above calculated shear in the basin.

The power needed for flocculation to generate needed velocity gradient in a rectangular chamber can be calculated as shown below:

$$P = Q\gamma h_f \qquad \text{----[8.1]}$$

where P = Power input, W

Q = Flow rate, m^3/s

γ = Unit weight of liquid, kg/m^3

h_f = Head loss in the chamber, m

The bed shear is given by:

$$\tau_o = \gamma R s \qquad \text{----[8.2]}$$

where τ_o = Bed shear stress, N/m^2

R = Hydraulic mean radius of the chamber, m

s = Slope of chamber

Dividing both sides of Eq. 8.1 by length of the chamber 'L_1'

$$\frac{P}{L_1} = \frac{Q\gamma h_f}{L_1}$$

$$\frac{P}{L_1} = Q\gamma s \qquad \text{----[8.3]}$$

or $$s = \frac{P}{Q\gamma L_1} \qquad \text{----[8.4]}$$

Substituting the value of slope 's' in Eq. 8.2

$$\tau_o^2 = \frac{\gamma R P}{Q\gamma L_1}$$

$$P = \frac{\tau_o^2 Q L_1}{R} \qquad \text{----[8.5]}$$

9.2.3 Design of Sedimentation Basins in Water and Wastewaters Treatment

The sedimentation basins or clarifiers are used in all water and wastewaters treatment plant. The design of sedimentation basin is normally done on the basis of overflow rate. However, if the settling characteristics of the particles are good, then the clarifiers can be overloaded for higher overflow rate. The critical bed shear play a key role to determine the extent of overloading which can be accommodated in the clarifier, without washing away the settled sludge particles and hindering the settling process. The bed shear in the basin due to horizontal velocities close to the bed has to be below the critical bed shear for the particular sludge particles to be removed in the basin. The design procedure for sedimentation basins or clarifiers on the basis of critical bed shear to optimize the capacity is shown in the following steps.

9.3 Aeration Tank Model

The aeration tank model, Eq. 6.2, can be applied to fix the operating conditions in units where diffused aeration is used as a mean for mixing purposes. This equation provides different options to have a certain predetermined horizontal velocity in the tank at 25 mm above the tank floor. The velocity requirements depend upon the purpose for which the unit is used. Diffused aeration tanks are commonly used in the activated sludge process for wastewater treatment; however, the use of these types of tanks are becoming popular in flocculation chambers, mixing chambers etc.. Aerated grit chamber is another application of diffused aeration in wastewater treatment.

The application of model Eq. 6.2 is described in the following steps:

a. Determine the physical properties of the liquid or suspension to be used in the aeration tank.

b. Fix the horizontal velocity at 25 mm above the tank floor using any of the approaches discussed in the previous sections, depending on the purpose of the unit.

c. Fix the dimensions of the aeration tank based on either detention time or mean cell residence time depending on the objective of the process.

d. Fix the location and submergence of the diffusers based on the convenience of maintenance.

e. Using the above values, calculate different dimensionless factors except power factor, F2.

f. Substitute the values of all calculated factors in Eq. 6.2 to obtain power factor, F2. This power factor value can be used to determine the air flow rate.

g. This air flow rate, as an operational parameter, will control the horizontal velocities in the tank.

If it is not possible to control the air flow rate, then the submergence of diffusers can be used as a operational parameter to control the velocities.

Appendix A

CALIBRATION OF BROOKFIELD VISCOMETER

The following tests were conducted on the Brookfield Viscometer in order to check its accuracy and performance.

a. Damaged or faulty pivot point or jewel bearing can affect the accuracy and repeatability of the viscometer. The Oscillation Test was performed on the viscometer to evaluate the conditions of pivot point and jewel bearing. This test revealed that they were in good condition.

b. The calibrated viscosity standards were used for final performance check. It was observed that the difference between the standard viscosity values and the observed viscosity values using the spindle # 1 was within -15%. This difference between the standard value and observed values was due to temperature difference.

c. The calibrated viscosity standards were also used for checking the performance of the Rheomat 30 viscometer. The difference between the standard viscosity values and observed visocosity values were in the range of ± 10%.

The difference between the results obtained using the Brookfield Viscometer and Rheomat 30 was due to the wide shearing rate range used in the Rheomat 30 as compared to only four shearing rates used in the Brookfield Viscometer.

Appendix B

DATA FROM BROOKFIELD VISCOMETER FOR DIFFERENT TYPES OF SLUDGES

B.1 Biological Sludges

FLUID: Mixed Liquor
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0465	13.02	0.7497	2,491
	30	0.0236	6.51	0.3809	
	12	0.011	2.604	0.1693	
	6	negligible			
2	60	0.0492	13.02	0.7932	2,909
	30	0.0253	6.51	0.4071	
	12	0.0123	2.604	0.1988	
	6	negligible			
3	60	0.0402	13.02	0.6481	2,387
	30	0.0185	6.51	0.3031	
	12	0.009	2.604	0.1370	
	6	negligible			

FLUID: Settled Biological Sludge
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant, Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.3783	13.02	6.0998	9,258
	30	0.2378	6.51	3.8332	
	12	0.1663	2.604	2.6804	
	6	0.1050	1.302	1.6929	
2	60		13.02		
	30		6.51		
	12		2.604		
	6		1.302		

FLUID: Mixed Liquor
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0404	13.02	0.6514	1,908
	30	0.0188	6.51	0.3037	
	12	0.0087	2.604	0.1897	
	6	negligible	1.302		
2	60	0.0474	13.02	0.7642	2,708
	30	0.0254	6.51	0.4095	
	12	0.0157	2.604	0.2526	
	6	negligible	1.302		

FLUID: Settled Biological Sludge
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.3413	13.02	5.5032	8,531
	30	0.2050	6.51	3.3052	
	12	0.1338	2.604	2.1565	
	6		1.302		
2	60	0.3650	13.02	5.8848	8,538
	30	0.2318	6.51	3.7365	
	12	0.1475	2.604	2.3781	
	6	0.1050	1.302	1.6929	

FLUID: Mixed Liquor
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0480	13.02	0.7739	3,787
	30	0.0296	6.51	0.4772	
	12	0.0145	2.604	0.2338	
	6	negligible	1.302		
2	60	0.0505	13.02	0.8142	3,851
	30	0.0292	6.51	0.4708	
	12	0.0175	2.604	0.2822	
	6	negligible	1.302		

FLUID: Settled Biological Sludge
SOURCE: Aeration Tank
LOCATION: Little River Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.5750	13.02	9.2705	11,969
	30	0.3950	6.51	6.3685	
	12	0.2700	2.604	4.3531	
	6	0.2060	1.302	3.3213	
2	60	0.5660	13.02	9.1255	11,967
	30	0.4130	6.51	6.6587	
	12	0.2775	2.604	4.4741	
	6	0.2320	1.302	3.7405	

B.2 Alum Sludges

FLUID: Alum Sludge
SOURCE: Underdrain of Settling Basin
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.044	13.02	0.7094	3,099
	30	0.0245	6.51	0.3950	
	12	0.0120	2.604	0.1935	
	6	0.0073	1.302	0.1169	
2	60	0.0455	13.02	0.7336	3,097
	30	0.0253	6.51	0.4071	
	12	0.0128	2.604	0.2056	
	6	0.0070	1.302	0.1129	

FLUID: Settled Alum Sludge
SOURCE: Underdrain of Settling Basin
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.6438	13.02	10.3790	12,688
	30	0.5113	6.51	8.2428	
	12	0.4175	2.604	6.7312	
	6	0.3350	1.302	5.4011	
2	60	0.6388	13.02	10.2984	13,362
	30	0.5250	6.51	8.4644	
	12	0.4025	2.604	6.4894	
	6	0.3210	1.302	5.1754	

FLUID: Alum Sludge
SOURCE: Underdrain of Settling Tank
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0485	13.02	0.7820	2,985
	30	0.0253	6.51	0.4071	
	12	0.0143	2.604	0.2257	
	6	0.0095	1.302	0.1532	
2	60	0.0483	13.02	0.7779	3,128
	30	0.0253	6.51	0.4071	
	12	0.0128	2.604	0.2056	
	6	0.0095	1.302	0.1532	

FLUID: Settled Alum Sludge
SOURCE: Underdrain of Settling Tank
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.5975	13.02	9.6333	11,447
	30	0.4375	6.51	7.0537	
	12	0.3275	2.604	5.2802	
	6	0.2675	1.302	4.3128	
2	60	0.5900	13.02	9.5124	11,613
	30	0.4450	6.51	7.1746	
	12	0.3313	2.604	5.3407	
	6	0.2625	1.302	4.2322	

FLUID: Alum Sludge
SOURCE: Underdrain of Settling Tank
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0435	13.02	0.7014	2,732
	30	0.0208	6.51	0.3346	
	12	0.0110	2.604	0.1774	
	6	0.0058	1.302	0.0887	
2	60	0.0435	13.02	0.7014	2,697
	30	0.0215	6.51	0.3467	
	12	0.0110	2.604	0.1774	
	6	0.0064	1.302	0.1028	

FLUID: Settled Alum Sludge
SOURCE: Underdrain of Settling Tank
LOCATION: Water Treatment Plant,
Amherstburg, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.6078	13.02	9.7986	11,573
	30	0.4628	6.51	7.4608	
	12	0.3488	2.604	5.6228	
	6	0.2875	1.302	4.6353	
2	60	0.5788	13.02	9.3310	11,493
	30	0.4563	6.51	7.3560	
	12	0.3575	2.604	5.7639	
	6	0.3140	1.302	5.0625	

B.3 Physico-Chemical Wastewater Sludges

FLUID: Physico-Chemical Wastewater Sludge (Diluted)
SOURCE: Underdrain of Clarifier
LOCATION: West Windsor Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0350	13.02	0.5643	3,557
	30	0.0130	6.51	0.2096	
	12	0.0038	2.604	0.0585	
	6	0.0020	1.302	0.0322	
2	60	0.0338	13.02	0.5442	1,649
	30	0.0118	6.51	0.1895	
	12	0.0025	2.604	0.0403	
	6	0.0010	1.302	0.0161	

FLUID: Physico-Chemical Wastewater Sludge
SOURCE: Underdrain of Clarifier
LOCATION: West Windsor Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr $\sec^{-1}$	SHEAR STRESS, τ dynes/cm^2	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.5581	13.02	8.9985	42,309
	30	0.3968	6.51	6.3967	
	12	0.2781	2.604	4.4841	
	6	0.2248	1.302	3.6236	
2	60	0.5588	13.02	9.0086	42,396
	30	0.3994	6.51	6.4390	
	12	0.2760	2.604	4.4500	
	6	0.2358	1.302	3,8010	

FLUID: Physico-Chemical Mixed Liquor
SOURCE: Clarifier
LOCATION: West Windsor Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0260	13.02	0.4192	675
	30	0.0103	6.51	0.1652	
	12	0.0023	2.604	0.0363	
	6	negligible	1.302		
2	60	0.0280	13.02	0.4514	784
	30	0.0105	6.51	0.1693	
	12	0.0025	2.604	0.0403	
	6	negligible	1.302		

FLUID: Physico-Chemical Settled Sludge
SOURCE: Clarifier
LOCATION: West Windsor Pollution Control Plant, Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.1718	13.02	2.7691	13,818
	30	0.1223	6.51	1.9710	
	12	0.0794	2.604	1.2797	
	6	0.0588	1.302	0.9472	
2	60	0.1425	13.02	2.2975	11,493
	30	0.0930	6.51	1.4994	
	12	0.0580	2.604	0.9351	
	6	0.0423	1.302	0.6812	

FLUID: Physico-Chemical Mixed Liquor
SOURCE: Clarifier
LOCATION: West Windsor Pollution Control Plant, Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.0358	13.02	0.5764	5,255
	30	0.0155	6.51	0.2499	
	12	0.0045	2.604	0.0726	
	6	0.0020	1.302	0.0322	
2	60	0.0365	13.02	0.5885	5,897
	30	0.0160	6.51	0.2580	
	12	0.0050	2.604	0.0806	
	6	0.0023	1.302	0.0363	

FLUID: Physico-Chemical Settled Sludge
SOURCE: Clarifier
LOCATION: West Windsor Pollution Control Plant,
Windsor, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.2063	13.02	3.3253	14,766
	30	0.1420	6.51	2.2895	
	12	0.0945	2.604	1.5236	
	6	0.0648	1.302	1.0440	
2	60	0.1070	13.02	1.7252	12,596
	30	0.0848	6.51	1.3664	
	12	0.0468	2.604	0.7538	
	6	0.0318	1.302	0.5119	

B.4 Secondary Digested Sludges

FLUID: Secondary Digested Sludge (Diluted)
SOURCE: Underdrain
LOCATION: Wastewater Treatment Plant,
Chatham, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.7150	13.02	11.5277	24,537
	30	0.5850	6.51	9.4318	
	12	0.4350	2.604	7.0286	
	6	0.3800	1.302	6.1266	
2	60	0.8288	13.02	13.3617	26,693
	30	0.6925	6.51	11.1650	
	12	0.5125	2.604	8.2629	
	6	0.4438	1.302	7.1544	

(continued)

FLUID: Secondary Digested Sludge (Diluted)
SOURCE: Underdrain
LOCATION: Wastewater Treatment Plant,
Chatham, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
3	60	0.3675	13.02	5.9251	18,837
	30	0.2925	6.51	4.7159	
	12	0.1963	2.604	3.1641	
	6	0.1629	1.302	2.6260	
4	60	0.5550	13.02	8.9481	22,040
	30	0.4375	6.51	7.0537	
	12	0.3250	2.604	5.2399	
	6	0.2753	1.302	4.4378	

B.5 Mixture of Primary and Secondary Sludges

FLUID: Mixture of Primary and Secondary Sludge
SOURCE: Underdrain to Primary Digester
LOCATION: Wastewater Treatment Plant,
Chatham, Ontario

SET #	SPEED OF SPINDLE, n rpm	DIAL READING D PERCENTAGE	RATE OF SHEAR, dv/dr sec^{-1}	SHEAR STRESS, τ $dynes/cm^2$	AVERAGE SUSPENDED SOLIDS CONCENTRATION mg/L
1	60	0.5137	13.02	8,2817	20,586
	30	0.3913	6.51	6.3099	
	12	0.2640	2.604	4.2564	
	6	0.2042	1.302	3.2923	
2	60	0.5087	13.02	8.2016	20,820
	30	0.3775	6.51	6.0863	
	12	0.2550	2.604	4.1113	
	6	0.1982	1.302	3,1955	

Appendix C

VELOCITY PROFILES IN AERATION TANK UNDER VARIOUS OPERATING CONDITIONS

Where F1 = Velocity Factor

F2 = Power Factor

F3 = Width Factor

F4 = Depth Factor

F5 = Submergence Factor

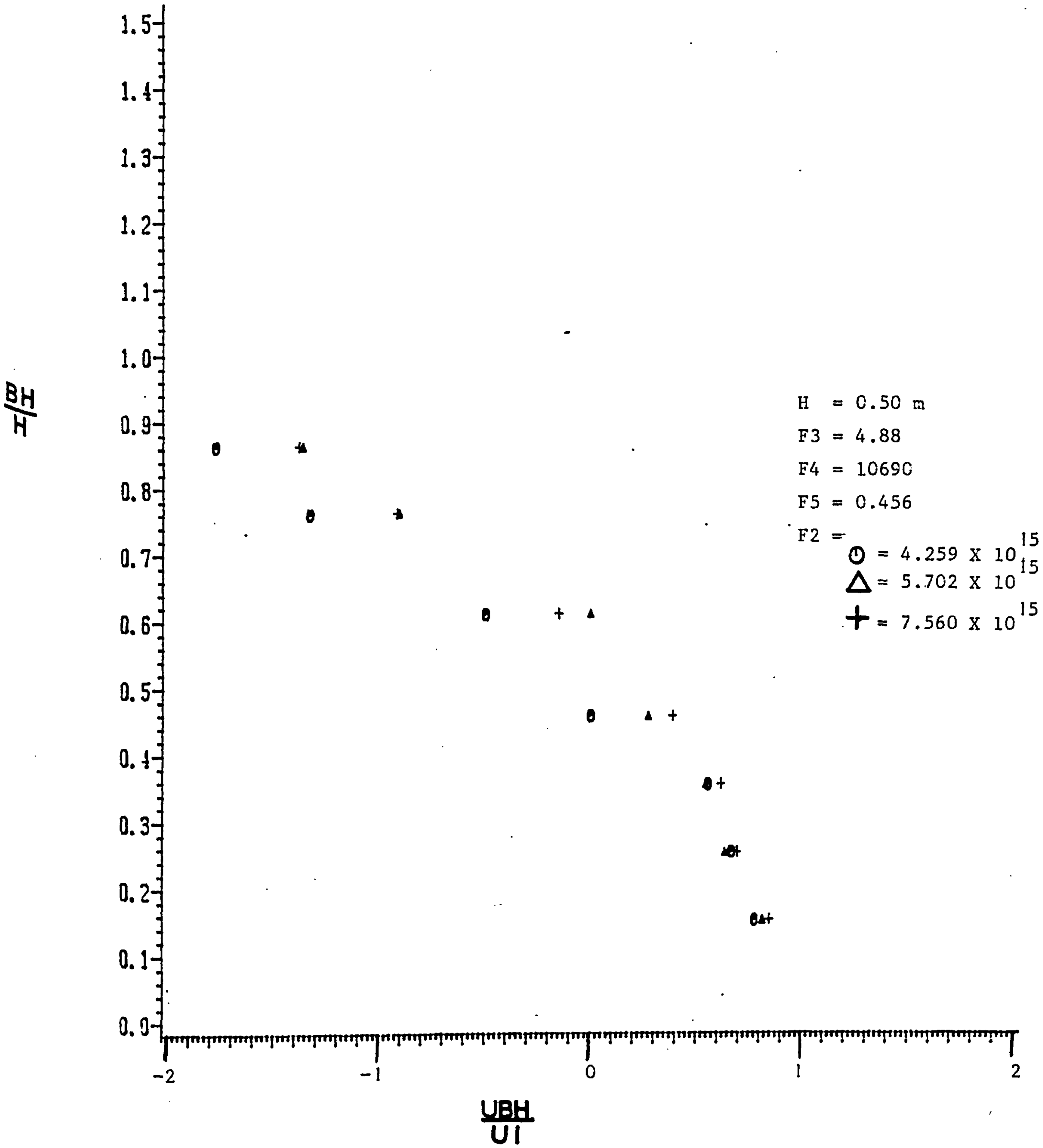
H = Depth of Liquid in the Tank

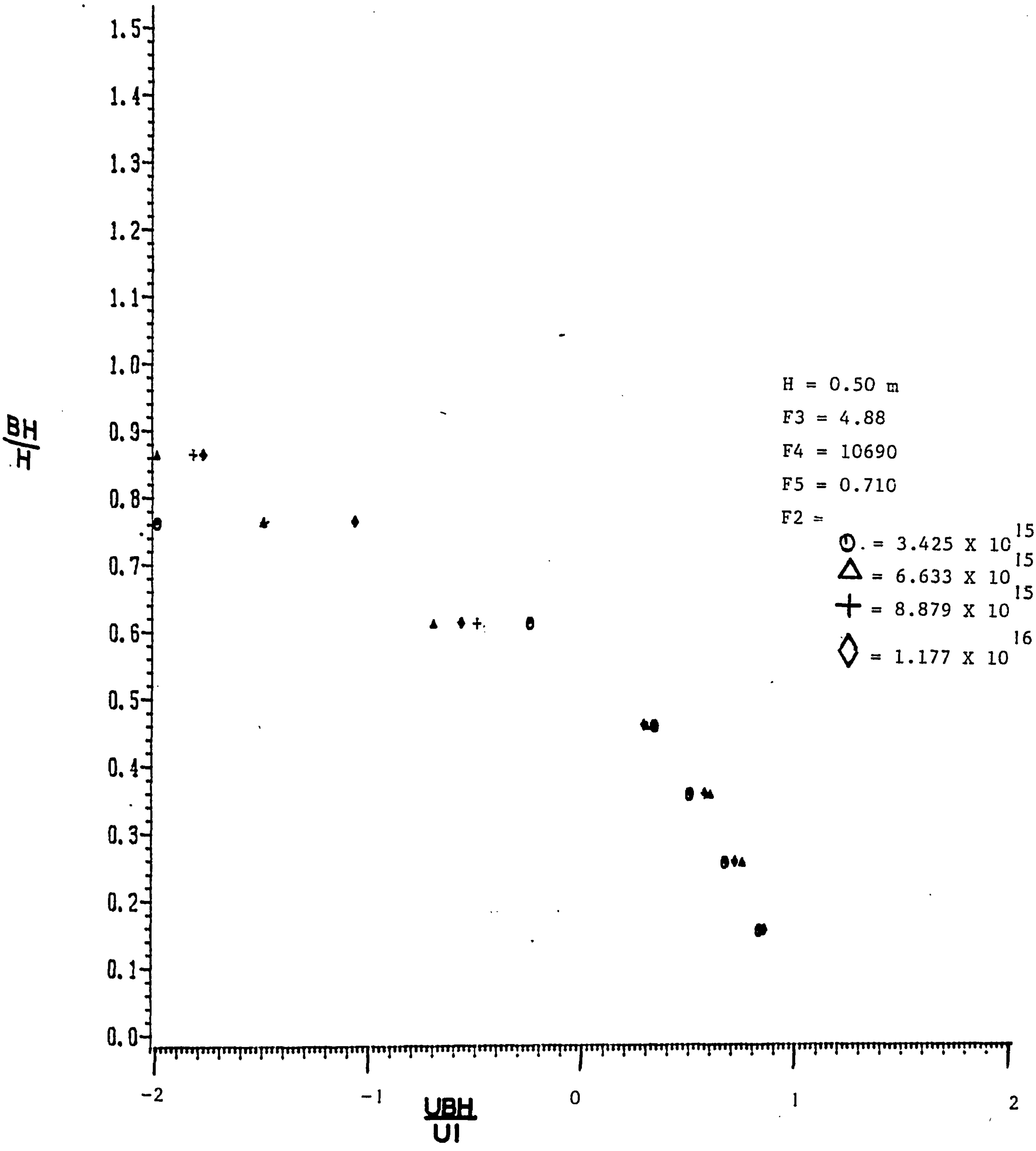
BH= Distance from Tank Bottom at which the Horizontal Point Velocities were Measured

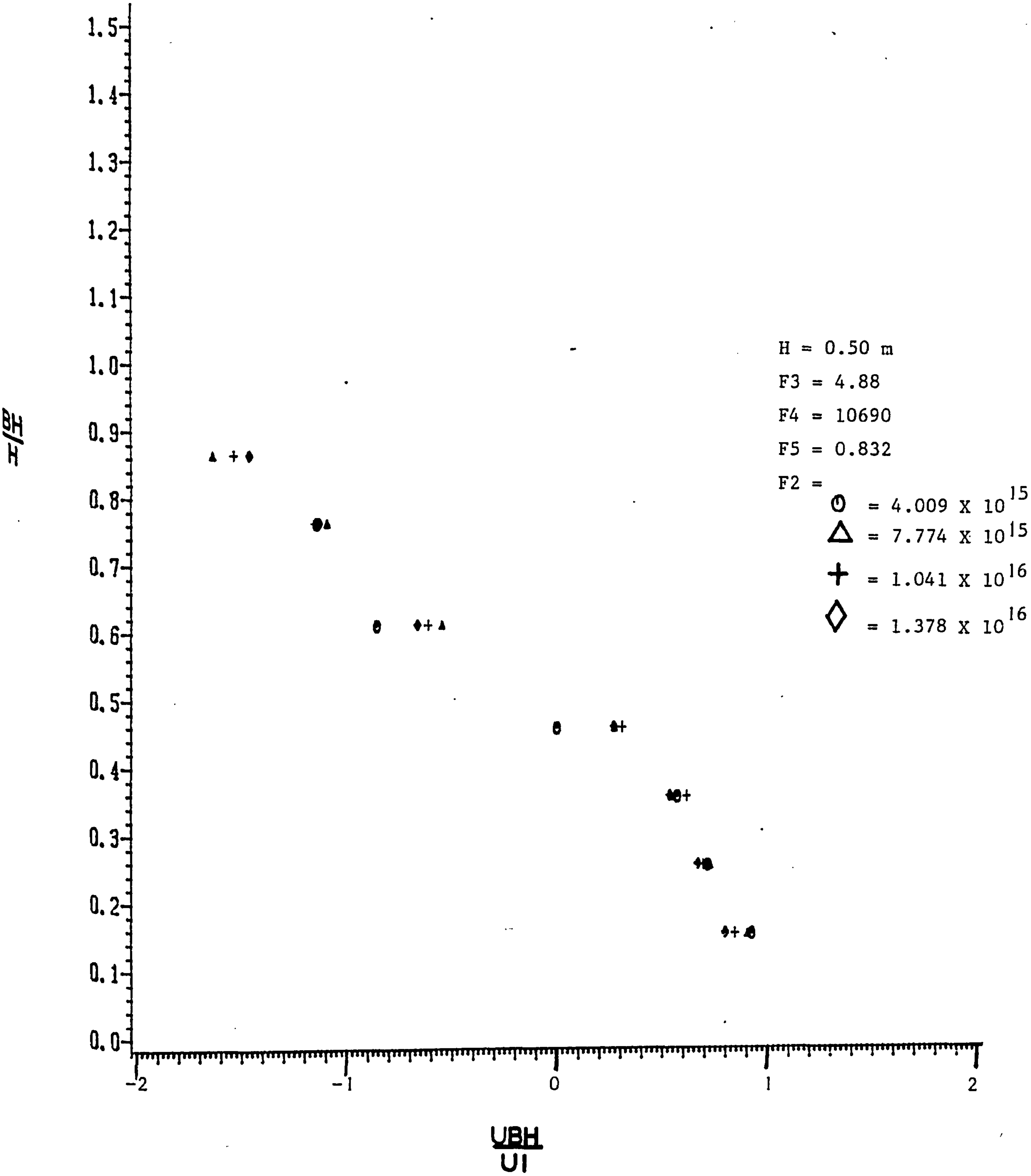
U1= Horizontal Velocity at 2.5 mm Above the Tank Bottom

UBH=Horizontal Velocity at a Distance BH from the Tank Bottom

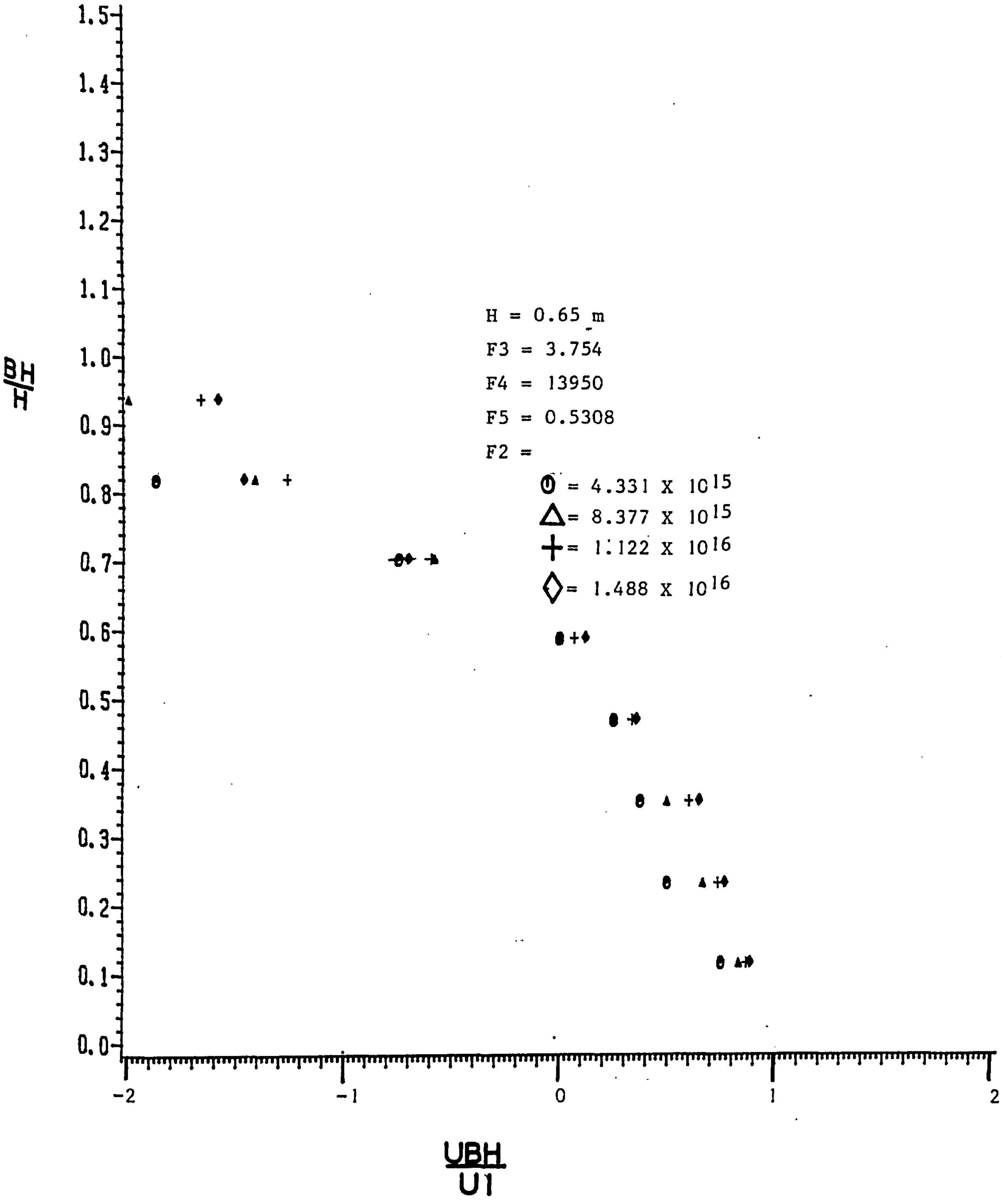
C.1 For Depth of 0.50 m

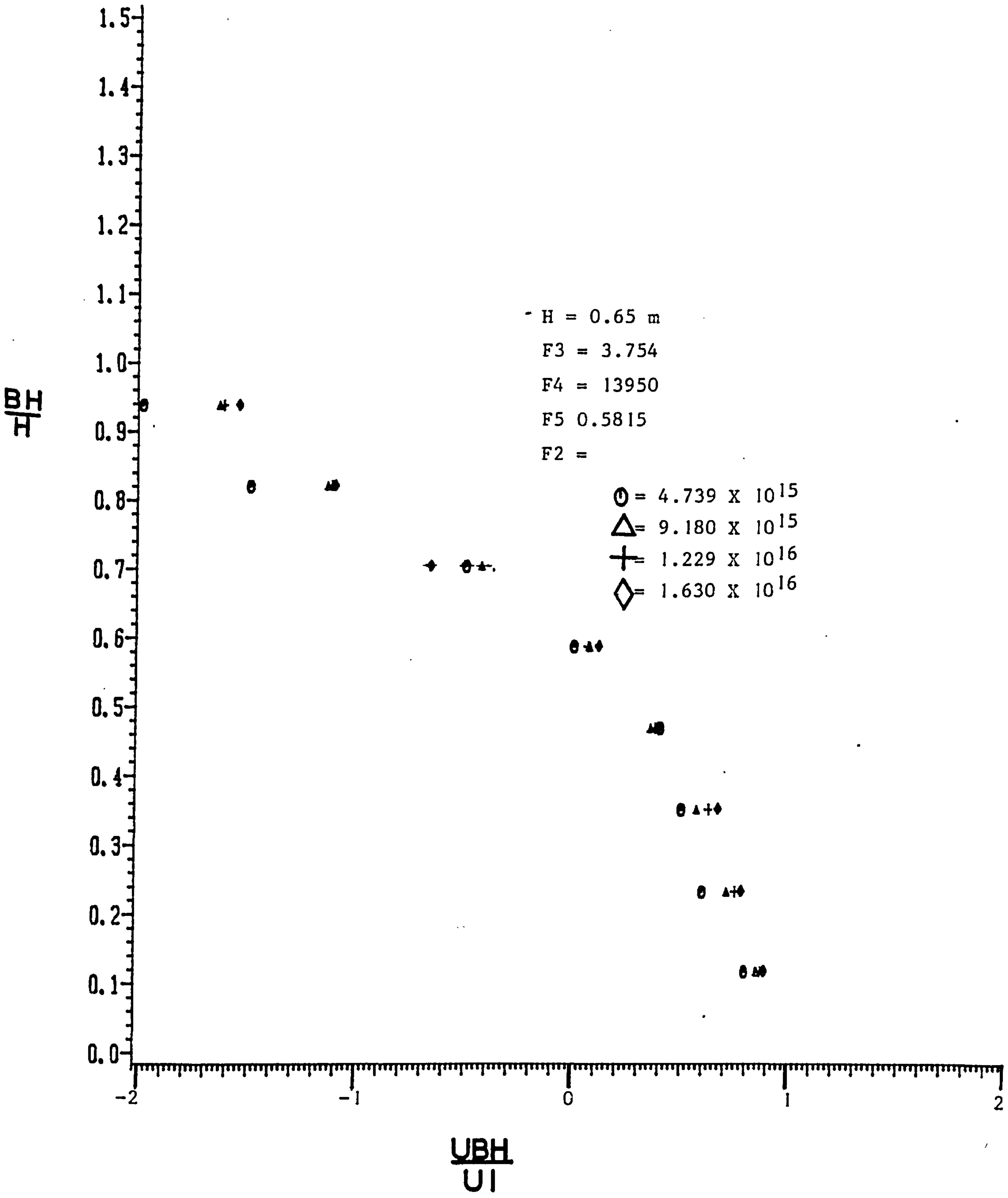

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 0.50 m
F3 = 4.88
F4 = 10690
F5 = 0.456
F2 =
O = 4.259 X 10^15
△ = 5.702 X 10^15
+ = 7.560 X 10^15

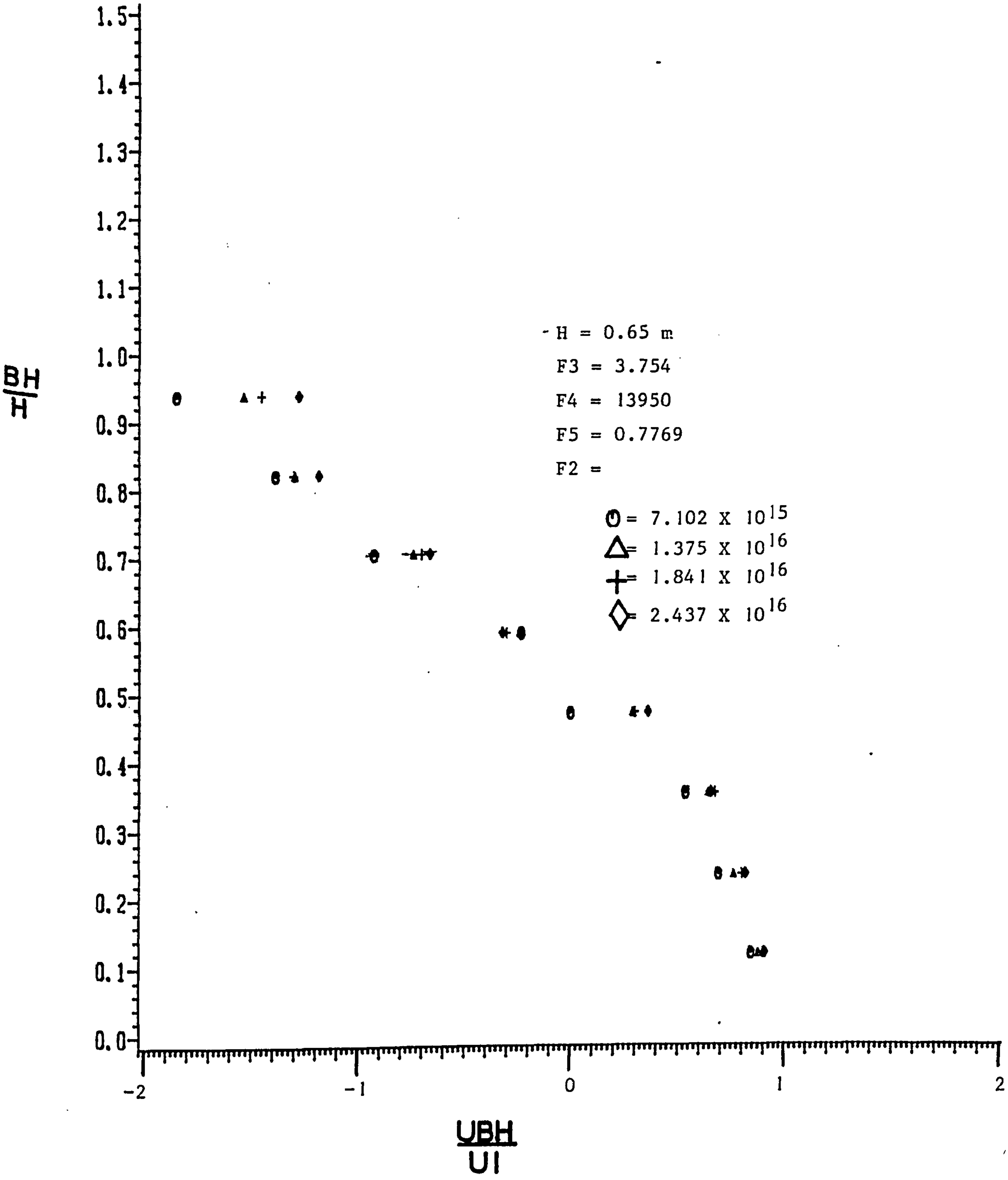

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 0.50 m
F3 = 4.88
F4 = 10690
F5 = 0.710
F2 =
○ = 3.425 X 10^15
△ = 6.633 X 10^15
+ = 8.879 X 10^15
◇ = 1.177 X 10^16

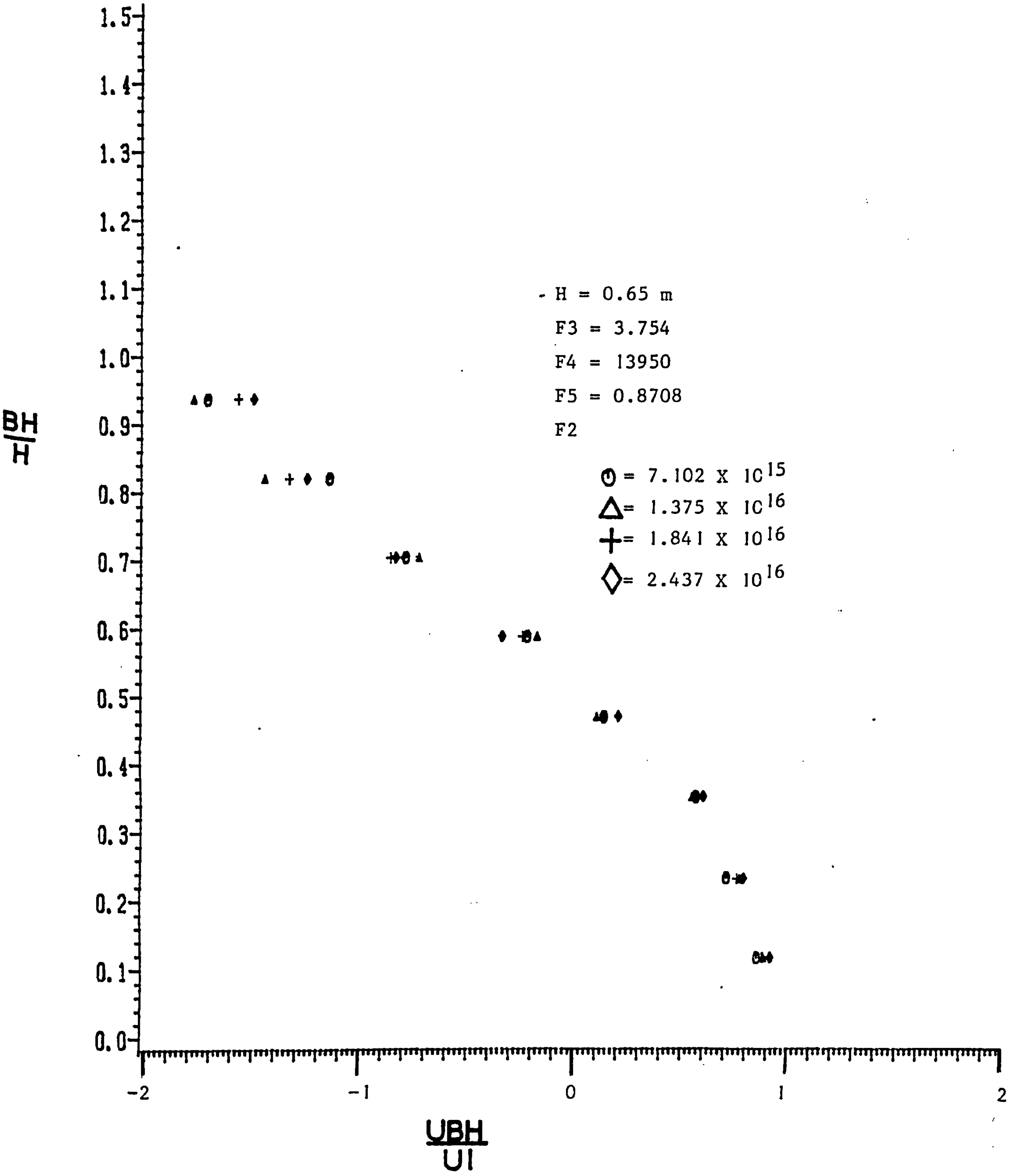

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
HB/H
-2
-1
0
1
2
UBH/UI
H = 0.50 m
F3 = 4.88
F4 = 10690
F5 = 0.832
F2 =
○ = 4.009 X 10^{15}
△ = 7.774 X 10^{15}
+ = 1.041 X 10^{16}
◇ = 1.378 X 10^{16}

C.2 For Depth of 0.65 m

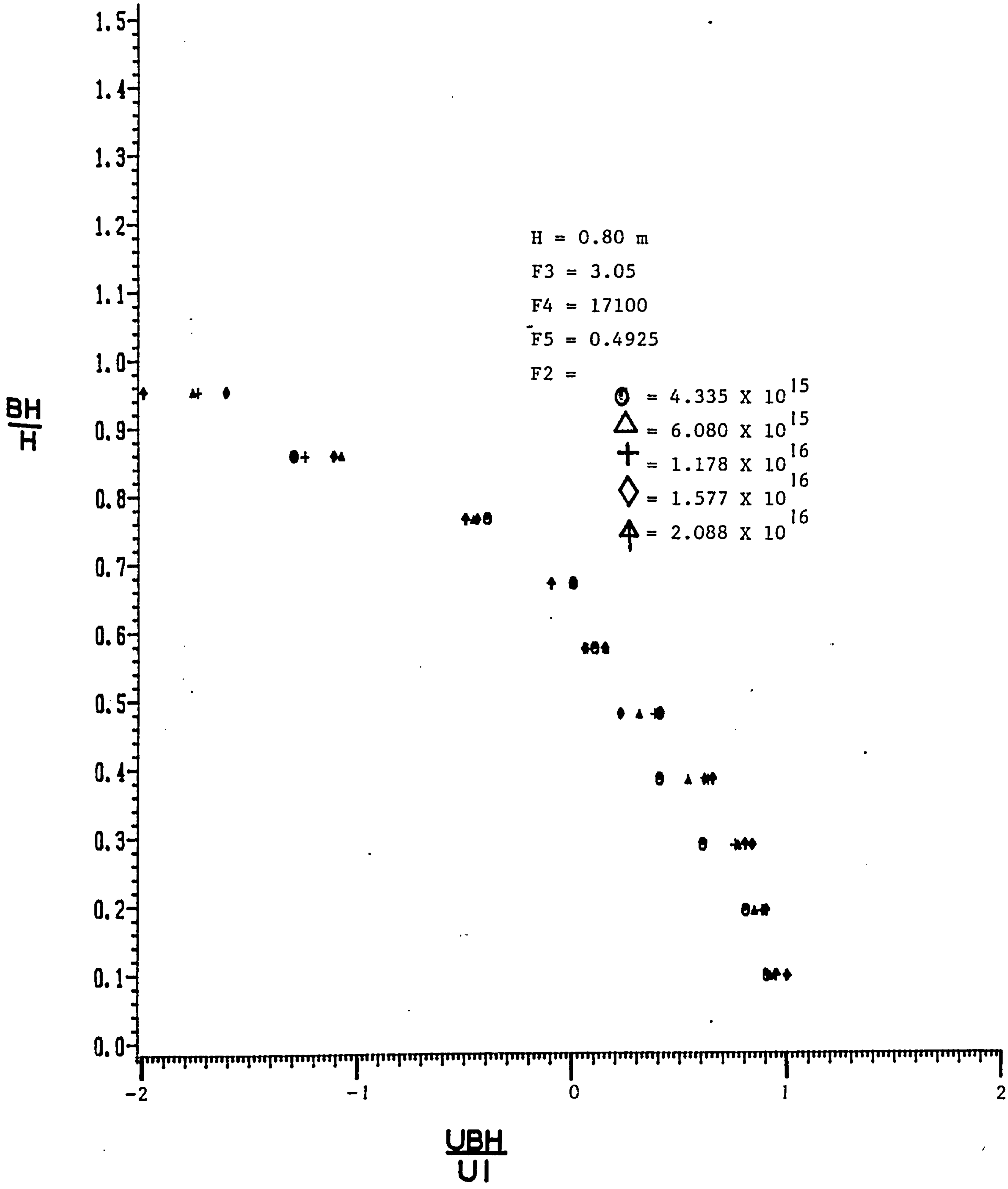

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/U1
H = 0.65 m
F3 = 3.754
F4 = 13950
F5 = 0.5308
F2 =
○ = 4.331 X 10^15
△ = 8.377 X 10^15
+ = 1.122 X 10^16
◇ = 1.488 X 10^16

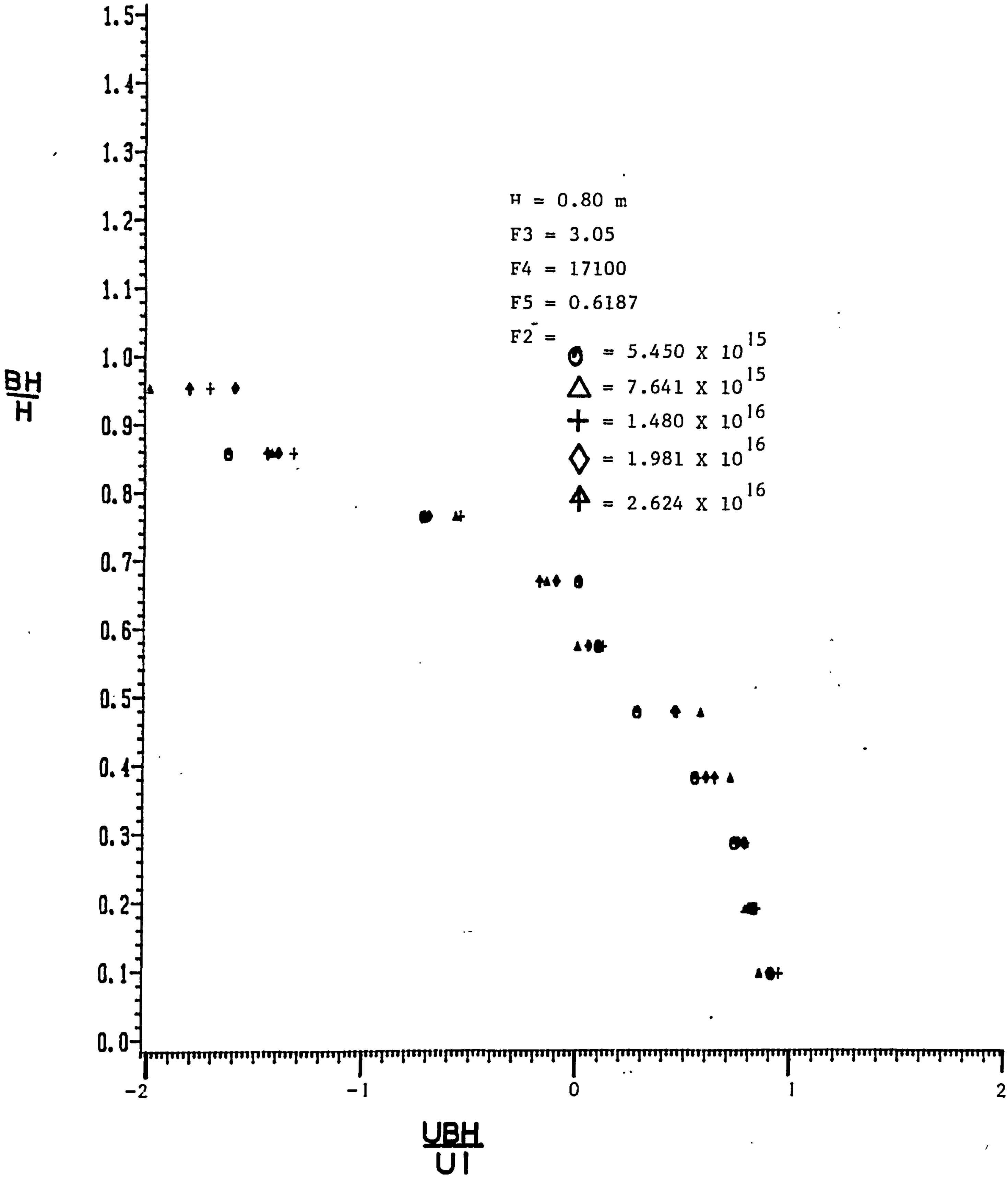

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
H = 0.65 m
F3 = 3.754
F4 = 13950
F5 0.5815
F2 =
○ = 4.739 X 10^15
△ = 9.180 X 10^15
+ = 1.229 X 10^16
◇ = 1.630 X 10^16
-2
-1
0
1
2
UBH/UI

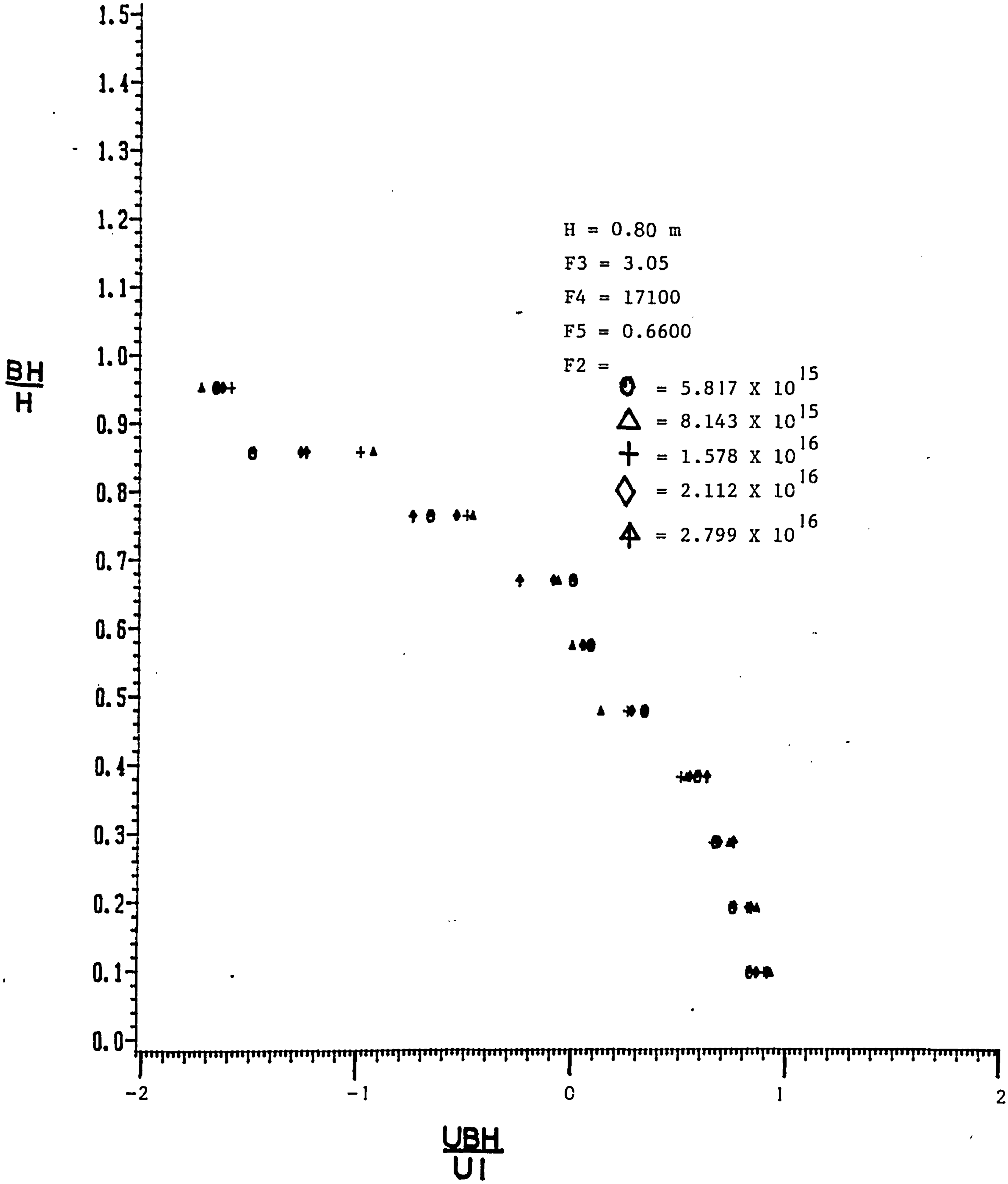

BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI
H = 0.65 m
F3 = 3.754
F4 = 13950
F5 = 0.7769
F2 =
○ = 7.102 X 10^15
△ = 1.375 X 10^16
+ = 1.841 X 10^16
◇ = 2.437 X 10^16

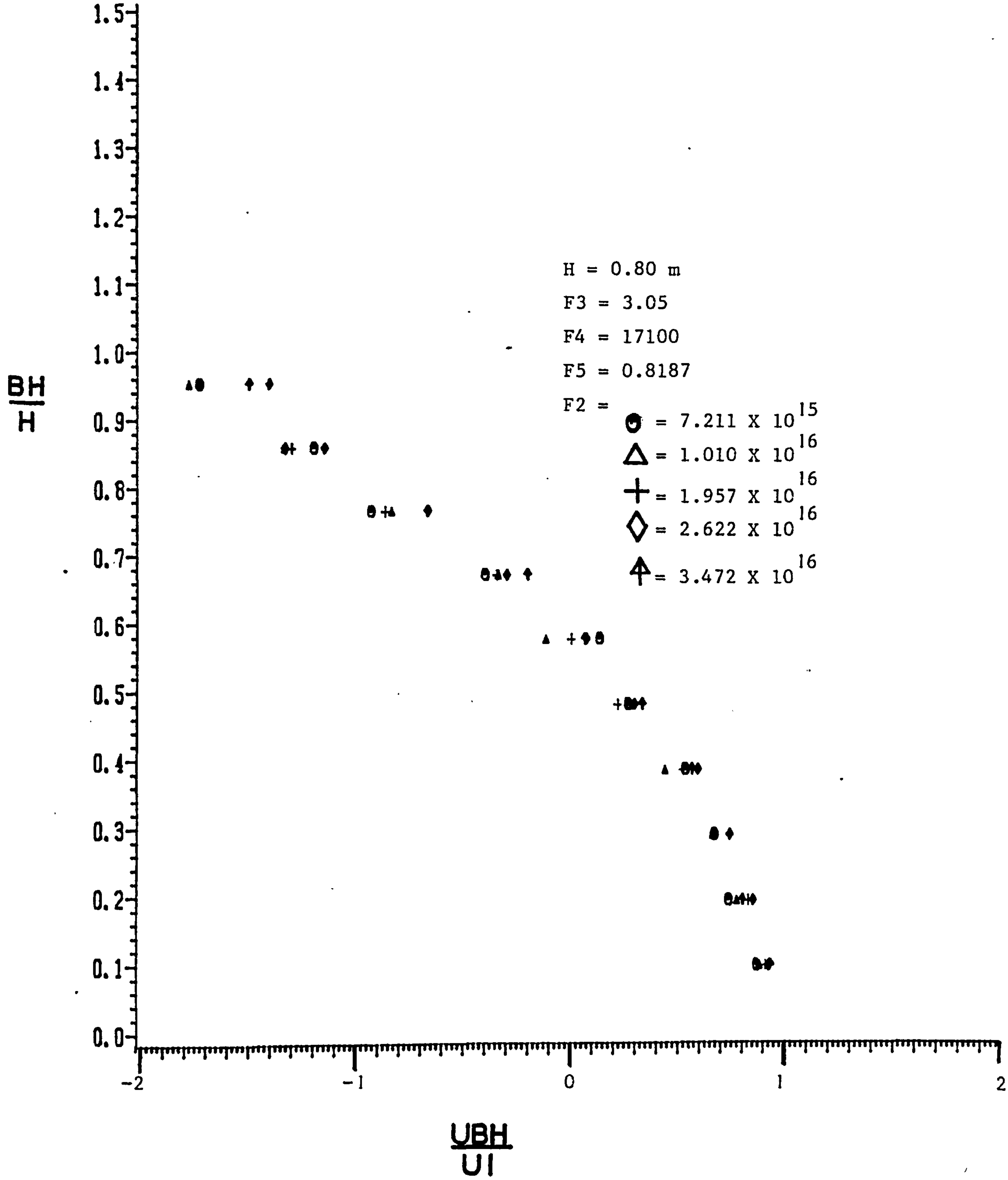

H = 0.65 m
F3 = 3.754
F4 = 13950
F5 = 0.8708
F2
○ = 7.102 X 10^15
△ = 1.375 X 10^16
+ = 1.841 X 10^16
◇ = 2.437 X 10^16
BH/H
UBH/UI
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2

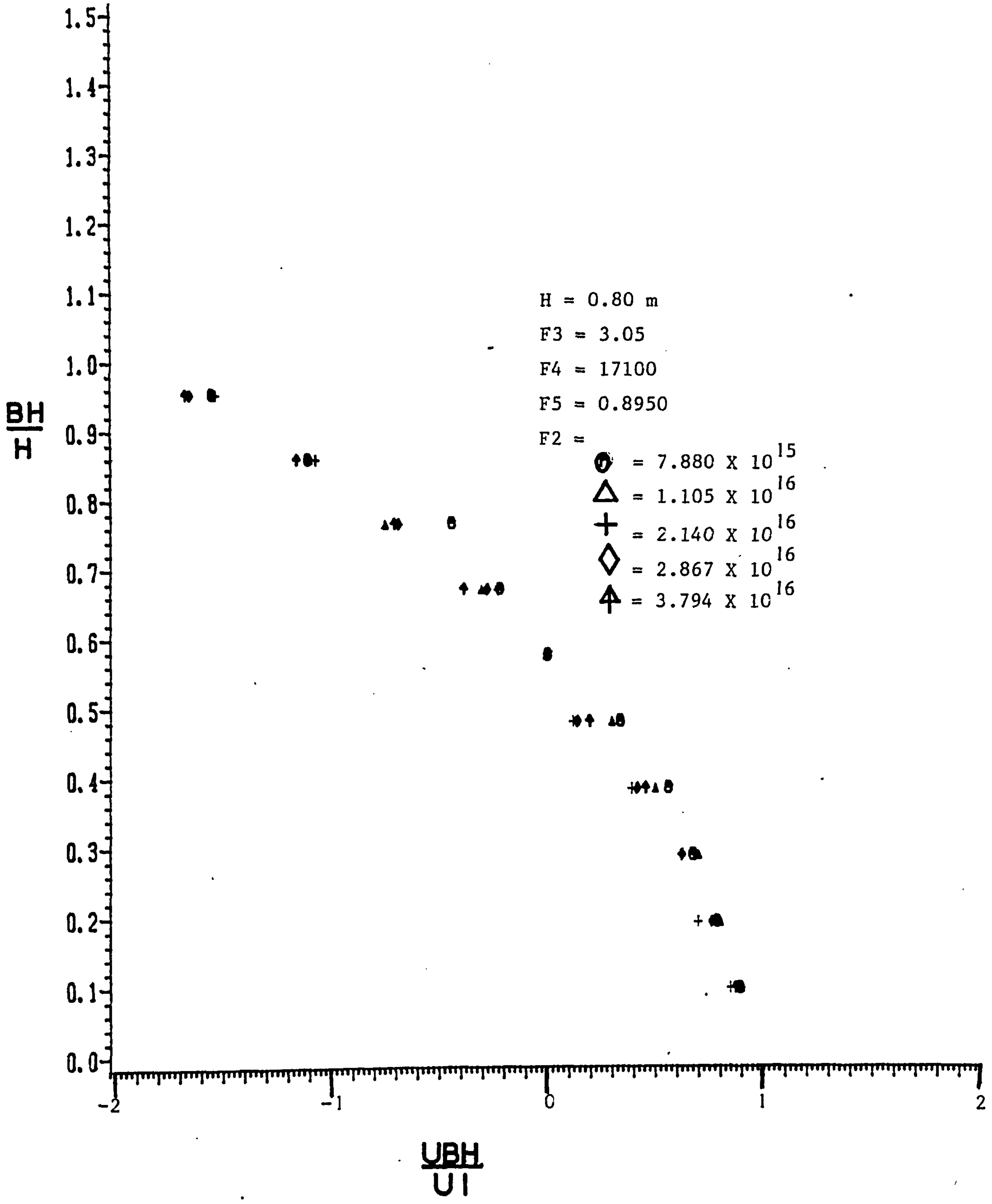
C.3 For Depth of 0.80 m


1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 0.80 m
F3 = 3.05
F4 = 17100
F5 = 0.4925
F2 =
⊖ = 4.335 X 10^15
△ = 6.080 X 10^15
+ = 1.178 X 10^16
◇ = 1.577 X 10^16
↑ = 2.088 X 10^16

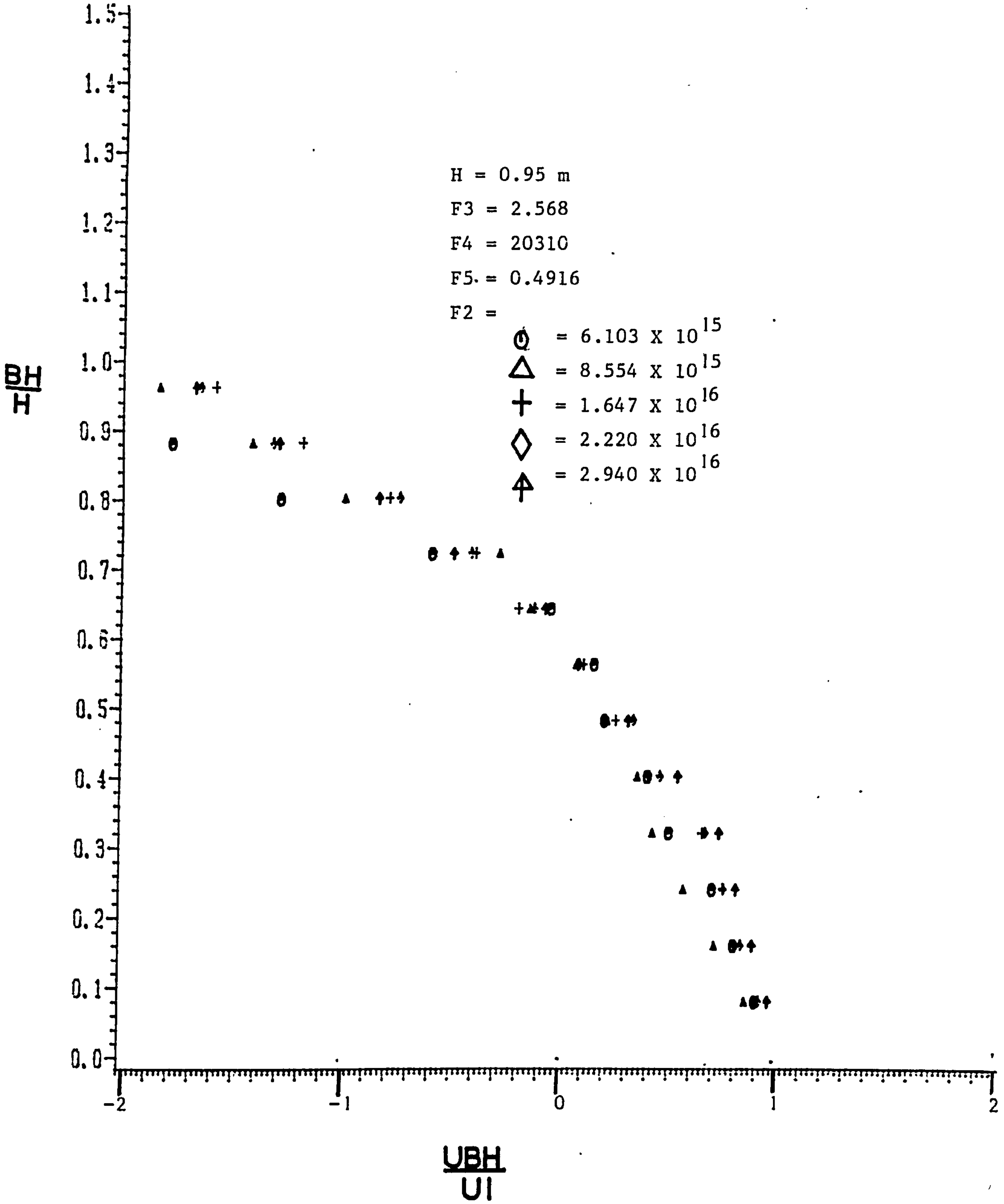

H = 0.80 m
F3 = 3.05
F4 = 17100
F5 = 0.6187
F2 =
⊖ = 5.450 X 10^15
△ = 7.641 X 10^15
+ = 1.480 X 10^16
◇ = 1.981 X 10^16
⍋ = 2.624 X 10^16
BH/H
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
UBH/UI
-2
-1
0
1
2

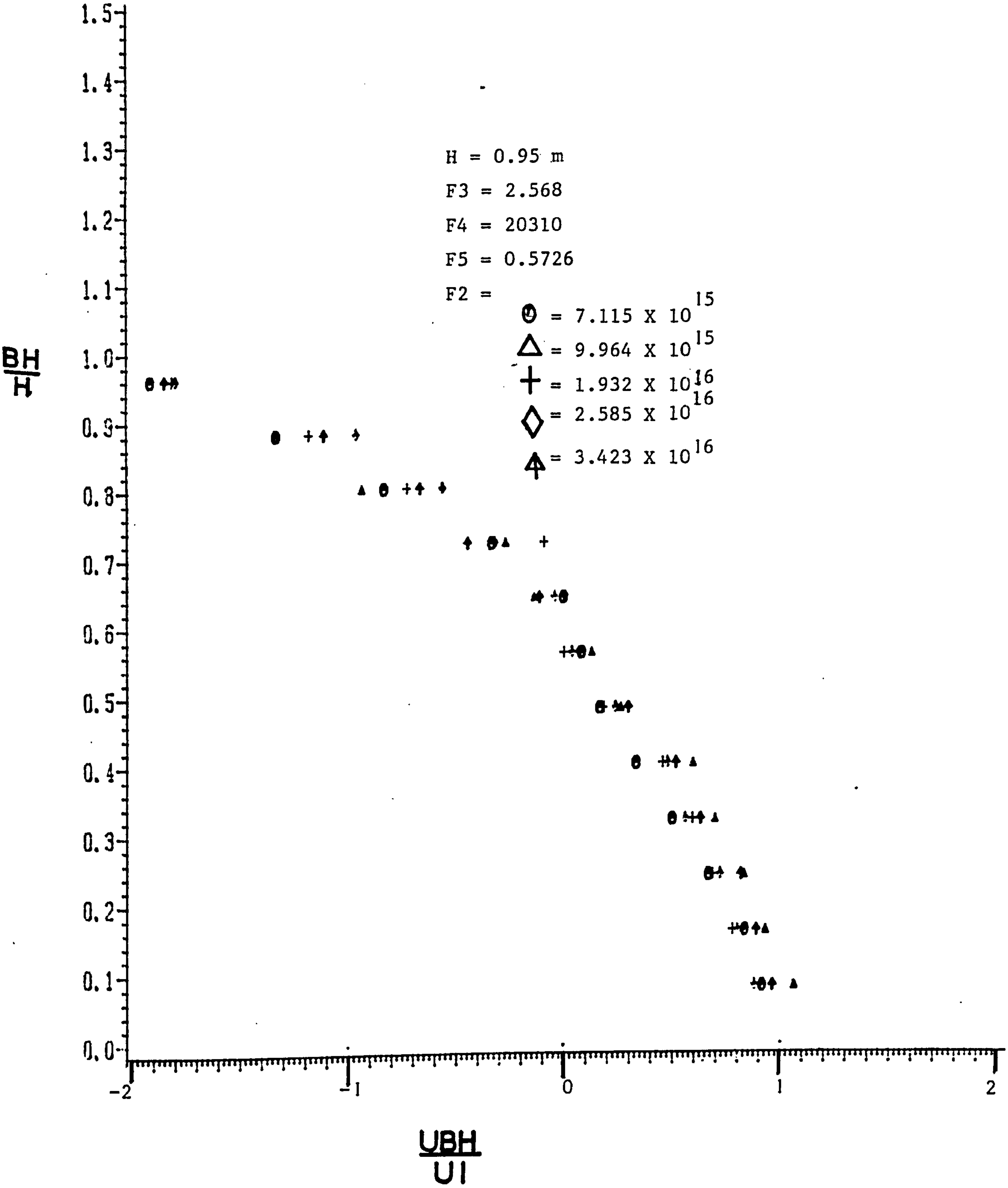

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 0.80 m
F3 = 3.05
F4 = 17100
F5 = 0.6600
F2 =
○ = 5.817 X 10^15
△ = 8.143 X 10^15
+ = 1.578 X 10^16
◇ = 2.112 X 10^16
↑ = 2.799 X 10^16

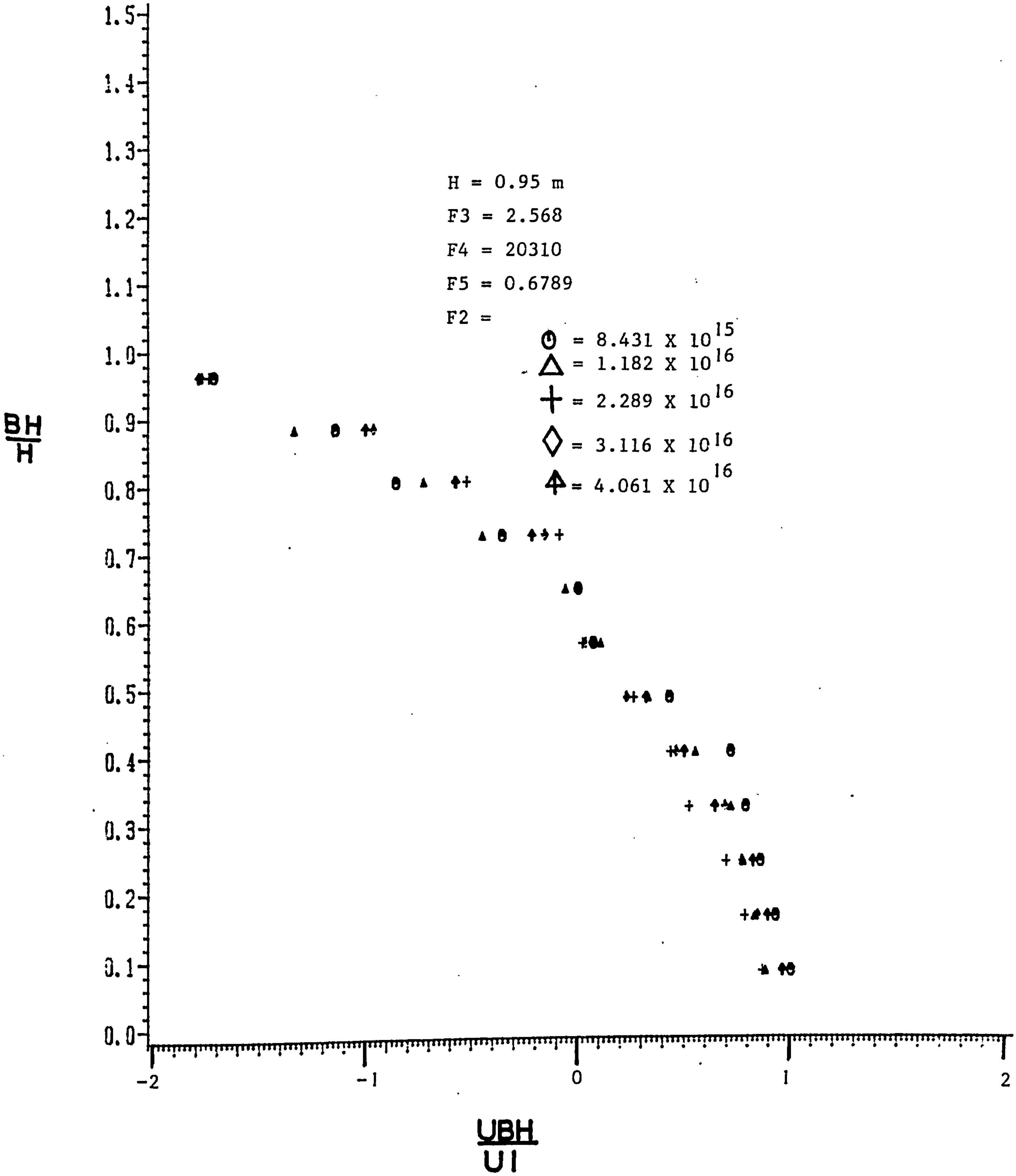

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 0.80 m
F3 = 3.05
F4 = 17100
F5 = 0.8187
F2 =
● = 7.211 X 10^15
△ = 1.010 X 10^16
+ = 1.957 X 10^16
◇ = 2.622 X 10^16
↑ = 3.472 X 10^16

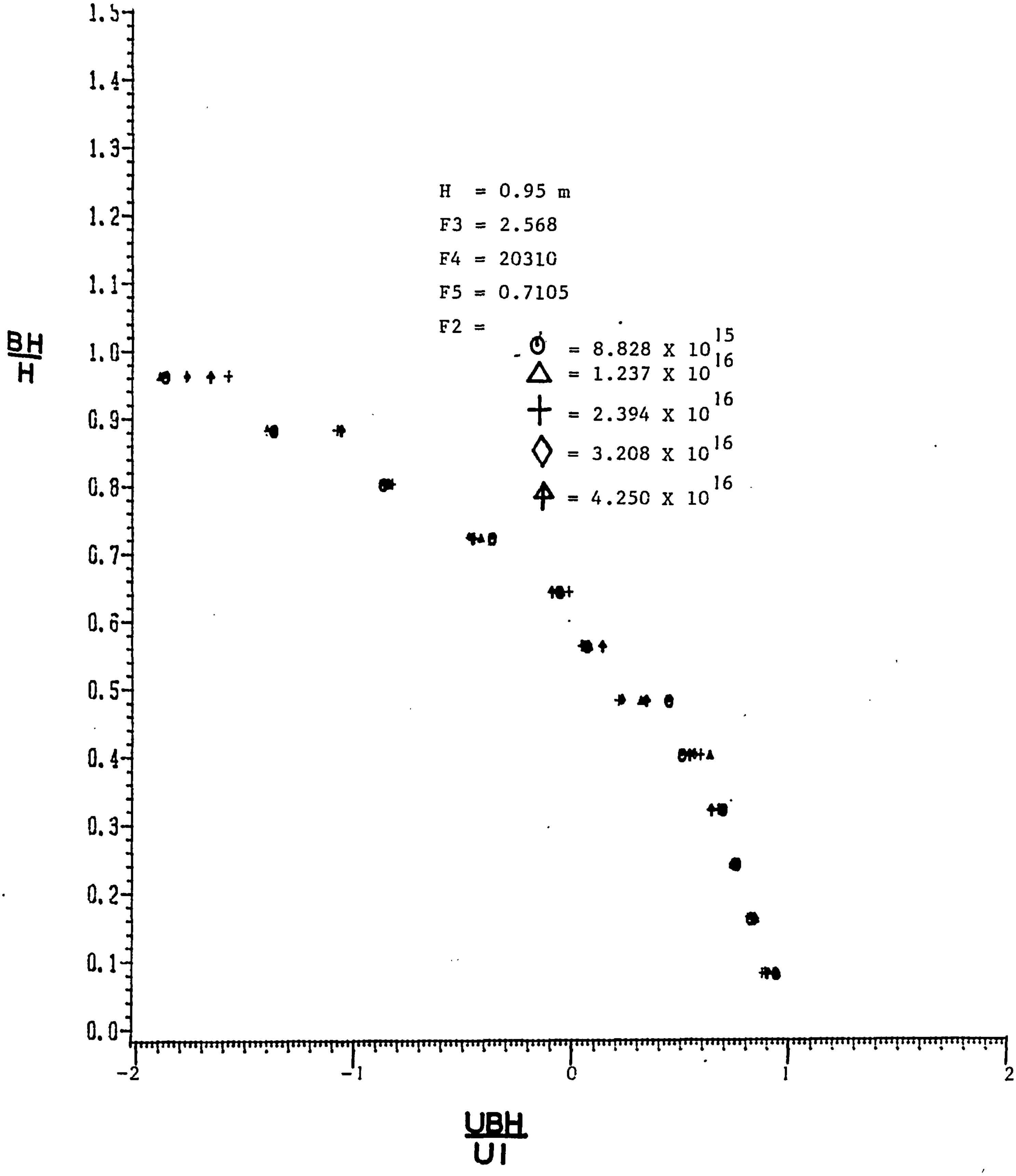

BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI
H = 0.80 m
F3 = 3.05
F4 = 17100
F5 = 0.8950
F2 =
○ = 7.880 X 10^15
△ = 1.105 X 10^16
+ = 2.140 X 10^16
◇ = 2.867 X 10^16
↑ = 3.794 X 10^16

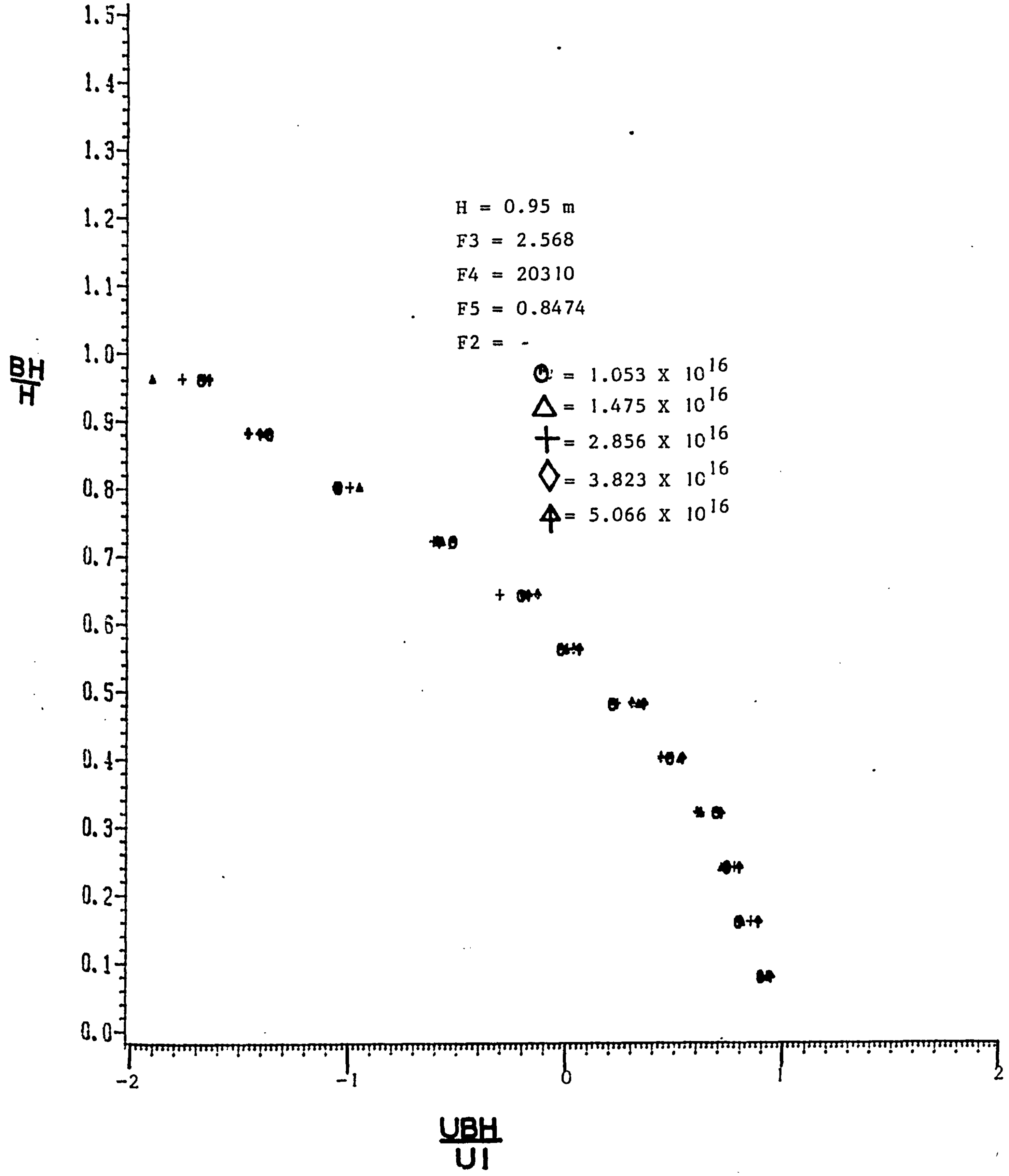
C.4 For Depth of 0.95 m

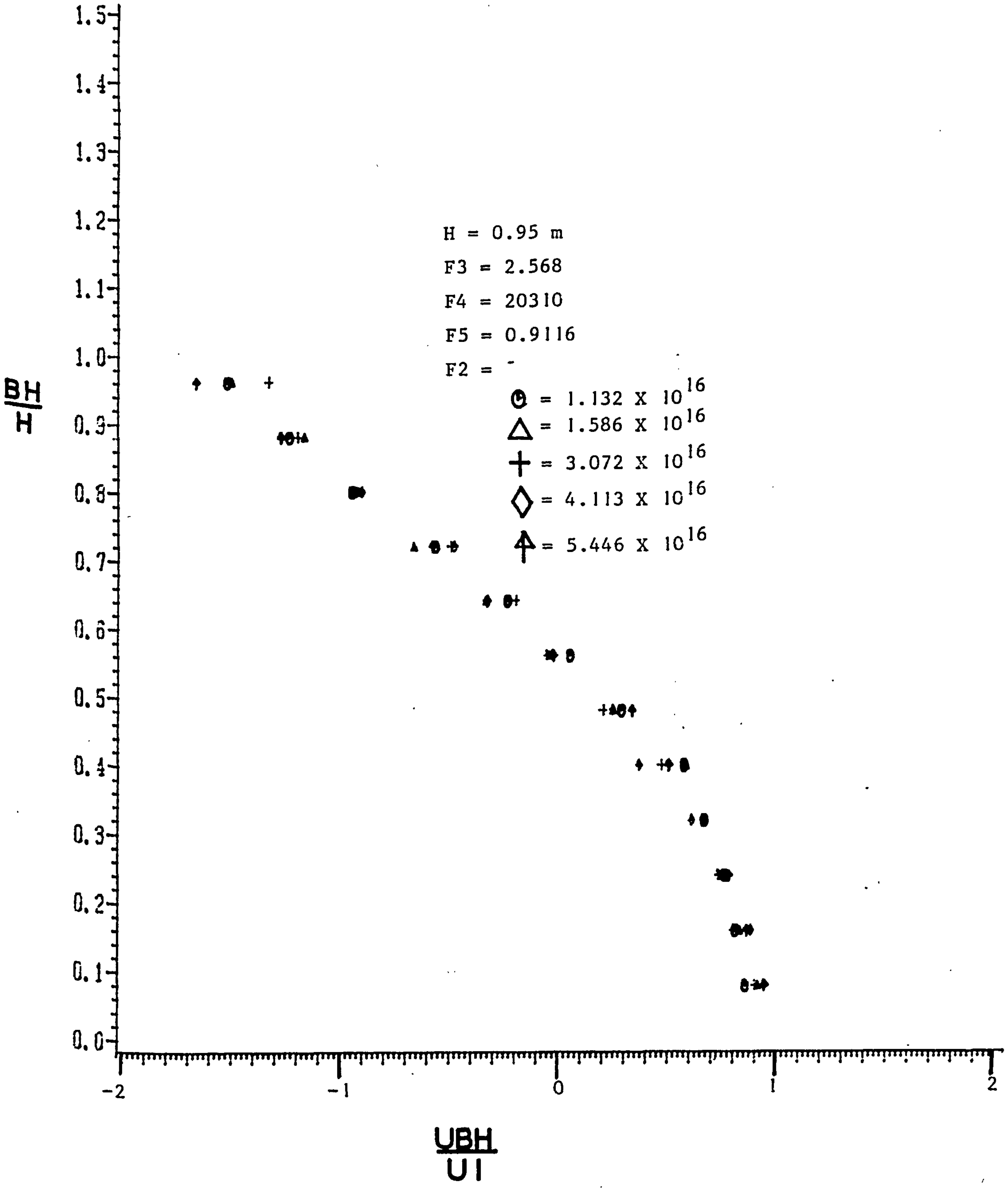

H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.4916
F2 =
○ = 6.103 X 10^{15}
△ = 8.554 X 10^{15}
+ = 1.647 X 10^{16}
◇ = 2.220 X 10^{16}
↑ = 2.940 X 10^{16}
BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI


H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.5726
F2 =
⊖ = 7.115 X 10^{15}
△ = 9.964 X 10^{15}
+ = 1.932 X 10^{16}
◇ = 2.585 X 10^{16}
⍋ = 3.423 X 10^{16}
BH/H
UBH/UI
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2

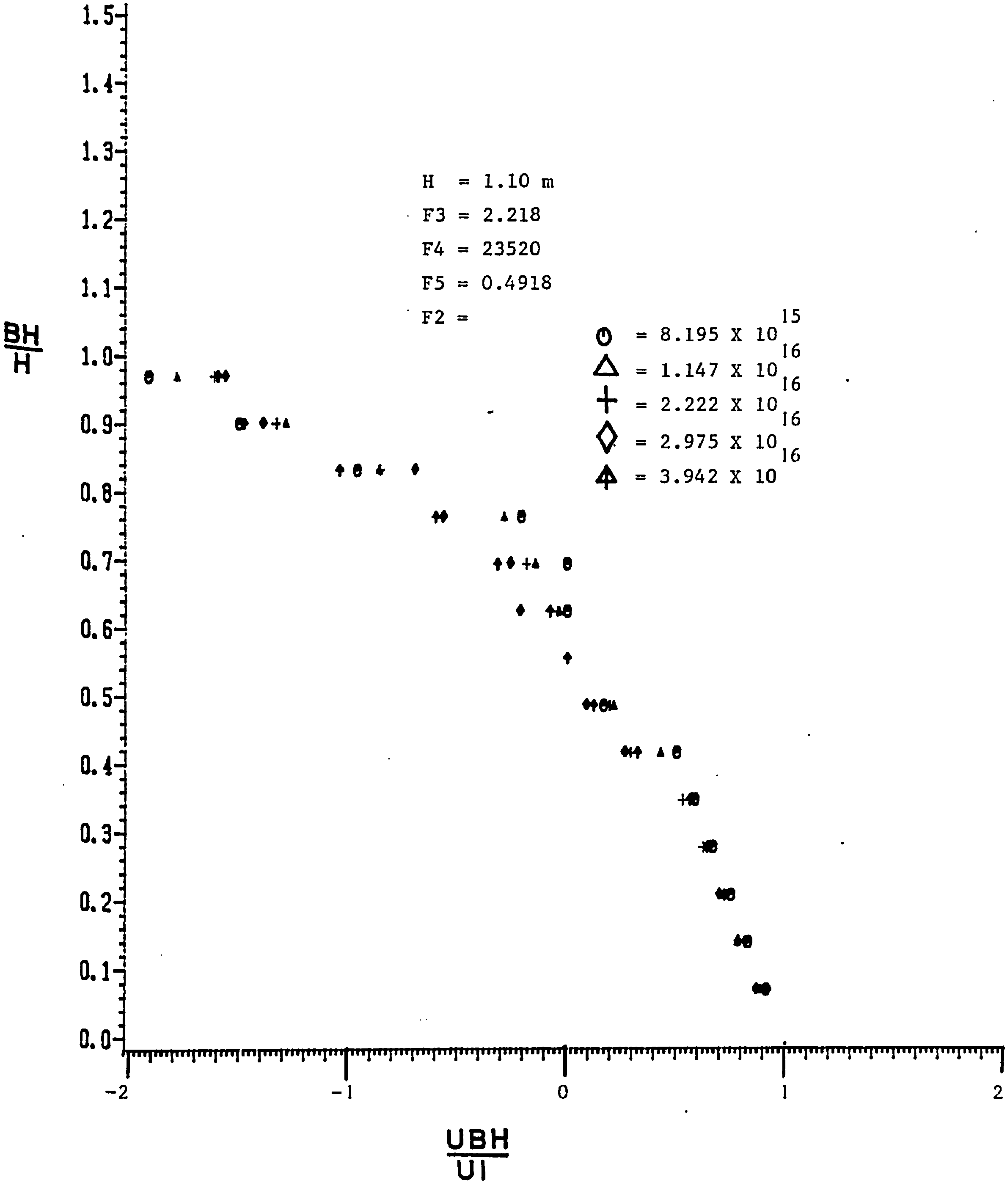

BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI
H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.6789
F2 =
○ = 8.431 X 10^15
△ = 1.182 X 10^16
+ = 2.289 X 10^16
◇ = 3.116 X 10^16
⧫ = 4.061 X 10^16

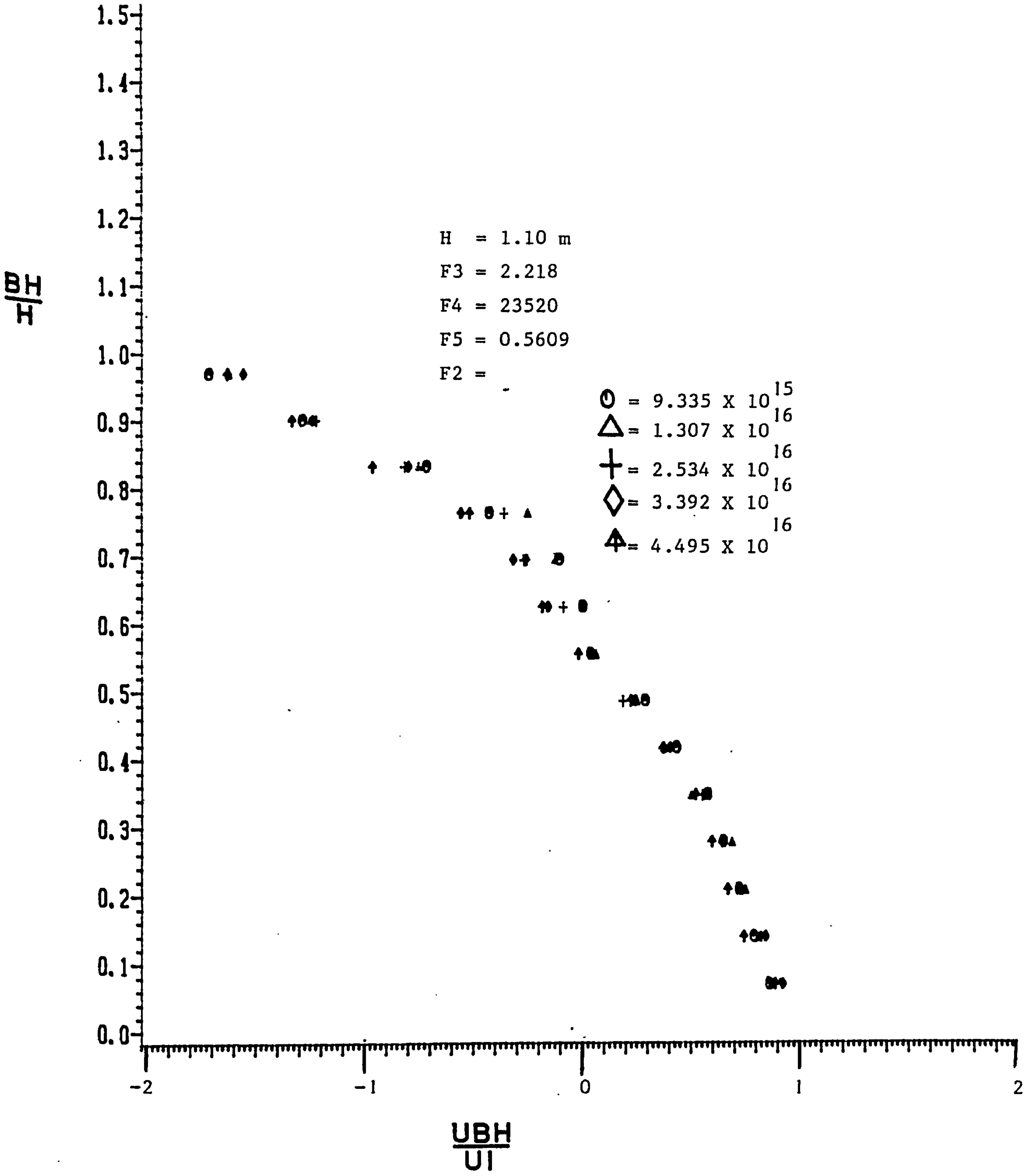

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH
H
-2
-1
0
1
2
UBH
UI
H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.7105
F2 =
= 8.828 X 10^15
= 1.237 X 10^16
= 2.394 X 10^16
= 3.208 X 10^16
= 4.250 X 10^16

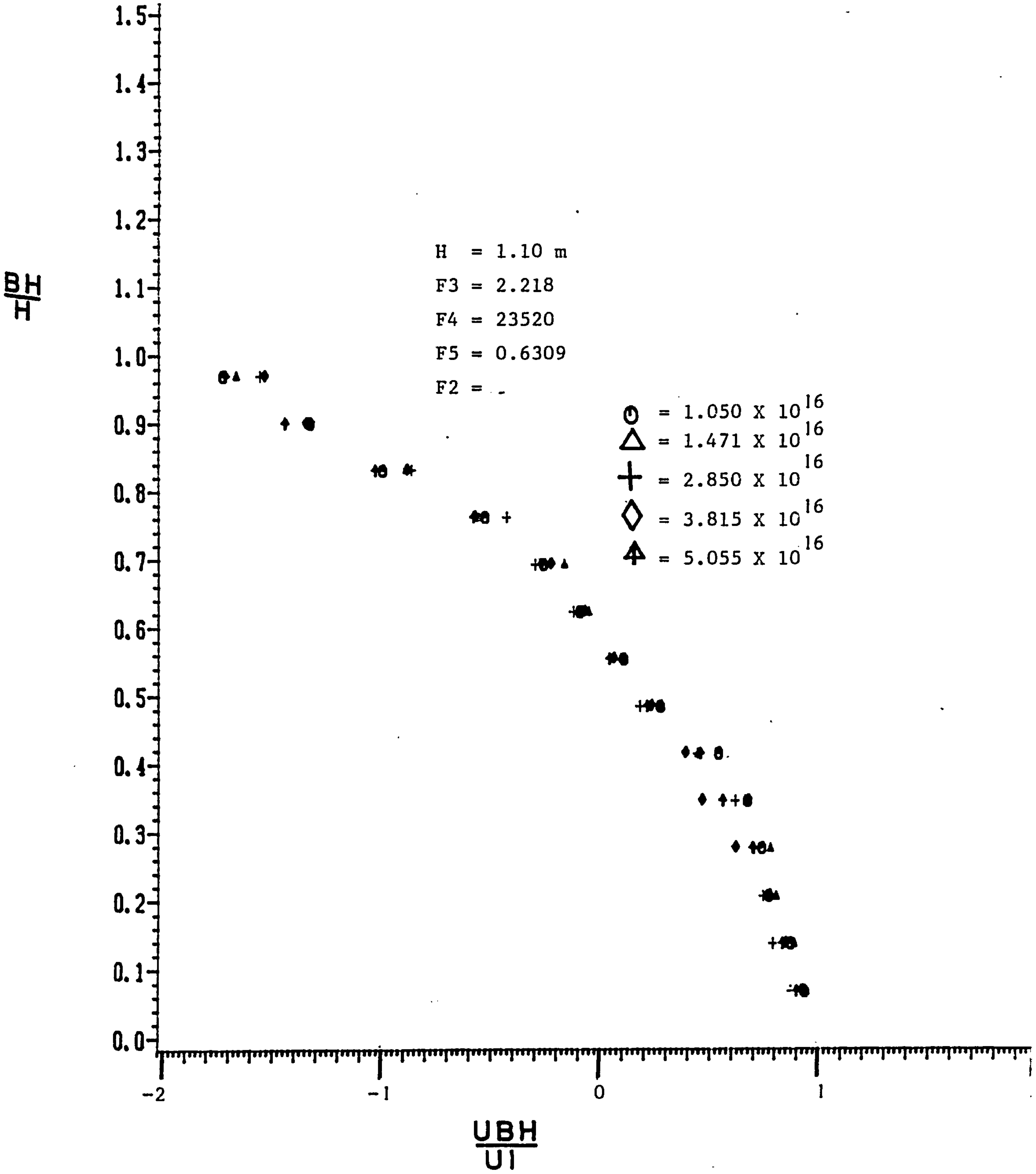

H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.8474
F2 = -
○ = 1.053 X 10^16
△ = 1.475 X 10^16
+ = 2.856 X 10^16
◇ = 3.823 X 10^16
⍋ = 5.066 X 10^16
BH/H
UBH/UI
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2

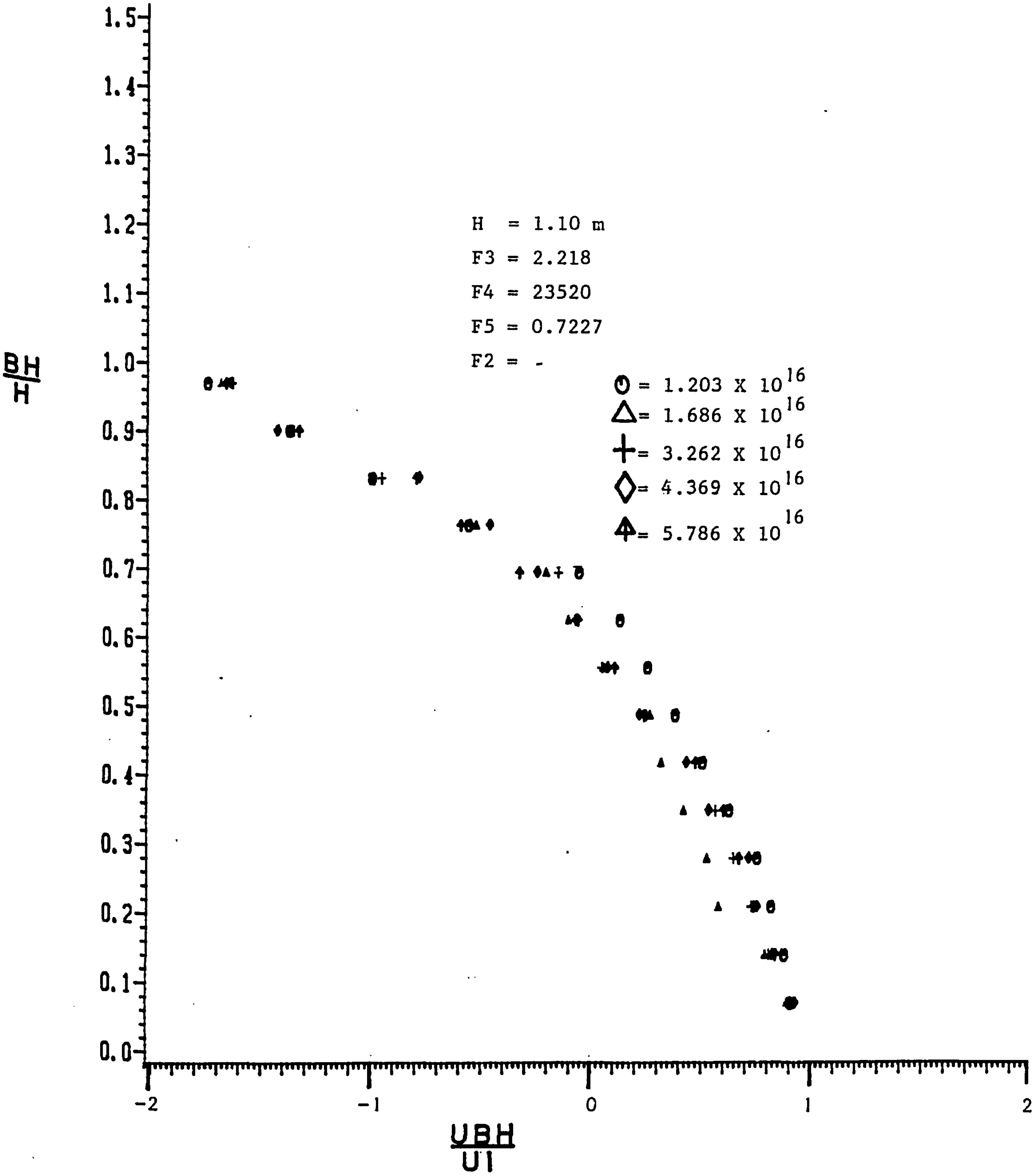

H = 0.95 m
F3 = 2.568
F4 = 20310
F5 = 0.9116
F2 =
○ = 1.132 X 10^16
△ = 1.586 X 10^16
+ = 3.072 X 10^16
◇ = 4.113 X 10^16
↑ = 5.446 X 10^16
BH/H
UBH/UI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
-2
-1
0
1
2

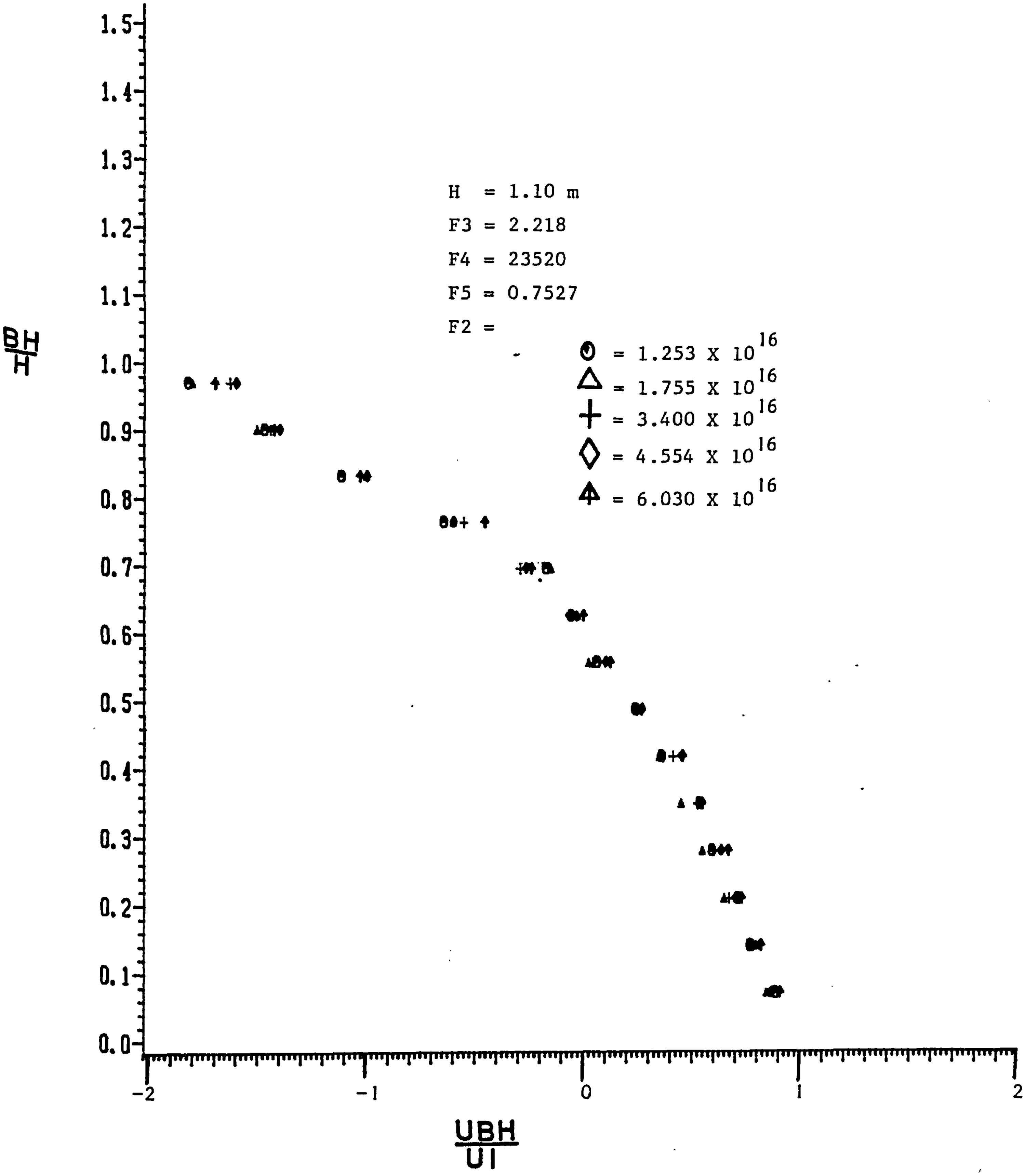
C.5 For Depth of 1.10 m

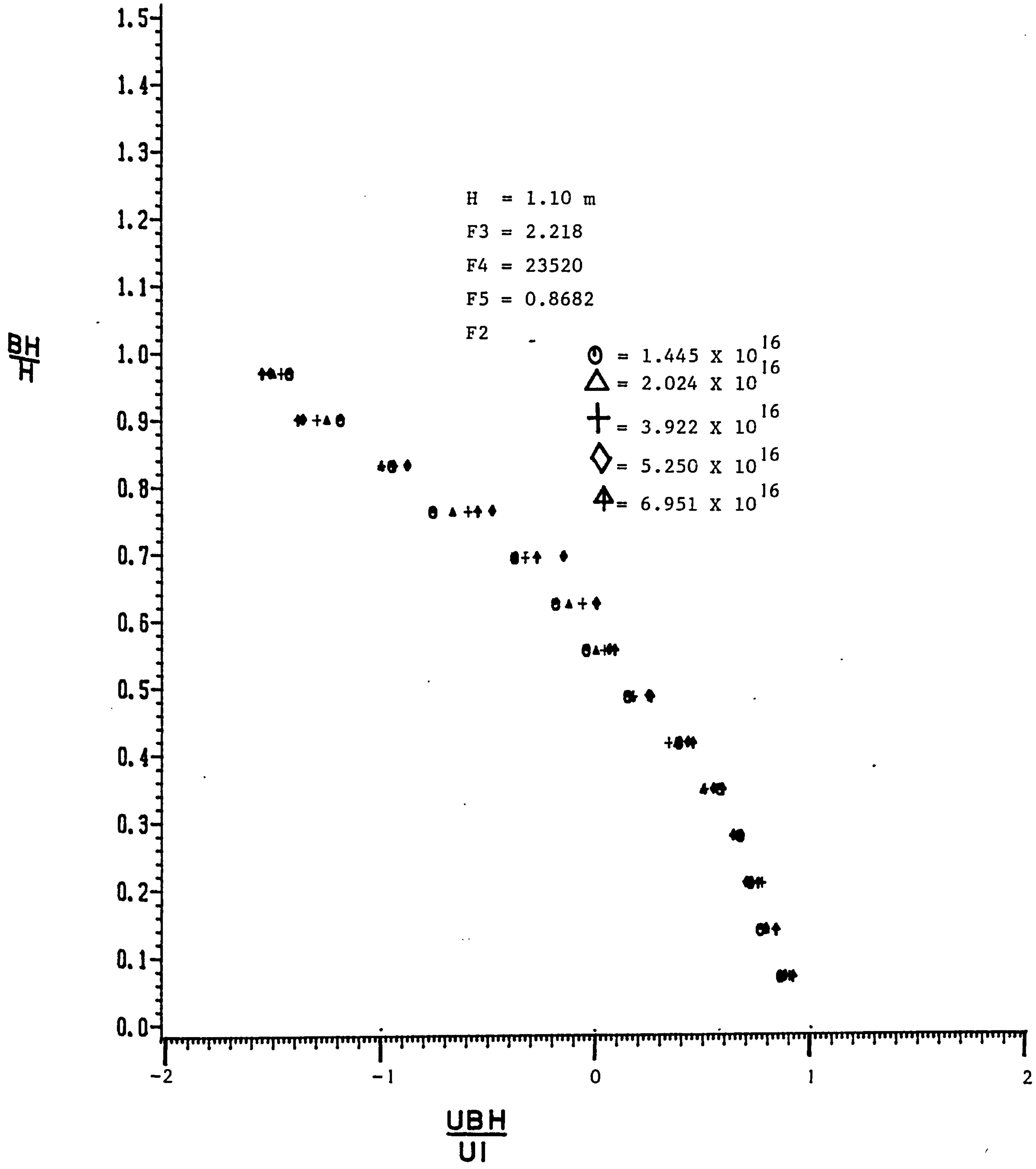

H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.4918
F2 =
○ = 8.195 X 10^15
△ = 1.147 X 10^16
+ = 2.222 X 10^16
◇ = 2.975 X 10^16
⍋ = 3.942 X 10^16
BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI

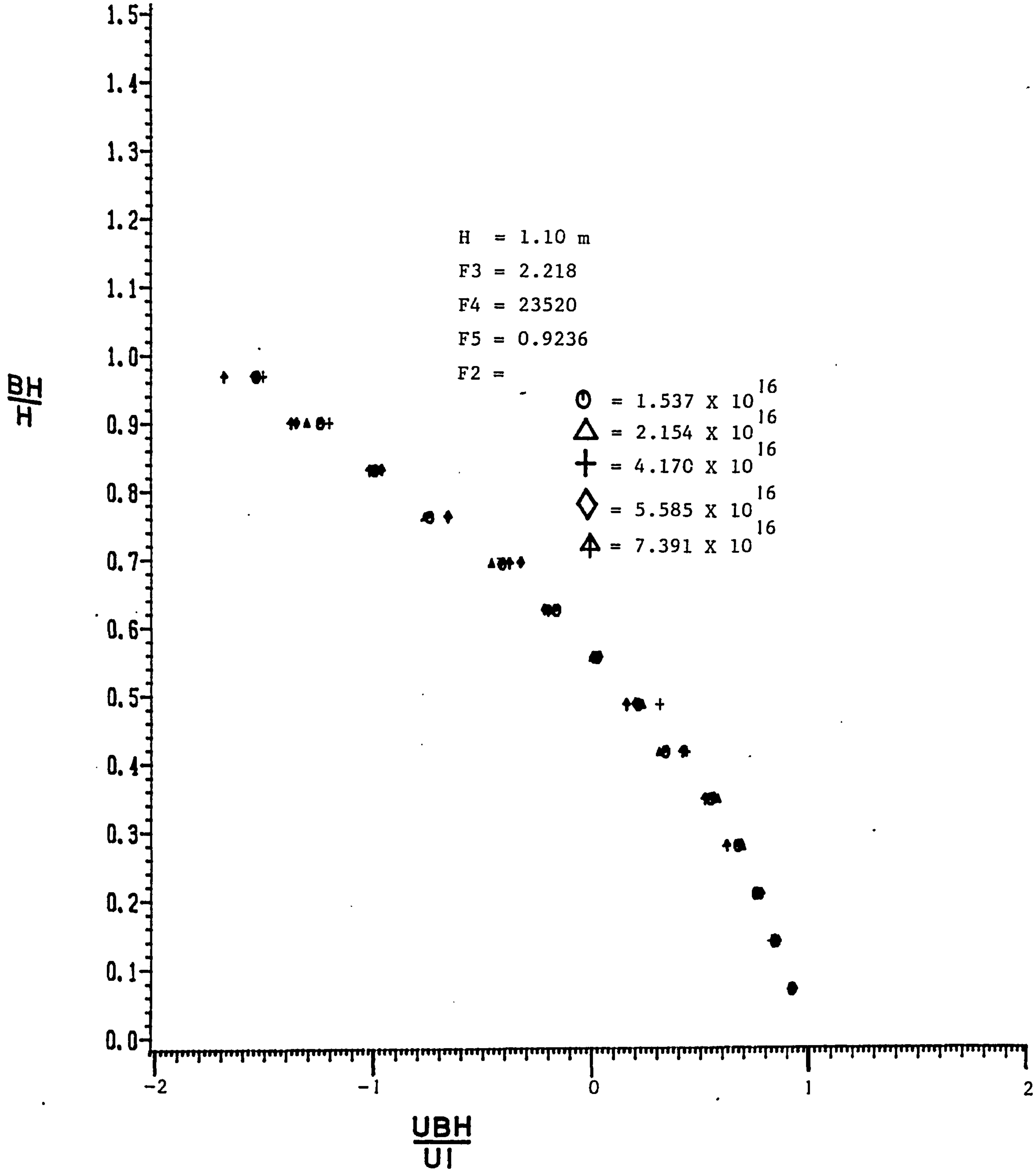

1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.5609
F2 =
○ = 9.335 X 10^15
△ = 1.307 X 10^16
+ = 2.534 X 10^16
◇ = 3.392 X 10^16
= 4.495 X 10^16


1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
UBH/UI
H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.6309
F2 = -
○ = 1.050 X 10^16
△ = 1.471 X 10^16
+ = 2.850 X 10^16
◇ = 3.815 X 10^16
△ = 5.055 X 10^16


H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.7227
F2 = -
○ = 1.203 X 10^16
△ = 1.686 X 10^16
+ = 3.262 X 10^16
◇ = 4.369 X 10^16
⊕ = 5.786 X 10^16
BH/H
UBH/UI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
-2
-1
0
1
2


1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
BH/H
-2
-1
0
1
2
UBH/UI
H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.7527
F2 =
○ = 1.253 X 10^16
△ = 1.755 X 10^16
+ = 3.400 X 10^16
◇ = 4.554 X 10^16
♀ = 6.030 X 10^16


H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.8682
F2
O = 1.445 X 10^16
△ = 2.024 X 10^16
+ = 3.922 X 10^16
◇ = 5.250 X 10^16
= 6.951 X 10^16
BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI


H = 1.10 m
F3 = 2.218
F4 = 23520
F5 = 0.9236
F2 =
⊙ = 1.537 X 10^16
△ = 2.154 X 10^16
+ = 4.170 X 10^16
◇ = 5.585 X 10^16
⍋ = 7.391 X 10^16
BH/H
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-2
-1
0
1
2
UBH/UI

Appendix.D

HORIZONTAL VELOCITIES AT 25 MM ABOVE THE AERATION TANK BOTTOM

Where SUBMER = Depth of Water above the Diffusers, m

U = Horizontal Velocity at 25 mm above Tank Bottom, m/s

H = Depth of Water in the Tank, m

P = Rate of Power Consumption (Useful) Using Submergence, Watts

X = Distance of Diffusers from the Right Sidewall of the tank, m

W = Width of the Tank, m

L = Length of the Tank (along the diffusers), m

```
OBSV   SUBMER        U             H             P             X             W             L

  1   0.4160E 00   0.1500E 00   0.5000E 00   0.2768E 02   0.1100E 00   0.2440E 01   0.6900E 00
  2   0.4160E 00   0.1300E 00   0.5000E 00   0.2090E 02   0.1100E 00   0.2440E 01   0.6900E 00
  3   0.4160E 00   0.1100E 00   0.5000E 00   0.1561E 02   0.1100E 00   0.2440E 01   0.6900E 00
  4   0.4160E 00   0.7000E-01   0.5000E 00   0.8050E 01   0.1100E 00   0.2440E 01   0.6900E 00
  5   0.3550E 00   0.1400E 00   0.5000E 00   0.2364E 02   0.4100E-01   0.2440E 01   0.6900E 00
  6   0.3550E 00   0.1200E 00   0.5000E 00   0.1783E 02   0.4100E-01   0.2440E 01   0.6900E 00
  7   0.3550E 00   0.1000E 00   0.5000E 00   0.1332E 02   0.4100E-01   0.2440E 01   0.6900E 00
  8   0.3550E 00   0.6000E-01   0.5000E 00   0.6878E 01   0.4100E-01   0.2440E 01   0.6900E 00
  9   0.2280E 00   0.1300E 00   0.5000E 00   0.1518E 02   0.1800E-01   0.2440E 01   0.6900E 00
 10   0.2280E 00   0.1100E 00   0.5000E 00   0.1145E 02   0.1800E-01   0.2440E 01   0.6900E 00
 11   0.2280E 00   0.9000E-01   0.5000E 00   0.8553E 01   0.1800E-01   0.2440E 01   0.6900E 00
 12   0.5660E 00   0.2400E 00   0.6500E 00   0.3765E 02   0.1100E 00   0.2440E 01   0.6900E 00
 13   0.5660E 00   0.2100E 00   0.6500E 00   0.2843E 02   0.1100E 00   0.2440E 01   0.6900E 00
 14   0.5660E 00   0.1800E 00   0.6500E 00   0.2124E 02   0.1100E 00   0.2440E 01   0.6900E 00
 15   0.5660E 00   0.1400E 00   0.6500E 00   0.1097E 02   0.1100E 00   0.2440E 01   0.6900E 00
 16   0.5050E 00   0.2200E 00   0.6500E 00   0.3361E 02   0.4100E-01   0.2440E 01   0.6900E 00
 17   0.5050E 00   0.2000E 00   0.6500E 00   0.2536E 02   0.4100E-01   0.2440E 01   0.6900E 00
 18   0.5050E 00   0.1700E 00   0.6500E 00   0.1896E 02   0.4100E-01   0.2440E 01   0.6900E 00
 19   0.5050E 00   0.1300E 00   0.6500E 00   0.9780E 01   0.4100E-01   0.2440E 01   0.6900E 00
 20   0.3780E 00   0.1800E 00   0.6500E 00   0.2517E 02   0.1800E-01   0.2440E 01   0.6900E 00
```

```
OBSV   SUBMER       U            H            P            X             W            L

 21  0.3780E 00  0.1600E 00  0.6500E 00  0.1899E 02  0.1800E-01  0.2440E 01  0.6900E 00

 22  0.3780E 00  0.1400E 00  0.6500E 00  0.1418E 02  0.1800E-01  0.2440E 01  0.6900E 00

 23  0.3780E 00  0.1000E 00  0.6500E 00  0.7320E 01  0.1800E-01  0.2440E 01  0.6900E 00

 24  0.3450E 00  0.1700E 00  0.6500E 00  0.2298E 02  0.2000E-01  0.2440E 01  0.6900E 00

 25  0.3450E 00  0.1500E 00  0.6500E 00  0.1733E 02  0.2000E-01  0.2440E 01  0.6900E 00

 26  0.3450E 00  0.1200E 00  0.6500E 00  0.1294E 02  0.2000E-01  0.2440E 01  0.6900E 00

 27  0.3450E 00  0.8000E-01  0.6500E 00  0.6690E 01  0.2000E-01  0.2440E 01  0.6900E 00

 28  0.7160E 00  0.3100E 00  0.8000E 00  0.4761E 02  0.1100E 00  0.2440E 01  0.6900E 00

 29  0.7160E 00  0.2900E 00  0.8000E 00  0.3598E 02  0.1100E 00  0.2440E 01  0.6900E 00

 30  0.7160E 00  0.2600E 00  0.8000E 00  0.2686E 02  0.1100E 00  0.2440E 01  0.6900E 00

 31  0.7160E 00  0.2000E 00  0.8000E 00  0.1387E 02  0.1100E 00  0.2440E 01  0.6900E 00

 32  0.7160E 00  0.1800E 00  0.8000E 00  0.9890E 01  0.1100E 00  0.2440E 01  0.6900E 00

 33  0.6550E 00  0.3000E 00  0.8000E 00  0.4358E 02  0.4100E-01  0.2440E 01  0.6900E 00

 34  0.6550E 00  0.2700E 00  0.8000E 00  0.3291E 02  0.4100E-01  0.2440E 01  0.6900E 00

 35  0.6550E 00  0.2300E 00  0.8000E 00  0.2456E 02  0.4100E-01  0.2440E 01  0.6900E 00

 36  0.6550E 00  0.1800E 00  0.8000E 00  0.1268E 02  0.4100E-01  0.2440E 01  0.6900E 00

 37  0.6550E 00  0.1500E 00  0.8000E 00  0.9050E 01  0.4100E-01  0.2440E 01  0.6900E 00

 38  0.5280E 00  0.2400E 00  0.8000E 00  0.3513E 02  0.1800E-01  0.2440E 01  0.6900E 00

 39  0.5280E 00  0.2200E 00  0.8000E 00  0.2650E 02  0.1800E-01  0.2440E 01  0.6900E 00

 40  0.5280E 00  0.2000E 00  0.8000E 00  0.1981E 02  0.1800E-01  0.2440E 01  0.6900E 00
```

```
OBSV   SUBMER       U           H           P           X           W           L

 41   0.5280E 00  0.1500E 00  0.8000E 00  0.1022E 02  0.1800E-01  0.2440E 01  0.6900E 00
 42   0.5280E 00  0.1200E 00  0.8000E 00  0.7300E 01  0.1800E-01  0.2440E 01  0.6900E 00
 43   0.4950E 00  0.2200E 00  0.8000E 00  0.3293E 02  0.2000E-01  0.2440E 01  0.6900E 00
 44   0.4950E 00  0.2000E 00  0.8000E 00  0.2486E 02  0.2000E-01  0.2440E 01  0.6900E 00
 45   0.4950E 00  0.1800E 00  0.8000E 00  0.1857E 02  0.2000E-01  0.2440E 01  0.6900E 00
 46   0.4950E 00  0.1400E 00  0.8000E 00  0.9590E 01  0.2000E-01  0.2440E 01  0.6900E 00
 47   0.4950E 00  0.1100E 00  0.8000E 00  0.6840E 01  0.2000E-01  0.2440E 01  0.6900E 00
 48   0.3940E 00  0.2000E 00  0.8000E 00  0.2621E 02  0.2000E-01  0.2440E 01  0.6900E 00
 49   0.3940E 00  0.1800E 00  0.8000E 00  0.1979E 02  0.2000E-01  0.2440E 01  0.6900E 00
 50   0.3940E 00  0.1600E 00  0.8000E 00  0.1478E 02  0.2000E-01  0.2440E 01  0.6900E 00
 51   0.3940E 00  0.1300E 00  0.8000E 00  0.7630E 01  0.2000E-01  0.2440E 01  0.6900E 00
 52   0.3940E 00  0.1000E 00  0.8000E 00  0.5440E 01  0.2000E-01  0.2440E 01  0.6900E 00
 53   0.8660E 00  0.3600E 00  0.9500E 00  0.5756E 02  0.1100E 00  0.2440E 01  0.6900E 00
 54   0.8660E 00  0.3300E 00  0.9500E 00  0.4347E 02  0.1100E 00  0.2440E 01  0.6900E 00
 55   0.8660E 00  0.3000E 00  0.9500E 00  0.3247E 02  0.1100E 00  0.2440E 01  0.6900E 00
 56   0.8660E 00  0.2400E 00  0.9500E 00  0.1676E 02  0.1100E 00  0.2440E 01  0.6900E 00
 57   0.8660E 00  0.2100E 00  0.9500E 00  0.1196E 02  0.1100E 00  0.2440E 01  0.6900E 00
 58   0.8050E 00  0.3400E 00  0.9500E 00  0.5354E 02  0.4100E-01  0.2440E 01  0.6900E 00
 59   0.8050E 00  0.3000E 00  0.9500E 00  0.4040E 02  0.4100E-01  0.2440E 01  0.6900E 00
 60   0.8050E 00  0.2600E 00  0.9500E 00  0.3018E 02  0.4100E-01  0.2440E 01  0.6900E 00
```

```
OBSV   SUBMER      U           H           P           X           W           L

 61  0.8050E 00  0.2100E 00  0.9500E 00  0.1559E 02  0.4100E-01  0.2440E 01  0.6900E 00
 62  0.8050E 00  0.1900E 00  0.9500E 00  0.1113E 02  0.4100E-01  0.2440E 01  0.6900E 00
 63  0.6750E 00  0.3000E 00  0.9500E 00  0.4492E 02  0.2000E-01  0.2440E 01  0.6900E 00
 64  0.6750E 00  0.2700E 00  0.9500E 00  0.3390E 02  0.2000E-01  0.2440E 01  0.6900E 00
 65  0.6750E 00  0.2400E 00  0.9500E 00  0.2530E 02  0.2000E-01  0.2440E 01  0.6900E 00
 66  0.6750E 00  0.1900E 00  0.9500E 00  0.1307E 02  0.2000E-01  0.2440E 01  0.6900E 00
 67  0.6750E 00  0.1600E 00  0.9500E 00  0.9330E 01  0.2000E-01  0.2440E 01  0.6900E 00
 68  0.6450E 00  0.2800E 00  0.9500E 00  0.4292E 02  0.2500E-01  0.2440E 01  0.6900E 00
 69  0.6450E 00  0.2600E 00  0.9500E 00  0.3293E 02  0.2500E-01  0.2440E 01  0.6900E 00
 70  0.6450E 00  0.2300E 00  0.9500E 00  0.2419E 02  0.2500E-01  0.2440E 01  0.6900E 00
 71  0.6450E 00  0.1800E 00  0.9500E 00  0.1249E 02  0.2500E-01  0.2440E 01  0.6900E 00
 72  0.6450E 00  0.1400E 00  0.9500E 00  0.8910E 01  0.2500E-01  0.2440E 01  0.6900E 00
 73  0.5440E 00  0.2700E 00  0.9500E 00  0.3618E 02  0.2500E-01  0.2440E 01  0.6900E 00
 74  0.5440E 00  0.2500E 00  0.9500E 00  0.2732E 02  0.2500E-01  0.2440E 01  0.6900E 00
 75  0.5440E 00  0.2200E 00  0.9500E 00  0.2042E 02  0.2500E-01  0.2440E 01  0.6900E 00
 76  0.5440E 00  0.1500E 00  0.9500E 00  0.1053E 02  0.2500E-01  0.2440E 01  0.6900E 00
 77  0.5440E 00  0.1200E 00  0.9500E 00  0.7520E 01  0.2500E-01  0.2440E 01  0.6900E 00
 78  0.4670E 00  0.2600E 00  0.9500E 00  0.3107E 02  0.2500E-01  0.2440E 01  0.6900E 00
 79  0.4670E 00  0.2400E 00  0.9500E 00  0.2346E 02  0.2500E-01  0.2440E 01  0.6900E 00
 80  0.4670E 00  0.2000E 00  0.9500E 00  0.1741E 02  0.2500E-01  0.2440E 01  0.6900E 00
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OBSV   SUBMER        U            H            P            X             W            L

 81   0.4670E 00   0.1400E 00   0.9500E 00   0.9040E 01   0.2500E-01   0.2440E 01   0.6900E 00
 82   0.4670E 00   0.1000E 00   0.9500E 00   0.6450E 01   0.2500E-01   0.2440E 01   0.6900E 00
 83   0.1016E 01   0.3900E 00   0.1100E 01   0.6746E 02   0.1100E 00   0.2440E 01   0.6900E 00
 84   0.1016E 01   0.3600E 00   0.1100E 01   0.5098E 02   0.1100E 00   0.2440E 01   0.6900E 00
 85   0.1016E 01   0.3300E 00   0.1100E 01   0.3806E 02   0.1100E 00   0.2440E 01   0.6900E 00
 86   0.1016E 01   0.2600E 00   0.1100E 01   0.1966E 02   0.1100E 00   0.2440E 01   0.6900E 00
 87   0.1016E 01   0.2400E 00   0.1100E 01   0.1403E 02   0.1100E 00   0.2440E 01   0.6900E 00
 88   0.9550E 00   0.3600E 00   0.1100E 01   0.6344E 02   0.4100E-01   0.2440E 01   0.6900E 00
 89   0.9550E 00   0.3300E 00   0.1100E 01   0.4792E 02   0.4100E-01   0.2440E 01   0.6900E 00
 90   0.9550E 00   0.3000E 00   0.1100E 01   0.3580E 02   0.4100E-01   0.2440E 01   0.6900E 00
 91   0.9550E 00   0.2400E 00   0.1100E 01   0.1847E 02   0.4100E-01   0.2440E 01   0.6900E 00
 92   0.9550E 00   0.2100E 00   0.1100E 01   0.1319E 02   0.4100E-01   0.2440E 01   0.6900E 00
 93   0.8280E 00   0.3300E 00   0.1100E 01   0.5504E 02   0.2000E-01   0.2440E 01   0.6900E 00
 94   0.8280E 00   0.3000E 00   0.1100E 01   0.4157E 02   0.2000E-01   0.2440E 01   0.6900E 00
 95   0.8280E 00   0.2700E 00   0.1100E 01   0.3103E 02   0.2000E-01   0.2440E 01   0.6900E 00
 96   0.8280E 00   0.2000E 00   0.1100E 01   0.1602E 02   0.2000E-01   0.2440E 01   0.6900E 00
 97   0.8280E 00   0.1700E 00   0.1100E 01   0.1144E 02   0.2000E-01   0.2440E 01   0.6900E 00
 98   0.7950E 00   0.3000E 00   0.1100E 01   0.5281E 02   0.2500E-01   0.2440E 01   0.6900E 00
 99   0.7950E 00   0.2800E 00   0.1100E 01   0.3988E 02   0.2500E-01   0.2440E 01   0.6900E 00
100   0.7950E 00   0.2500E 00   0.1100E 01   0.2977E 02   0.2500E-01   0.2440E 01   0.6900E 00
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OBSV   SUBMER       U            H            P            X            W            L

101   0.7950E 00   0.1900E 00   0.1100E 01   0.1539E 02   0.2500E-01   0.2440E 01   0.6900E 00
102   0.7950E 00   0.1600E 00   0.1100E 01   0.1098E 02   0.2500E-01   0.2440E 01   0.6900E 00
103   0.6940E 00   0.2900E 00   0.1100E 01   0.4614E 02   0.2500E-01   0.2440E 01   0.6900E 00
104   0.6940E 00   0.2600E 00   0.1100E 01   0.3482E 02   0.2500E-01   0.2440E 01   0.6900E 00
105   0.6940E 00   0.2300E 00   0.1100E 01   0.2601E 02   0.2500E-01   0.2440E 01   0.6900E 00
106   0.6940E 00   0.1800E 00   0.1100E 01   0.1343E 02   0.2500E-01   0.2440E 01   0.6900E 00
107   0.6940E 00   0.1500E 00   0.1100E 01   0.9580E 01   0.2500E-01   0.2440E 01   0.6900E 00
108   0.6170E 00   0.2700E 00   0.1100E 01   0.4103E 02   0.2500E-01   0.2440E 01   0.6900E 00
109   0.6170E 00   0.2500E 00   0.1100E 01   0.3096E 02   0.2500E-01   0.2440E 01   0.6900E 00
110   0.6170E 00   0.2200E 00   0.1100E 01   0.2313E 02   0.2500E-01   0.2440E 01   0.6900E 00
111   0.6170E 00   0.1600E 00   0.1100E 01   0.1193E 02   0.2500E-01   0.2440E 01   0.6900E 00
112   0.6170E 00   0.1400E 00   0.1100E 01   0.8520E 01   0.2500E-01   0.2440E 01   0.6900E 00
113   0.5410E 00   0.2500E 00   0.1100E 01   0.3598E 02   0.2500E-01   0.2440E 01   0.6900E 00
114   0.5410E 00   0.2300E 00   0.1100E 01   0.2715E 02   0.2500E-01   0.2440E 01   0.6900E 00
115   0.5410E 00   0.2100E 00   0.1100E 01   0.2028E 02   0.2500E-01   0.2440E 01   0.6900E 00
116   0.5410E 00   0.1400E 00   0.1100E 01   0.1047E 02   0.2500E-01   0.2440E 01   0.6900E 00
117   0.5410E 00   0.1200E 00   0.1100E 01   0.7480E 01   0.2500E-01   0.2440E 01   0.6900E 00
118   0.4160E 00   0.1700E 00   0.5000E 00   0.2623E 02   0.1100E 00   0.2210E 01   0.6900E 00
119   0.4160E 00   0.1500E 00   0.5000E 00   0.1995E 02   0.1100E 00   0.2210E 01   0.6900E 00
120   0.4160E 00   0.1300E 00   0.5000E 00   0.1496E 02   0.1100E 00   0.2210E 01   0.6900E 00
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OBSV   SUBMER       U            H            P            X            W            L

121  0.4160E 00  0.8000E-01  0.5000E 00  0.7760E 01  0.1100E 00  0.2210E 01  0.6900E 00
122  0.3550E 00  0.1600E 00  0.5000E 00  0.2251E 02  0.4100E-01  0.2210E 01  0.6900E 00
123  0.3550E 00  0.1400E 00  0.5000E 00  0.1712E 02  0.4100E-01  0.2210E 01  0.6900E 00
124  0.3550E 00  0.1200E 00  0.5000E 00  0.1284E 02  0.4100E-01  0.2210E 01  0.6900E 00
125  0.3550E 00  0.8000E-01  0.5000E 00  0.6659E 01  0.4100E-01  0.2210E 01  0.6900E 00
126  0.2280E 00  0.1500E 00  0.5000E 00  0.1463E 02  0.1800E-01  0.2210E 01  0.6900E 00
127  0.2280E 00  0.1250E 00  0.5000E 00  0.1113E 02  0.1800E-01  0.2210E 01  0.6900E 00
128  0.2280E 00  0.1100E 00  0.5000E 00  0.8348E 01  0.1800E-01  0.2210E 01  0.6900E 00
129  0.5660E 00  0.2600E 00  0.6500E 00  0.3519E 02  0.1100E 00  0.2210E 01  0.6900E 00
130  0.5660E 00  0.2300E 00  0.6500E 00  0.2677E 02  0.1100E 00  0.2210E 01  0.6900E 00
131  0.5660E 00  0.2100E 00  0.6500E 00  0.2008E 02  0.1100E 00  0.2210E 01  0.6900E 00
132  0.5660E 00  0.1600E 00  0.6500E 00  0.1041E 02  0.1100E 00  0.2210E 01  0.6900E 00
133  0.5050E 00  0.2500E 00  0.6500E 00  0.3158E 02  0.4100E-01  0.2210E 01  0.6900E 00
134  0.5050E 00  0.2200E 00  0.6500E 00  0.2402E 02  0.4100E-01  0.2210E 01  0.6900E 00
135  0.5050E 00  0.2000E 00  0.6500E 00  0.1802E 02  0.4100E-01  0.2210E 01  0.6900E 00
136  0.5050E 00  0.1500E 00  0.6500E 00  0.9340E 01  0.4100E-01  0.2210E 01  0.6900E 00
137  0.3780E 00  0.2100E 00  0.6500E 00  0.2392E 02  0.1800E-01  0.2210E 01  0.6900E 00
138  0.3780E 00  0.1800E 00  0.6500E 00  0.1819E 02  0.1800E-01  0.2210E 01  0.6900E 00
139  0.3780E 00  0.1600E 00  0.6500E 00  0.1365E 02  0.1800E-01  0.2210E 01  0.6900E 00
140  0.3780E 00  0.1200E 00  0.6500E 00  0.7080E 01  0.1800E-01  0.2210E 01  0.6900E 00
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OBSV  SUBMER      U           H           P           X           W           L

141   0.3450E 00  0.1900E 00  0.6500E 00  0.2190E 02  0.2000E-01  0.2210E 01  0.6900E 00
142   0.3450E 00  0.1700E 00  0.6500E 00  0.1666E 02  0.2000E-01  0.2210E 01  0.6900E 00
143   0.3450E 00  0.1400E 00  0.6500E 00  0.1249E 02  0.2000E-01  0.2210E 01  0.6900E 00
144   0.3450E 00  0.9000E-01  0.6500E 00  0.6480E 01  0.2000E-01  0.2210E 01  0.6900E 00
145   0.7160E 00  0.3400E 00  0.8000E 00  0.4392E 02  0.1100E 00  0.2210E 01  0.6900E 00
146   0.7160E 00  0.3100E 00  0.8000E 00  0.3340E 02  0.1100E 00  0.2210E 01  0.6900E 00
147   0.7160E 00  0.2800E 00  0.8000E 00  0.2505E 02  0.1100E 00  0.2210E 01  0.6900E 00
148   0.7160E 00  0.2200E 00  0.8000E 00  0.1299E 02  0.1100E 00  0.2210E 01  0.6900E 00
149   0.7160E 00  0.1900E 00  0.8000E 00  0.9280E 01  0.1100E 00  0.2210E 01  0.6900E 00
150   0.6550E 00  0.3200E 00  0.8000E 00  0.4040E 02  0.4100E-01  0.2210E 01  0.6900E 00
151   0.6550E 00  0.2800E 00  0.8000E 00  0.3073E 02  0.4100E-01  0.2210E 01  0.6900E 00
152   0.6550E 00  0.2500E 00  0.8000E 00  0.2305E 02  0.4100E-01  0.2210E 01  0.6900E 00
153   0.6550E 00  0.1900E 00  0.8000E 00  0.1195E 02  0.4100E-01  0.2210E 01  0.6900E 00
154   0.6550E 00  0.1600E 00  0.8000E 00  0.8540E 01  0.4100E-01  0.2210E 01  0.6900E 00
155   0.5280E 00  0.2800E 00  0.8000E 00  0.3295E 02  0.1800E-01  0.2210E 01  0.6900E 00
156   0.5280E 00  0.2500E 00  0.8000E 00  0.2506E 02  0.1800E-01  0.2210E 01  0.6900E 00
157   0.5280E 00  0.2100E 00  0.8000E 00  0.1880E 02  0.1800E-01  0.2210E 01  0.6900E 00
158   0.5280E 00  0.1600E 00  0.8000E 00  0.9750E 01  0.1800E-01  0.2210E 01  0.6900E 00
159   0.5280E 00  0.1300E 00  0.8000E 00  0.6960E 01  0.1800E-01  0.2210E 01  0.6900E 00
160   0.4950E 00  0.2600E 00  0.8000E 00  0.3099E 02  0.2000E-01  0.2210E 01  0.6900E 00
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OBSV	SUBMER	U	H	P	X	W	L
161	0.4950E 00	0.2400E 00	0.8000E 00	0.2357E 02	0.2000E-01	0.2210E 01	0.6900E 00
162	0.4950E 00	0.2000E 00	0.8000E 00	0.1768E 02	0.2000E-01	0.2210E 01	0.6900E 00
163	0.4950E 00	0.1500E 00	0.8000E 00	0.9160E 01	0.2000E-01	0.2210E 01	0.6900E 00
164	0.4950E 00	0.1200E 00	0.8000E 00	0.6550E 01	0.2000E-01	0.2210E 01	0.6900E 00
165	0.3940E 00	0.2400E 00	0.8000E 00	0.2490E 02	0.2000E-01	0.2210E 01	0.6900E 00
166	0.3940E 00	0.2200E 00	0.8000E 00	0.1894E 02	0.2000E-01	0.2210E 01	0.6900E 00
167	0.3940E 00	0.1900E 00	0.8000E 00	0.1420E 02	0.2000E-01	0.2210E 01	0.6900E 00
168	0.3940E 00	0.1400E 00	0.8000E 00	0.7360E 01	0.2000E-01	0.2210E 01	0.6900E 00
169	0.3940E 00	0.1100E 00	0.8000E 00	0.5260E 01	0.2000E-01	0.2210E 01	0.6900E 00
170	0.8660E 00	0.4000E 00	0.9500E 00	0.5241E 02	0.1100E 00	0.2210E 01	0.6900E 00
171	0.8660E 00	0.3600E 00	0.9500E 00	0.3986E 02	0.1100E 00	0.2210E 01	0.6900E 00
172	0.8660E 00	0.3300E 00	0.9500E 00	0.2989E 02	0.1100E 00	0.2210E 01	0.6900E 00
173	0.8660E 00	0.2700E 00	0.9500E 00	0.1550E 02	0.1100E 00	0.2210E 01	0.6900E 00
174	0.8660E 00	0.2400E 00	0.9500E 00	0.1107E 02	0.1100E 00	0.2210E 01	0.6900E 00
175	0.8050E 00	0.3500E 00	0.9500E 00	0.4898E 02	0.4100E-01	0.2210E 01	0.6900E 00
176	0.8050E 00	0.3250E 00	0.9500E 00	0.3726E 02	0.4100E-01	0.2210E 01	0.6900E 00
177	0.8050E 00	0.2800E 00	0.9500E 00	0.2794E 02	0.4100E-01	0.2210E 01	0.6900E 00
178	0.8050E 00	0.2300E 00	0.9500E 00	0.1449E 02	0.4100E-01	0.2210E 01	0.6900E 00
179	0.8050E 00	0.2100E 00	0.9500E 00	0.1035E 02	0.4100E-01	0.2210E 01	0.6900E 00
180	0.6750E 00	0.3300E 00	0.9500E 00	0.4156E 02	0.2000E-01	0.2210E 01	0.6900E 00

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OBSV   SUBMER       U           H           P           X           W           L

181  0.6750E 00  0.3000E 00  0.9500E 00  0.3161E 02  0.2000E-01  0.2210E 01  0.6900E 00
182  0.6750E 00  0.2600E 00  0.9500E 00  0.2371E 02  0.2000E-01  0.2210E 01  0.6900E 00
183  0.6750E 00  0.2100E 00  0.9500E 00  0.1229E 02  0.2000E-01  0.2210E 01  0.6900E 00
184  0.6750E 00  0.1750E 00  0.9500E 00  0.8780E 01  0.2000E-01  0.2210E 01  0.6900E 00
185  0.6450E 00  0.3150E 00  0.9500E 00  0.3982E 02  0.2500E-01  0.2210E 01  0.6900E 00
186  0.6450E 00  0.2800E 00  0.9500E 00  0.3029E 02  0.2500E-01  0.2210E 01  0.6900E 00
187  0.6450E 00  0.2400E 00  0.9500E 00  0.2272E 02  0.2500E-01  0.2210E 01  0.6900E 00
188  0.6450E 00  0.1950E 00  0.9500E 00  0.1178E 02  0.2500E-01  0.2210E 01  0.6900E 00
189  0.6450E 00  0.1600E 00  0.9500E 00  0.8410E 01  0.2500E-01  0.2210E 01  0.6900E 00
190  0.5440E 00  0.2900E 00  0.9500E 00  0.3390E 02  0.2500E-01  0.2210E 01  0.6900E 00
191  0.5440E 00  0.2600E 00  0.9500E 00  0.2578E 02  0.2500E-01  0.2210E 01  0.6900E 00
192  0.5440E 00  0.2300E 00  0.9500E 00  0.1934E 02  0.2500E-01  0.2210E 01  0.6900E 00
193  0.5440E 00  0.1800E 00  0.9500E 00  0.1003E 02  0.2500E-01  0.2210E 01  0.6900E 00
194  0.5440E 00  0.1500E 00  0.9500E 00  0.7160E 01  0.2500E-01  0.2210E 01  0.6900E 00
195  0.4670E 00  0.2600E 00  0.9500E 00  0.2931E 02  0.2500E-01  0.2210E 01  0.6900E 00
196  0.4670E 00  0.2400E 00  0.9500E 00  0.2229E 02  0.2500E-01  0.2210E 01  0.6900E 00
197  0.4670E 00  0.2100E 00  0.9500E 00  0.1672E 02  0.2500E-01  0.2210E 01  0.6900E 00
198  0.4670E 00  0.1700E 00  0.9500E 00  0.8670E 01  0.2500E-01  0.2210E 01  0.6900E 00
199  0.4670E 00  0.1400E 00  0.9500E 00  0.6190E 01  0.2500E-01  0.2210E 01  0.6900E 00
200  0.1016E 01  0.4500E 00  0.1100E 01  0.6067E 02  0.1100E 00  0.2210E 01  0.6900E 00
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OBSV   SUBMER       U            H            P            X            W            L

201  0.1016E 01  0.4200E 00  0.1100E 01  0.4614E 02  0.1100E 00  0.2210E 01  0.6900E 00
202  0.1016E 01  0.3800E 00  0.1100E 01  0.3461E 02  0.1100E 00  0.2210E 01  0.6900E 00
203  0.1016E 01  0.3200E 00  0.1100E 01  0.1794E 02  0.1100E 00  0.2210E 01  0.6900E 00
204  0.1016E 01  0.3000E 00  0.1100E 01  0.1282E 02  0.1100E 00  0.2210E 01  0.6900E 00
205  0.9550E 00  0.4200E 00  0.1100E 01  0.5733E 02  0.4100E-01  0.2210E 01  0.6900E 00
206  0.9550E 00  0.3900E 00  0.1100E 01  0.4361E 02  0.4100E-01  0.2210E 01  0.6900E 00
207  0.9550E 00  0.3600E 00  0.1100E 01  0.3270E 02  0.4100E-01  0.2210E 01  0.6900E 00
208  0.9550E 00  0.3000E 00  0.1100E 01  0.1696E 02  0.4100E-01  0.2210E 01  0.6900E 00
209  0.9550E 00  0.2800E 00  0.1100E 01  0.1211E 02  0.4100E-01  0.2210E 01  0.6900E 00
210  0.8280E 00  0.3900E 00  0.1100E 01  0.5028E 02  0.2000E-01  0.2210E 01  0.6900E 00
211  0.8280E 00  0.3600E 00  0.1100E 01  0.3824E 02  0.2000E-01  0.2210E 01  0.6900E 00
212  0.8280E 00  0.3200E 00  0.1100E 01  0.2868E 02  0.2000E-01  0.2210E 01  0.6900E 00
213  0.8280E 00  0.2500E 00  0.1100E 01  0.1487E 02  0.2000E-01  0.2210E 01  0.6900E 00
214  0.8280E 00  0.2300E 00  0.1100E 01  0.1062E 02  0.2000E-01  0.2210E 01  0.6900E 00
215  0.7950E 00  0.3600E 00  0.1100E 01  0.4842E 02  0.2500E-01  0.2210E 01  0.6900E 00
216  0.7950E 00  0.3300E 00  0.1100E 01  0.3683E 02  0.2500E-01  0.2210E 01  0.6900E 00
217  0.7950E 00  0.3000E 00  0.1100E 01  0.2762E 02  0.2500E-01  0.2210E 01  0.6900E 00
218  0.7950E 00  0.2400E 00  0.1100E 01  0.1432E 02  0.2500E-01  0.2210E 01  0.6900E 00
219  0.7950E 00  0.2200E 00  0.1100E 01  0.1023E 02  0.2500E-01  0.2210E 01  0.6900E 00
220  0.6940E 00  0.3400E 00  0.1100E 01  0.4266E 02  0.2500E-01  0.2210E 01  0.6900E 00
```

OBSV	SUBMER	U	H	P	X	W	L
221	0.6940E 00	0.3200E 00	0.1100E 01	0.3244E 02	0.2500E-01	0.2210E 01	0.6900E 00
222	0.6940E 00	0.2900E 00	0.1100E 01	0.2433E 02	0.2500E-01	0.2210E 01	0.6900E 00
223	0.6940E 00	0.2200E 00	0.1100E 01	0.1262E 02	0.2500E-01	0.2210E 01	0.6900E 00
224	0.6940E 00	0.2000E 00	0.1100E 01	0.9010E 01	0.2500E-01	0.2210E 01	0.6900E 00
225	0.6170E 00	0.3200E 00	0.1100E 01	0.3820E 02	0.2500E-01	0.2210E 01	0.6900E 00
226	0.6170E 00	0.3000E 00	0.1100E 01	0.2905E 02	0.2500E-01	0.2210E 01	0.6900E 00
227	0.6170E 00	0.2800E 00	0.1100E 01	0.2179E 02	0.2500E-01	0.2210E 01	0.6900E 00
228	0.6170E 00	0.2100E 00	0.1100E 01	0.1130E 02	0.2500E-01	0.2210E 01	0.6900E 00
229	0.6170E 00	0.1900E 00	0.1100E 01	0.8070E 01	0.2500E-01	0.2210E 01	0.6900E 00
230	0.5410E 00	0.3000E 00	0.1100E 01	0.3372E 02	0.2500E-01	0.2210E 01	0.6900E 00
231	0.5410E 00	0.2800E 00	0.1100E 01	0.2565E 02	0.2500E-01	0.2210E 01	0.6900E 00
232	0.5410E 00	0.2600E 00	0.1100E 01	0.1924E 02	0.2500E-01	0.2210E 01	0.6900E 00
233	0.5410E 00	0.2000E 00	0.1100E 01	0.9970E 01	0.2500E-01	0.2210E 01	0.6900E 00
234	0.5410E 00	0.1800E 00	0.1100E 01	0.7120E 01	0.2500E-01	0.2210E 01	0.6900E 00
235	0.4160E 00	0.1800E 00	0.5000E 00	0.2623E 02	0.1100E 00	0.1980E 01	0.6900E 00
236	0.4160E 00	0.1600E 00	0.5000E 00	0.1995E 02	0.1100E 00	0.1980E 01	0.6900E 00
237	0.4160E 00	0.1400E 00	0.5000E 00	0.1496E 02	0.1100E 00	0.1980E 01	0.6900E 00
238	0.4160E 00	0.8500E-01	0.5000E 00	0.7760E 01	0.1100E 00	0.1980E 01	0.6900E 00
239	0.3550E 00	0.1750E 00	0.5000E 00	0.2251E 02	0.4100E-01	0.1980E 01	0.6900E 00
240	0.3550E 00	0.1500E 00	0.5000E 00	0.1712E 02	0.4100E-01	0.1980E 01	0.6900E 00

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OBSV   SUBMER      U            H            P            X            W            L

241   0.3550E 00  0.1350E 00   0.5000E 00   0.1284E 02   0.4100E-01   0.1980E 01   0.6900E 00
242   0.3550E 00  0.8000E-01   0.5000E 00   0.6659E 01   0.4100E-01   0.1980E 01   0.6900E 00
243   0.2280E 00  0.1650E 00   0.5000E 00   0.1463E 02   0.1800E-01   0.1980E 01   0.6900E 00
244   0.2280E 00  0.1450E 00   0.5000E 00   0.1113E 02   0.1800E-01   0.1980E 01   0.6900E 00
245   0.2280E 00  0.1300E 00   0.5000E 00   0.8348E 01   0.1800E-01   0.1980E 01   0.6900E 00
246   0.5660E 00  0.3100E 00   0.6500E 00   0.3519E 02   0.1100E 00   0.1980E 01   0.6900E 00
247   0.5660E 00  0.2800E 00   0.6500E 00   0.2677E 02   0.1100E 00   0.1980E 01   0.6900E 00
248   0.5660E 00  0.2400E 00   0.6500E 00   0.2008E 02   0.1100E 00   0.1980E 01   0.6900E 00
249   0.5660E 00  0.1800E 00   0.6500E 00   0.1041E 02   0.1100E 00   0.1980E 01   0.6900E 00
250   0.5050E 00  0.2800E 00   0.6500E 00   0.3158E 02   0.4100E-01   0.1980E 01   0.6900E 00
251   0.5050E 00  0.2500E 00   0.6500E 00   0.2402E 02   0.4100E-01   0.1980E 01   0.6900E 00
252   0.5050E 00  0.2200E 00   0.6500E 00   0.1802E 02   0.4100E-01   0.1980E 01   0.6900E 00
253   0.5050E 00  0.1600E 00   0.6500E 00   0.9340E 01   0.4100E-01   0.1980E 01   0.6900E 00
254   0.3780E 00  0.2250E 00   0.6500E 00   0.2392E 02   0.1800E-01   0.1980E 01   0.6900E 00
255   0.3780E 00  0.1900E 00   0.6500E 00   0.1819E 02   0.1800E-01   0.1980E 01   0.6900E 00
256   0.3780E 00  0.1700E 00   0.6500E 00   0.1365E 02   0.1800E-01   0.1980E 01   0.6900E 00
257   0.3780E 00  0.1400E 00   0.6500E 00   0.7080E 01   0.1800E-01   0.1980E 01   0.6900E 00
258   0.3450E 00  0.2000E 00   0.6500E 00   0.2190E 02   0.2000E-01   0.1980E 01   0.6900E 00
259   0.3450E 00  0.1800E 00   0.6500E 00   0.1666E 02   0.2000E-01   0.1980E 01   0.6900E 00
260   0.3450E 00  0.1600E 00   0.6500E 00   0.1249E 02   0.2000E-01   0.1980E 01   0.6900E 00
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OBSV   SUBMER      U           H           P           X           W           L

 261   0.3450E 00  0.1100E 00  0.6500E 00  0.6480E 01  0.2000E-01  0.1980E 01  0.6900E 00
 262   0.7160E 00  0.3600E 00  0.8000E 00  0.4392E 02  0.1100E 00  0.1980E 01  0.6900E 00
 263   0.7160E 00  0.3200E 00  0.8000E 00  0.3340E 02  0.1100E 00  0.1980E 01  0.6900E 00
 264   0.7160E 00  0.3000E 00  0.8000E 00  0.2505E 02  0.1100E 00  0.1980E 01  0.6900E 00
 265   0.7160E 00  0.2400E 00  0.8000E 00  0.1299E 02  0.1100E 00  0.1980E 01  0.6900E 00
 266   0.7160E 00  0.2000E 00  0.8000E 00  0.9280E 01  0.1100E 00  0.1980E 01  0.6900E 00
 267   0.6550E 00  0.3400E 00  0.8000E 00  0.4040E 02  0.4100E-01  0.1980E 01  0.6900E 00
 268   0.6550E 00  0.3000E 00  0.8000E 00  0.3073E 02  0.4100E-01  0.1980E 01  0.6900E 00
 269   0.6550E 00  0.2800E 00  0.8000E 00  0.2305E 02  0.4100E-01  0.1980E 01  0.6900E 00
 270   0.6550E 00  0.2200E 00  0.8000E 00  0.1195E 02  0.4100E-01  0.1980E 01  0.6900E 00
 271   0.6550E 00  0.1800E 00  0.8000E 00  0.8540E 01  0.4100E-01  0.1980E 01  0.6900E 00
 272   0.5280E 00  0.3200E 00  0.8000E 00  0.3295E 02  0.1800E-01  0.1980E 01  0.6900E 00
 273   0.5280E 00  0.2900E 00  0.8000E 00  0.2506E 02  0.1800E-01  0.1980E 01  0.6900E 00
 274   0.5280E 00  0.2700E 00  0.8000E 00  0.1880E 02  0.1800E-01  0.1980E 01  0.6900E 00
 275   0.5280E 00  0.2100E 00  0.8000E 00  0.9750E 01  0.1800E-01  0.1980E 01  0.6900E 00
 276   0.5280E 00  0.1700E 00  0.8000E 00  0.6960E 01  0.1800E-01  0.1980E 01  0.6900E 00
 277   0.4950E 00  0.3000E 00  0.8000E 00  0.3099E 02  0.2000E-01  0.1980E 01  0.6900E 00
 278   0.4950E 00  0.2800E 00  0.8000E 00  0.2357E 02  0.2000E-01  0.1980E 01  0.6900E 00
 279   0.4950E 00  0.2500E 00  0.8000E 00  0.1768E 02  0.2000E-01  0.1980E 01  0.6900E 00
 280   0.4950E 00  0.2000E 00  0.8000E 00  0.9160E 01  0.2000E-01  0.1980E 01  0.6900E 00
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OBSV	SUBMER	U	H	P	X	W	L
281	0.4950E 00	0.1600E 00	0.8000E 00	0.6550E 01	0.2000E-01	0.1980E 01	0.6900E 00
282	0.3940E 00	0.2800E 00	0.8000E 00	0.2490E 02	0.2000E-01	0.1980E 01	0.6900E 00
283	0.3940E 00	0.2600E 00	0.8000E 00	0.1894E 02	0.2000E-01	0.1980E 01	0.6900E 00
284	0.3940E 00	0.2400E 00	0.8000E 00	0.1420E 02	0.2000E-01	0.1980E 01	0.6900E 00
285	0.3940E 00	0.1800E 00	0.8000E 00	0.7360E 01	0.2000E-01	0.1980E 01	0.6900E 00
286	0.3940E 00	0.1400E 00	0.8000E 00	0.5260E 01	0.2000E-01	0.1980E 01	0.6900E 00
287	0.8660E 00	0.4100E 00	0.9500E 00	0.5241E 02	0.1100E 00	0.1980E 01	0.6900E 00
288	0.8660E 00	0.3700E 00	0.9500E 00	0.3986E 02	0.1100E 00	0.1980E 01	0.6900E 00
289	0.8660E 00	0.3400E 00	0.9500E 00	0.2989E 02	0.1100E 00	0.1980E 01	0.6900E 00
290	0.8660E 00	0.2900E 00	0.9500E 00	0.1550E 02	0.1100E 00	0.1980E 01	0.6900E 00
291	0.8660E 00	0.2600E 00	0.9500E 00	0.1107E 02	0.1100E 00	0.1980E 01	0.6900E 00
292	0.8050E 00	0.3600E 00	0.9500E 00	0.4898E 02	0.4100E-01	0.1980E 01	0.6900E 00
293	0.8050E 00	0.3300E 00	0.9500E 00	0.3726E 02	0.4100E-01	0.1980E 01	0.6900E 00
294	0.8050E 00	0.3000E 00	0.9500E 00	0.2794E 02	0.4100E-01	0.1980E 01	0.6900E 00
295	0.8050E 00	0.2500E 00	0.9500E 00	0.1449E 02	0.4100E-01	0.1980E 01	0.6900E 00
296	0.8050E 00	0.2300E 00	0.9500E 00	0.1035E 02	0.4100E-01	0.1980E 01	0.6900E 00
297	0.6750E 00	0.3400E 00	0.9500E 00	0.4156E 02	0.2000E-01	0.1980E 01	0.6900E 00
298	0.6750E 00	0.3100E 00	0.9500E 00	0.3161E 02	0.2000E-01	0.1980E 01	0.6900E 00
299	0.6750E 00	0.2800E 00	0.9500E 00	0.2371E 02	0.2000E-01	0.1980E 01	0.6900E 00
300	0.6750E 00	0.2200E 00	0.9500E 00	0.1229E 02	0.2000E-01	0.1980E 01	0.6900E 00

OBSV	SUBMER	U	H	P	X	W	L
301	0.6750E 00	0.2000E 00	0.9500E 00	0.8780E 01	0.2000E-01	0.1980E 01	0.6900E 00
302	0.6450E 00	0.3200E 00	0.9500E 00	0.3982E 02	0.2500E-01	0.1980E 01	0.6900E 00
303	0.6450E 00	0.3000E 00	0.9500E 00	0.3029E 02	0.2500E-01	0.1980E 01	0.6900E 00
304	0.6450E 00	0.2700E 00	0.9500E 00	0.2272E 02	0.2500E-01	0.1980E 01	0.6900E 00
305	0.6450E 00	0.2100E 00	0.9500E 00	0.1178E 02	0.2500E-01	0.1980E 01	0.6900E 00
306	0.6450E 00	0.1900E 00	0.9500E 00	0.8410E 01	0.2500E-01	0.1980E 01	0.6900E 00
307	0.5440E 00	0.3050E 00	0.9500E 00	0.3390E 02	0.2500E-01	0.1980E 01	0.6900E 00
308	0.5440E 00	0.2800E 00	0.9500E 00	0.2578E 02	0.2500E-01	0.1980E 01	0.6900E 00
309	0.5440E 00	0.2600E 00	0.9500E 00	0.1934E 02	0.2500E-01	0.1980E 01	0.6900E 00
310	0.5440E 00	0.1900E 00	0.9500E 00	0.1003E 02	0.2500E-01	0.1980E 01	0.6900E 00
311	0.5440E 00	0.1700E 00	0.9500E 00	0.7160E 01	0.2500E-01	0.1980E 01	0.6900E 00
312	0.4670E 00	0.2800E 00	0.9500E 00	0.2931E 02	0.2500E-01	0.1980E 01	0.6900E 00
313	0.4670E 00	0.2600E 00	0.9500E 00	0.2229E 02	0.2500E-01	0.1980E 01	0.6900E 00
314	0.4670E 00	0.2400E 00	0.9500E 00	0.1672E 02	0.2500E-01	0.1980E 01	0.6900E 00
315	0.4670E 00	0.1800E 00	0.9500E 00	0.8670E 01	0.2500E-01	0.1980E 01	0.6900E 00
316	0.4670E 00	0.1600E 00	0.9500E 00	0.6190E 01	0.2500E-01	0.1980E 01	0.6900E 00
317	0.1016E 01	0.4700E 00	0.1100E 01	0.6067E 02	0.1100E 00	0.1980E 01	0.6900E 00
318	0.1016E 01	0.4500E 00	0.1100E 01	0.4514E 02	0.1100E 00	0.1980E 01	0.6900E 00
319	0.1016E 01	0.4200E 00	0.1100E 01	0.3461E 02	0.1100E 00	0.1980E 01	0.6900E 00
320	0.1016E 01	0.3600E 00	0.1100E 01	0.1794E 02	0.1100E 00	0.1980E 01	0.6900E 00

OBSV	SUBMER	U	H	P	X	W	L
321	0.1016E 01	0.3300E 00	0.1100E 01	0.1282E 02	0.1100E 00	0.1980E 01	0.6900E 00
322	0.9550E 00	0.4500E 00	0.1100E 01	0.5733E 02	0.4100E-01	0.1980E 01	0.6900E 00
323	0.9550E 00	0.4200E 00	0.1100E 01	0.4361E 02	0.4100E-01	0.1980E 01	0.6900E 00
324	0.9550E 00	0.3900E 00	0.1100E 01	0.3270E 02	0.4100E-01	0.1980E 01	0.6900E 00
325	0.9550E 00	0.3200E 00	0.1100E 01	0.1696E 02	0.4100E-01	0.1980E 01	0.6900E 00
326	0.9550E 00	0.3000E 00	0.1100E 01	0.1211E 02	0.4100E-01	0.1980E 01	0.6900E 00
327	0.8280E 00	0.4200E 00	0.1100E 01	0.5028E 02	0.2000E-01	0.1980E 01	0.6900E 00
328	0.8280E 00	0.4000E 00	0.1100E 01	0.3824E 02	0.2000E-01	0.1980E 01	0.6900E 00
329	0.8280E 00	0.3700E 00	0.1100E 01	0.2868E 02	0.2000E-01	0.1980E 01	0.6900E 00
330	0.8280E 00	0.3000E 00	0.1100E 01	0.1487E 02	0.2000E-01	0.1980E 01	0.6900E 00
331	0.8280E 00	0.2800E 00	0.1100E 01	0.1062E 02	0.2000E-01	0.1980E 01	0.6900E 00
332	0.7950E 00	0.4100E 00	0.1100E 01	0.4842E 02	0.2500E-01	0.1980E 01	0.6900E 00
333	0.7950E 00	0.3900E 00	0.1100E 01	0.3683E 02	0.2500E-01	0.1980E 01	0.6900E 00
334	0.7950E 00	0.3600E 00	0.1100E 01	0.2762E 02	0.2500E-01	0.1980E 01	0.6900E 00
335	0.7950E 00	0.2900E 00	0.1100E 01	0.1432E 02	0.2500E-01	0.1980E 01	0.6900E 00
336	0.7950E 00	0.2700E 00	0.1100E 01	0.1023E 02	0.2500E-01	0.1980E 01	0.6900E 00
337	0.6940E 00	0.3900E 00	0.1100E 01	0.4266E 02	0.2500E-01	0.1980E 01	0.6900E 00
338	0.6940E 00	0.3600E 00	0.1100E 01	0.3244E 02	0.2500E-01	0.1980E 01	0.6900E 00
339	0.6940E 00	0.3300E 00	0.1100E 01	0.2433E 02	0.2500E-01	0.1980E 01	0.6900E 00
340	0.6940E 00	0.2600E 00	0.1100E 01	0.1262E 02	0.2500E-01	0.1980E 01	0.6900E 00

OBSV	SUBMER	U	H	P	X	W	L
341	0.6940E 00	0.2400E 00	0.1100E 01	0.9010E 01	0.2500E-01	0.1980E 01	0.6900E 00
342	0.6170E 00	0.3600E 00	0.1100E 01	0.3820E 02	0.2500E-01	0.1980E 01	0.6900E 00
343	0.6170E 00	0.3400E 00	0.1100E 01	0.2905E 02	0.2500E-01	0.1980E 01	0.6900E 00
344	0.6170E 00	0.3100E 00	0.1100E 01	0.2179E 02	0.2500E-01	0.1980E 01	0.6900E 00
345	0.6170E 00	0.2500E 00	0.1100E 01	0.1130E 02	0.2500E-01	0.1980E 01	0.6900E 00
346	0.6170E 00	0.2300E 00	0.1100E 01	0.8070E 01	0.2500E-01	0.1980E 01	0.6900E 00
347	0.5410E 00	0.3400E 00	0.1100E 01	0.3372E 02	0.2500E-01	0.1980E 01	0.6900E 00
348	0.5410E 00	0.3200E 00	0.1100E 01	0.2565E 02	0.2500E-01	0.1980E 01	0.6900E 00
349	0.5410E 00	0.2900E 00	0.1100E 01	0.1924E 02	0.2500E-01	0.1980E 01	0.6900E 00
350	0.5410E 00	0.2300E 00	0.1100E 01	0.9970E 01	0.2500E-01	0.1980E 01	0.6900E 00
351	0.5410E 00	0.2100E 00	0.1100E 01	0.7120E 01	0.2500E-01	0.1980E 01	0.6900E 00
352	0.4160E 00	0.2100E 00	0.5000E 00	0.2623E 02	0.1100E 00	0.1750E 01	0.6900E 00
353	0.4160E 00	0.1900E 00	0.5000E 00	0.1995E 02	0.1100E 00	0.1750E 01	0.6900E 00
354	0.4160E 00	0.1450E 00	0.5000E 00	0.1496E 02	0.1100E 00	0.1750E 01	0.6900E 00
355	0.4160E 00	0.9000E-01	0.5000E 00	0.7760E 01	0.1100E 00	0.1750E 01	0.6900E 00
356	0.3550E 00	0.2000E 00	0.5000E 00	0.2251E 02	0.4100E-01	0.1750E 01	0.6900E 00
357	0.3550E 00	0.1800E 00	0.5000E 00	0.1712E 02	0.4100E-01	0.1750E 01	0.6900E 00
358	0.3550E 00	0.1400E 00	0.5000E 00	0.1284E 02	0.4100E-01	0.1750E 01	0.6900E 00
359	0.3550E 00	0.8500E-01	0.5000E 00	0.6659E 01	0.4100E-01	0.1750E 01	0.6900E 00
360	0.2280E 00	0.1800E 00	0.5000E 00	0.1463E 02	0.1800E-01	0.1750E 01	0.6900E 00

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OBSV   SUBMER        U            H            P            X            W            L

361   0.2280E 00   0.1600E 00   0.5000E 00   0.1113E 02   0.1800E-01   0.1750E 01   0.6900E 00
362   0.2280E 00   0.1400E 00   0.5000E 00   0.8348E 01   0.1800E-01   0.1750E 01   0.6900E 00
363   0.5660E 00   0.3600E 00   0.6500E 00   0.3519E 02   0.1100E 00   0.1750E 01   0.6900E 00
364   0.5660E 00   0.3100E 00   0.6500E 00   0.2677E 02   0.1100E 00   0.1750E 01   0.6900E 00
365   0.5660E 00   0.2700E 00   0.6500E 00   0.2008E 02   0.1100E 00   0.1750E 01   0.6900E 00
366   0.5660E 00   0.2100E 00   0.6500E 00   0.1041E 02   0.1100E 00   0.1750E 01   0.6900E 00
367   0.5050E 00   0.3250E 00   0.6500E 00   0.3158E 02   0.4100E-01   0.1750E 01   0.6900E 00
368   0.5050E 00   0.2600E 00   0.6500E 00   0.2402E 02   0.4100E-01   0.1750E 01   0.6900E 00
369   0.5050E 00   0.2100E 00   0.6500E 00   0.1802E 02   0.4100E-01   0.1750E 01   0.6900E 00
370   0.5050E 00   0.1650E 00   0.6500E 00   0.9340E 01   0.4100E-01   0.1750E 01   0.6900E 00
371   0.3780E 00   0.2800E 00   0.6500E 00   0.2392E 02   0.1800E-01   0.1750E 01   0.6900E 00
372   0.3780E 00   0.2300E 00   0.6500E 00   0.1819E 02   0.1800E-01   0.1750E 01   0.6900E 00
373   0.3780E 00   0.2000E 00   0.6500E 00   0.1365E 02   0.1800E-01   0.1750E 01   0.6900E 00
374   0.3780E 00   0.1600E 00   0.6500E 00   0.7080E 01   0.1800E-01   0.1750E 01   0.6900E 00
375   0.3450E 00   0.2500E 00   0.6500E 00   0.2190E 02   0.2000E-01   0.1750E 01   0.6900E 00
376   0.3450E 00   0.2200E 00   0.6500E 00   0.1666E 02   0.2000E-01   0.1750E 01   0.6900E 00
377   0.3450E 00   0.1900E 00   0.6500E 00   0.1249E 02   0.2000E-01   0.1750E 01   0.6900E 00
378   0.3450E 00   0.1500E 00   0.6500E 00   0.6480E 01   0.2000E-01   0.1750E 01   0.6900E 00
379   0.7160E 00   0.4000E 00   0.8000E 00   0.4392E 02   0.1100E 00   0.1750E 01   0.6900E 00
380   0.7160E 00   0.3700E 00   0.8000E 00   0.3340E 02   0.1100E 00   0.1750E 01   0.6900E 00
```

OBSV	SUBMER	U	H	P	X	W	L
381	0.7160E 00	0.3400E 00	0.8000E 00	0.2505E 02	0.1100E 00	0.1750E 01	0.6900E 00
382	0.7160E 00	0.2800E 00	0.8000E 00	0.1299E 02	0.1100E 00	0.1750E 01	0.6900E 00
383	0.7160E 00	0.2400E 00	0.8000E 00	0.9280E 01	0.1100E 00	0.1750E 01	0.6900E 00
384	0.6550E 00	0.3800E 00	0.8000E 00	0.4040E 02	0.4100E-01	0.1750E 01	0.6900E 00
385	0.6550E 00	0.3500E 00	0.8000E 00	0.3073E 02	0.4100E-01	0.1750E 01	0.6900E 00
386	0.6550E 00	0.3100E 00	0.8000E 00	0.2305E 02	0.4100E-01	0.1750E 01	0.6900E 00
387	0.6550E 00	0.2500E 00	0.8000E 00	0.1195E 02	0.4100E-01	0.1750E 01	0.6900E 00
388	0.6550E 00	0.2200E 00	0.8000E 00	0.8540E 01	0.4100E-01	0.1750E 01	0.6900E 00
389	0.5280E 00	0.3650E 00	0.8000E 00	0.3295E 02	0.1800E-01	0.1750E 01	0.6900E 00
390	0.5280E 00	0.3400E 00	0.8000E 00	0.2506E 02	0.1800E-01	0.1750E 01	0.6900E 00
391	0.5280E 00	0.2900E 00	0.8000E 00	0.1880E 02	0.1800E-01	0.1750E 01	0.6900E 00
392	0.5280E 00	0.2400E 00	0.8000E 00	0.9750E 01	0.1800E-01	0.1750E 01	0.6900E 00
393	0.5280E 00	0.2100E 00	0.8000E 00	0.6960E 01	0.1800E-01	0.1750E 01	0.6900E 00
394	0.4950E 00	0.3500E 00	0.8000E 00	0.3099E 02	0.2000E-01	0.1750E 01	0.6900E 00
395	0.4950E 00	0.3200E 00	0.8000E 00	0.2357E 02	0.2000E-01	0.1750E 01	0.6900E 00
396	0.4950E 00	0.2800E 00	0.8000E 00	0.1768E 02	0.2000E-01	0.1750E 01	0.6900E 00
397	0.4950E 00	0.2300E 00	0.8000E 00	0.9160E 01	0.2000E-01	0.1750E 01	0.6900E 00
398	0.4950E 00	0.2000E 00	0.8000E 00	0.6550E 01	0.2000E-01	0.1750E 01	0.6900E 00
399	0.3940E 00	0.3300E 00	0.8000E 00	0.2490E 02	0.2000E-01	0.1750E 01	0.6900E 00
400	0.3940E 00	0.2900E 00	0.8000E 00	0.1894E 02	0.2000E-01	0.1750E 01	0.6900E 00

```
OBSV   SUBMER       U            H            P            X            W            L

401  0.3940E 00  0.2600E 00  0.8000E 00  0.1420E 02  0.2000E-01  0.1750E 01  0.6900E 00
402  0.3940E 00  0.2100E 00  0.8000E 00  0.7360E 01  0.2000E-01  0.1750E 01  0.6900E 00
403  0.3940E 00  0.1900E 00  0.8000E 00  0.5260E 01  0.2000E-01  0.1750E 01  0.6900E 00
404  0.8660E 00  0.4400E 00  0.9500E 00  0.5241E 02  0.1100E 00  0.1750E 01  0.6900E 00
405  0.8660E 00  0.4100E 00  0.9500E 00  0.3986E 02  0.1100E 00  0.1750E 01  0.6900E 00
406  0.8660E 00  0.3800E 00  0.9500E 00  0.2989E 02  0.1100E 00  0.1750E 01  0.6900E 00
407  0.8660E 00  0.3200E 00  0.9500E 00  0.1550E 02  0.1100E 00  0.1750E 01  0.6900E 00
408  0.8660E 00  0.2850E 00  0.9500E 00  0.1107E 02  0.1100E 00  0.1750E 01  0.6900E 00
409  0.8050E 00  0.4000E 00  0.9500E 00  0.4898E 02  0.4100E-01  0.1750E 01  0.6900E 00
410  0.8050E 00  0.3600E 00  0.9500E 00  0.3726E 02  0.4100E-01  0.1750E 01  0.6900E 00
411  0.8050E 00  0.3300E 00  0.9500E 00  0.2794E 02  0.4100E-01  0.1750E 01  0.6900E 00
412  0.8050E 00  0.2800E 00  0.9500E 00  0.1449E 02  0.4100E-01  0.1750E 01  0.6900E 00
413  0.8050E 00  0.2500E 00  0.9500E 00  0.1035E 02  0.4100E-01  0.1750E 01  0.6900E 00
414  0.6750E 00  0.3600E 00  0.9500E 00  0.4156E 02  0.2000E-01  0.1750E 01  0.6900E 00
415  0.6750E 00  0.3300E 00  0.9500E 00  0.3161E 02  0.2000E-01  0.1750E 01  0.6900E 00
416  0.6750E 00  0.3000E 00  0.9500E 00  0.2371E 02  0.2000E-01  0.1750E 01  0.6900E 00
417  0.6750E 00  0.2500E 00  0.9500E 00  0.1229E 02  0.2000E-01  0.1750E 01  0.6900E 00
418  0.6750E 00  0.2300E 00  0.9500E 00  0.8780E 01  0.2000E-01  0.1750E 01  0.6900E 00
419  0.6450E 00  0.3400E 00  0.9500E 00  0.3982E 02  0.2500E-01  0.1750E 01  0.6900E 00
420  0.6450E 00  0.3200E 00  0.9500E 00  0.3029E 02  0.2500E-01  0.1750E 01  0.6900E 00
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OBSV  SUBMER       U            H            P            X             W            L

 421  0.6450E 00   0.2900E 00   0.9500E 00   0.2272E 02   0.2500E-01   0.1750E 01   0.6900E 00
 422  0.6450E 00   0.2400E 00   0.9500E 00   0.1178E 02   0.2500E-01   0.1750E 01   0.6900E 00
 423  0.6450E 00   0.2200E 00   0.9500E 00   0.8410E 01   0.2500E-01   0.1750E 01   0.6900E 00
 424  0.5440E 00   0.3200E 00   0.9500E 00   0.3390E 02   0.2500E-01   0.1750E 01   0.6900E 00
 425  0.5440E 00   0.3000E 00   0.9500E 00   0.2578E 02   0.2500E-01   0.1750E 01   0.6900E 00
 426  0.5440E 00   0.2800E 00   0.9500E 00   0.1934E 02   0.2500E-01   0.1750E 01   0.6900E 00
 427  0.5440E 00   0.2400E 00   0.9500E 00   0.1003E 02   0.2500E-01   0.1750E 01   0.6900E 00
 428  0.5440E 00   0.2100E 00   0.9500E 00   0.7160E 01   0.2500E-01   0.1750E 01   0.6900E 00
 429  0.4670E 00   0.3100E 00   0.9500E 00   0.2931E 02   0.2500E-01   0.1750E 01   0.6900E 00
 430  0.4670E 00   0.2900E 00   0.9500E 00   0.2229E 02   0.2500E-01   0.1750E 01   0.6900E 00
 431  0.4670E 00   0.2650E 00   0.9500E 00   0.1672E 02   0.2500E-01   0.1750E 01   0.6900E 00
 432  0.4670E 00   0.2300E 00   0.9500E 00   0.8670E 01   0.2500E-01   0.1750E 01   0.6900E 00
 433  0.4670E 00   0.2000E 00   0.9500E 00   0.6190E 01   0.2500E-01   0.1750E 01   0.6900E 00
 434  0.1016E 01   0.4900E 00   0.1100E 01   0.6067E 02   0.1100E 00   0.1750E 01   0.6900E 00
 435  0.1016E 01   0.4600E 00   0.1100E 01   0.4614E 02   0.1100E 00   0.1750E 01   0.6900E 00
 436  0.1016E 01   0.4300E 00   0.1100E 01   0.3461E 02   0.1100E 00   0.1750E 01   0.6900E 00
 437  0.1016E 01   0.3700E 00   0.1100E 01   0.1794E 02   0.1100E 00   0.1750E 01   0.6900E 00
 438  0.1016E 01   0.3500E 00   0.1100E 01   0.1282E 02   0.1100E 00   0.1750E 01   0.6900E 00
 439  0.9550E 00   0.4600E 00   0.1100E 01   0.5733E 02   0.4100E-01   0.1750E 01   0.6900E 00
 440  0.9550E 00   0.4400E 00   0.1100E 01   0.4361E 02   0.4100E-01   0.1750E 01   0.6900E 00
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OBSV   SUBMER       U            H            P            X            W            L

441   0.9550E 00   0.4100E 00   0.1100E 01   0.3270E 02   0.4100E-01   0.1750E 01   0.6900E 00

442   0.9550E 00   0.3400E 00   0.1100E 01   0.1696E 02   0.4100E-01   0.1750E 01   0.6900E 00

443   0.9550E 00   0.3200E 00   0.1100E 01   0.1211E 02   0.4100E-01   0.1750E 01   0.6900E 00

444   0.8280E 00   0.4300E 00   0.1100E 01   0.5028E 02   0.2000E-01   0.1750E 01   0.6900E 00

445   0.8280E 00   0.4100E 00   0.1100E 01   0.3824E 02   0.2000E-01   0.1750E 01   0.6900E 00

446   0.8280E 00   0.3800E 00   0.1100E 01   0.2868E 02   0.2000E-01   0.1750E 01   0.6900E 00

447   0.8280E 00   0.3200E 00   0.1100E 01   0.1487E 02   0.2000E-01   0.1750E 01   0.6900E 00

448   0.8280E 00   0.3000E 00   0.1100E 01   0.1062E 02   0.2000E-01   0.1750E 01   0.6900E 00

449   0.7950E 00   0.4200E 00   0.1100E 01   0.4842E 02   0.2500E-01   0.1750E 01   0.6900E 00

450   0.7950E 00   0.4000E 00   0.1100E 01   0.3683E 02   0.2500E-01   0.1750E 01   0.6900E 00

451   0.7950E 00   0.3700E 00   0.1100E 01   0.2762E 02   0.2500E-01   0.1750E 01   0.6900E 00

452   0.7950E 00   0.3000E 00   0.1100E 01   0.1432E 02   0.2500E-01   0.1750E 01   0.6900E 00

453   0.7950E 00   0.2800E 00   0.1100E 01   0.1023E 02   0.2500E-01   0.1750E 01   0.6900E 00

454   0.6940E 00   0.4000E 00   0.1100E 01   0.4266E 02   0.2500E-01   0.1750E 01   0.6900E 00

455   0.6940E 00   0.3800E 00   0.1100E 01   0.3244E 02   0.2500E-01   0.1750E 01   0.6900E 00

456   0.6940E 00   0.3500E 00   0.1100E 01   0.2433E 02   0.2500E-01   0.1750E 01   0.6900E 00

457   0.6940E 00   0.2800E 00   0.1100E 01   0.1262E 02   0.2500E-01   0.1750E 01   0.6900E 00

458   0.6940E 00   0.2600E 00   0.1100E 01   0.9010E 01   0.2500E-01   0.1750E 01   0.6900E 00

459   0.6170E 00   0.3800E 00   0.1100E 01   0.3820E 02   0.2500E-01   0.1750E 01   0.6900E 00

460   0.6170E 00   0.3600E 00   0.1100E 01   0.2905E 02   0.2500E-01   0.1750E 01   0.6900E 00
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OBSV	SUBMER	U	H	P	X	W	L
461	0.6170E 00	0.3300E 00	0.1100E 01	0.2179E 02	0.2500E-01	0.1750E 01	0.6900E 00
462	0.6170E 00	0.2700E 00	0.1100E 01	0.1130E 02	0.2500E-01	0.1750E 01	0.6900E 00
463	0.6170E 00	0.2500E 00	0.1100E 01	0.8070E 01	0.2500E-01	0.1750E 01	0.6900E 00
464	0.5410E 00	0.3600E 00	0.1100E 01	0.3372E 02	0.2500E-01	0.1750E 01	0.6900E 00
465	0.5410E 00	0.3400E 00	0.1100E 01	0.2565E 02	0.2500E-01	0.1750E 01	0.6900E 00
466	0.5410E 00	0.3100E 00	0.1100E 01	0.1924E 02	0.2500E-01	0.1750E 01	0.6900E 00
467	0.5410E 00	0.2600E 00	0.1100E 01	0.9970E 01	0.2500E-01	0.1750E 01	0.6900E 00
468	0.5410E 00	0.2300E 00	0.1100E 01	0.7120E 01	0.2500E-01	0.1750E 01	0.6900E 00
469	0.4160E 00	0.2300E 00	0.5000E 00	0.2623E 02	0.1100E 00	0.1520E 01	0.6900E 00
470	0.4160E 00	0.2000E 00	0.5000E 00	0.1995E 02	0.1100E 00	0.1520E 01	0.6900E 00
471	0.4160E 00	0.1650E 00	0.5000E 00	0.1496E 02	0.1100E 00	0.1520E 01	0.6900E 00
472	0.4160E 00	0.1300E 00	0.5000E 00	0.7760E 01	0.1100E 00	0.1520E 01	0.6900E 00
473	0.3550E 00	0.2200E 00	0.5000E 00	0.2251E 02	0.4100E-01	0.1520E 01	0.6900E 00
474	0.3550E 00	0.1900E 00	0.5000E 00	0.1712E 02	0.4100E-01	0.1520E 01	0.6900E 00
475	0.3550E 00	0.1600E 00	0.5000E 00	0.1284E 02	0.4100E-01	0.1520E 01	0.6900E 00
476	0.3550E 00	0.1200E 00	0.5000E 00	0.6659E 01	0.4100E-01	0.1520E 01	0.6900E 00
477	0.2280E 00	0.2000E 00	0.5000E 00	0.1463E 02	0.1800E-01	0.1520E 01	0.6900E 00
478	0.2280E 00	0.1750E 00	0.5000E 00	0.1113E 02	0.1800E-01	0.1520E 01	0.6900E 00
479	0.2280E 00	0.1200E 00	0.5000E 00	0.8348E 01	0.1800E-01	0.1520E 01	0.6900E 00
480	0.5660E 00	0.4200E 00	0.6500E 00	0.3519E 02	0.1100E 00	0.1520E 01	0.6900E 00

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OBSV   SUBMER        U             H             P             X             W             L
 481  0.5660E 00  0.3700E 00  0.6500E 00  0.2677E 02  0.1100E 00  0.1520E 01  0.6900E 00
 482  0.5660E 00  0.3200E 00  0.6500E 00  0.2008E 02  0.1100E 00  0.1520E 01  0.6900E 00
 483  0.5660E 00  0.2500E 00  0.6500E 00  0.1041E 02  0.1100E 00  0.1520E 01  0.6900E 00
 484  0.5050E 00  0.3600E 00  0.6500E 00  0.3158E 02  0.4100E-01  0.1520E 01  0.6900E 00
 485  0.5050E 00  0.3200E 00  0.6500E 00  0.2402E 02  0.4100E-01  0.1520E 01  0.6900E 00
 486  0.5050E 00  0.2600E 00  0.6500E 00  0.1802E 02  0.4100E-01  0.1520E 01  0.6900E 00
 487  0.5050E 00  0.2200E 00  0.6500E 00  0.9340E 01  0.4100E-01  0.1520E 01  0.6900E 00
 488  0.3780E 00  0.3100E 00  0.6500E 00  0.2392E 02  0.1800E-01  0.1520E 01  0.6900E 00
 489  0.3780E 00  0.2800E 00  0.6500E 00  0.1819E 02  0.1800E-01  0.1520E 01  0.6900E 00
 490  0.3780E 00  0.2400E 00  0.6500E 00  0.1365E 02  0.1800E-01  0.1520E 01  0.6900E 00
 491  0.3780E 00  0.1800E 00  0.6500E 00  0.7080E 01  0.1800E-01  0.1520E 01  0.6900E 00
 492  0.3450E 00  0.2700E 00  0.6500E 00  0.2190E 02  0.2000E-01  0.1520E 01  0.6900E 00
 493  0.3450E 00  0.2400E 00  0.6500E 00  0.1666E 02  0.2000E-01  0.1520E 01  0.6900E 00
 494  0.3450E 00  0.2200E 00  0.6500E 00  0.1249E 02  0.2000E-01  0.1520E 01  0.6900E 00
 495  0.3450E 00  0.1700E 00  0.6500E 00  0.6480E 01  0.2000E-01  0.1520E 01  0.6900E 00
 496  0.7160E 00  0.4600E 00  0.8000E 00  0.4392E 02  0.1100E 00  0.1520E 01  0.6900E 00
 497  0.7160E 00  0.4200E 00  0.8000E 00  0.3340E 02  0.1100E 00  0.1520E 01  0.6900E 00
 498  0.7160E 00  0.4000E 00  0.8000E 00  0.2505E 02  0.1100E 00  0.1520E 01  0.6900E 00
 499  0.7160E 00  0.3200E 00  0.8000E 00  0.1299E 02  0.1100E 00  0.1520E 01  0.6900E 00
 500  0.7160E 00  0.2800E 00  0.8000E 00  0.9280E 01  0.1100E 00  0.1520E 01  0.6900E 00
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OBSV   SUBMER        U            H            P            X            W            L

 501  0.6550E 00  0.4400E 00  0.8000E 00  0.4040E 02  0.4100E-01  0.1520E 01  0.6900E 00
 502  0.6550E 00  0.4000E 00  0.8000E 00  0.3073E 02  0.4100E-01  0.1520E 01  0.6900E 00
 503  0.6550E 00  0.3600E 00  0.8000E 00  0.2305E 02  0.4100E-01  0.1520E 01  0.6900E 00
 504  0.6550E 00  0.3000E 00  0.8000E 00  0.1195E 02  0.4100E-01  0.1520E 01  0.6900E 00
 505  0.6550E 00  0.2600E 00  0.8000E 00  0.8540E 01  0.4100E-01  0.1520E 01  0.6900E 00
 506  0.5280E 00  0.3900E 00  0.8000E 00  0.3295E 02  0.1800E-01  0.1520E 01  0.6900E 00
 507  0.5280E 00  0.3600E 00  0.8000E 00  0.2506E 02  0.1800E-01  0.1520E 01  0.6900E 00
 508  0.5280E 00  0.3100E 00  0.8000E 00  0.1880E 02  0.1800E-01  0.1520E 01  0.6900E 00
 509  0.5280E 00  0.2600E 00  0.8000E 00  0.9750E 01  0.1800E-01  0.1520E 01  0.6900E 00
 510  0.5280E 00  0.2400E 00  0.8000E 00  0.6960E 01  0.1800E-01  0.1520E 01  0.6900E 00
 511  0.4950E 00  0.3700E 00  0.8000E 00  0.3099E 02  0.2000E-01  0.1520E 01  0.6900E 00
 512  0.4950E 00  0.3400E 00  0.8000E 00  0.2357E 02  0.2000E-01  0.1520E 01  0.6900E 00
 513  0.4950E 00  0.3000E 00  0.8000E 00  0.1768E 02  0.2000E-01  0.1520E 01  0.6900E 00
 514  0.4950E 00  0.2450E 00  0.8000E 00  0.9160E 01  0.2000E-01  0.1520E 01  0.6900E 00
 515  0.4950E 00  0.2250E 00  0.8000E 00  0.6550E 01  0.2000E-01  0.1520E 01  0.6900E 00
 516  0.3940E 00  0.3400E 00  0.8000E 00  0.2490E 02  0.2000E-01  0.1520E 01  0.6900E 00
 517  0.3940E 00  0.3000E 00  0.8000E 00  0.1894E 02  0.2000E-01  0.1520E 01  0.6900E 00
 518  0.3940E 00  0.2700E 00  0.8000E 00  0.1420E 02  0.2000E-01  0.1520E 01  0.6900E 00
 519  0.3940E 00  0.2200E 00  0.8000E 00  0.7360E 01  0.2000E-01  0.1520E 01  0.6900E 00
 520  0.3940E 00  0.2000E 00  0.8000E 00  0.5260E 01  0.2000E-01  0.1520E 01  0.6900E 00
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OBSV  SUBMER      U           H           P           X           W           L

 521  0.8660E 00  0.4600E 00  0.9500E 00  0.5241E 02  0.1100E 00  0.1520E 01  0.6900E 00

 522  0.8660E 00  0.4300E 00  0.9500E 00  0.3986E 02  0.1100E 00  0.1520E 01  0.6900E 00

 523  0.8660E 00  0.4000E 00  0.9500E 00  0.2989E 02  0.1100E 00  0.1520E 01  0.6900E 00

 524  0.8660E 00  0.3400E 00  0.9500E 00  0.1550E 02  0.1100E 00  0.1520E 01  0.6900E 00

 525  0.8660E 00  0.3200E 00  0.9500E 00  0.1107E 02  0.1100E 00  0.1520E 01  0.6900E 00

 526  0.8050E 00  0.4300E 00  0.9500E 00  0.4898E 02  0.4100E-01  0.1520E 01  0.6900E 00

 527  0.8050E 00  0.4000E 00  0.9500E 00  0.3726E 02  0.4100E-01  0.1520E 01  0.6900E 00

 528  0.8050E 00  0.3700E 00  0.9500E 00  0.2794E 02  0.4100E-01  0.1520E 01  0.6900E 00

 529  0.8050E 00  0.3200E 00  0.9500E 00  0.1449E 02  0.4100E-01  0.1520E 01  0.6900E 00

 530  0.8050E 00  0.3000E 00  0.9500E 00  0.1035E 02  0.4100E-01  0.1520E 01  0.6900E 00

 531  0.6750E 00  0.4000E 00  0.9500E 00  0.4156E 02  0.2000E-01  0.1520E 01  0.6900E 00

 532  0.6750E 00  0.3800E 00  0.9500E 00  0.3161E 02  0.2000E-01  0.1520E 01  0.6900E 00

 533  0.6750E 00  0.3400E 00  0.9500E 00  0.2371E 02  0.2000E-01  0.1520E 01  0.6900E 00

 534  0.6750E 00  0.2900E 00  0.9500E 00  0.1229E 02  0.2000E-01  0.1520E 01  0.6900E 00

 535  0.6750E 00  0.2700E 00  0.9500E 00  0.8780E 01  0.2000E-01  0.1520E 01  0.6900E 00

 536  0.6450E 00  0.3800E 00  0.9500E 00  0.3982E 02  0.2500E-01  0.1520E 01  0.6900E 00

 537  0.6450E 00  0.3600E 00  0.9500E 00  0.3029E 02  0.2500E-01  0.1520E 01  0.6900E 00

 538  0.6450E 00  0.3200E 00  0.9500E 00  0.2272E 02  0.2500E-01  0.1520E 01  0.6900E 00

 539  0.6450E 00  0.2700E 00  0.9500E 00  0.1178E 02  0.2500E-01  0.1520E 01  0.6900E 00

 540  0.6450E 00  0.2500E 00  0.9500E 00  0.8410E 01  0.2500E-01  0.1520E 01  0.6900E 00
```

OBSV	SUBMER	U	H	P	X	W	L
541	0.5440E 00	0.3600E 00	0.9500E 00	0.3390E 02	0.2500E-01	0.1520E 01	0.6900E 00
542	0.5440E 00	0.3400E 00	0.9500E 00	0.2578E 02	0.2500E-01	0.1520E 01	0.6900E 00
543	0.5440E 00	0.3100E 00	0.9500E 00	0.1934E 02	0.2500E-01	0.1520E 01	0.6900E 00
544	0.5440E 00	0.2600E 00	0.9500E 00	0.1003E 02	0.2500E-01	0.1520E 01	0.6900E 00
545	0.5440E 00	0.2400E 00	0.9500E 00	0.7160E 01	0.2500E-01	0.1520E 01	0.6900E 00
546	0.4670E 00	0.3300E 00	0.9500E 00	0.2931E 02	0.2500E-01	0.1520E 01	0.6900E 00
547	0.4670E 00	0.3050E 00	0.9500E 00	0.2229E 02	0.2500E-01	0.1520E 01	0.6900E 00
548	0.4670E 00	0.2800E 00	0.9500E 00	0.1672E 02	0.2500E-01	0.1520E 01	0.6900E 00
549	0.4670E 00	0.2400E 00	0.9500E 00	0.8670E 01	0.2500E-01	0.1520E 01	0.6900E 00
550	0.4670E 00	0.2100E 00	0.9500E 00	0.6190E 01	0.2500E-01	0.1520E 01	0.6900E 00
551	0.1016E 01	0.5300E 00	0.1100E 01	0.6067E 02	0.1100E 00	0.1520E 01	0.6900E 00
552	0.1016E 01	0.5100E 00	0.1100E 01	0.4614E 02	0.1100E 00	0.1520E 01	0.6900E 00
553	0.1016E 01	0.4800E 00	0.1100E 01	0.3461E 02	0.1100E 00	0.1520E 01	0.6900E 00
554	0.1016E 01	0.4100E 00	0.1100E 01	0.1794E 02	0.1100E 00	0.1520E 01	0.6900E 00
555	0.1016E 01	0.3800E 00	0.1100E 01	0.1282E 02	0.1100E 00	0.1520E 01	0.6900E 00
556	0.9550E 00	0.5000E 00	0.1100E 01	0.5733E 02	0.4100E-01	0.1520E 01	0.6900E 00
557	0.9550E 00	0.4800E 00	0.1100E 01	0.4361E 02	0.4100E-01	0.1520E 01	0.6900E 00
558	0.9550E 00	0.4600E 00	0.1100E 01	0.3270E 02	0.4100E-01	0.1520E 01	0.6900E 00
559	0.9550E 00	0.3900E 00	0.1100E 01	0.1696E 02	0.4100E-01	0.1520E 01	0.6900E 00
560	0.9550E 00	0.3600E 00	0.1100E 01	0.1211E 02	0.4100E-01	0.1520E 01	0.6900E 00

```
OBSV  SUBMER      U           H           P           X            W           L

561   0.8280E 00  0.4700E 00  0.1100E 01  0.5028E 02  0.2000E-01  0.1520E 01  0.6900E 00
562   0.8280E 00  0.4400E 00  0.1100E 01  0.3824E 02  0.2000E-01  0.1520E 01  0.6900E 00
563   0.8280E 00  0.4200E 00  0.1100E 01  0.2868E 02  0.2000E-01  0.1520E 01  0.6900E 00
564   0.8280E 00  0.3500E 00  0.1100E 01  0.1487E 02  0.2000E-01  0.1520E 01  0.6900E 00
565   0.8280E 00  0.3300E 00  0.1100E 01  0.1062E 02  0.2000E-01  0.1520E 01  0.6900E 00
566   0.7950E 00  0.4450E 00  0.1100E 01  0.4842E 02  0.2500E-01  0.1520E 01  0.6900E 00
567   0.7950E 00  0.4200E 00  0.1100E 01  0.3683E 02  0.2500E-01  0.1520E 01  0.6900E 00
568   0.7950E 00  0.3900E 00  0.1100E 01  0.2762E 02  0.2500E-01  0.1520E 01  0.6900E 00
569   0.7950E 00  0.3300E 00  0.1100E 01  0.1432E 02  0.2500E-01  0.1520E 01  0.6900E 00
570   0.7950E 00  0.3100E 00  0.1100E 01  0.1023E 02  0.2500E-01  0.1520E 01  0.6900E 00
571   0.6940E 00  0.4300E 00  0.1100E 01  0.4266E 02  0.2500E-01  0.1520E 01  0.6900E 00
572   0.6940E 00  0.4100E 00  0.1100E 01  0.3244E 02  0.2500E-01  0.1520E 01  0.6900E 00
573   0.6940E 00  0.3800E 00  0.1100E 01  0.2433E 02  0.2500E-01  0.1520E 01  0.6900E 00
574   0.6940E 00  0.3200E 00  0.1100E 01  0.1262E 02  0.2500E-01  0.1520E 01  0.6900E 00
575   0.6940E 00  0.3000E 00  0.1100E 01  0.9010E 01  0.2500E-01  0.1520E 01  0.6900E 00
576   0.6170E 00  0.3900E 00  0.1100E 01  0.3820E 02  0.2500E-01  0.1520E 01  0.6900E 00
577   0.6170E 00  0.3700E 00  0.1100E 01  0.2905E 02  0.2500E-01  0.1520E 01  0.6900E 00
578   0.6170E 00  0.3400E 00  0.1100E 01  0.2179E 02  0.2500E-01  0.1520E 01  0.6900E 00
579   0.6170E 00  0.2800E 00  0.1100E 01  0.1130E 02  0.2500E-01  0.1520E 01  0.6900E 00
580   0.6170E 00  0.2600E 00  0.1100E 01  0.8070E 01  0.2500E-01  0.1520E 01  0.6900E 00
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OBSV	SUBMER	U	H	P	X	W	L
581	0.5410E 00	0.3700E 00	0.1100E 01	0.3372E 02	0.2500E-01	0.1520E 01	0.6900E 00
582	0.5410E 00	0.3500E 00	0.1100E 01	0.2565E 02	0.2500E-01	0.1520E 01	0.6900E 00
583	0.5410E 00	0.3300E 00	0.1100E 01	0.1924E 02	0.2500E-01	0.1520E 01	0.6900E 00
584	0.5410E 00	0.2700E 00	0.1100E 01	0.9970E 01	0.2500E-01	0.1520E 01	0.6900E 00
585	0.5410E 00	0.2500E 00	0.1100E 01	0.7120E 01	0.2500E-01	0.1520E 01	0.6900E 00
586	0.4160E 00	0.2400E 00	0.5000E 00	0.2623E 02	0.1100E 00	0.1290E 01	0.6900E 00
587	0.4160E 00	0.2100E 00	0.5000E 00	0.1995E 02	0.1100E 00	0.1290E 01	0.6900E 00
588	0.4160E 00	0.1800E 00	0.5000E 00	0.1496E 02	0.1100E 00	0.1290E 01	0.6900E 00
589	0.4160E 00	0.1450E 00	0.5000E 00	0.7760E 01	0.1100E 00	0.1290E 01	0.6900E 00
590	0.3550E 00	0.2300E 00	0.5000E 00	0.2251E 02	0.4100E-01	0.1290E 01	0.6900E 00
591	0.3550E 00	0.2000E 00	0.5000E 00	0.1712E 02	0.4100E-01	0.1290E 01	0.6900E 00
592	0.3550E 00	0.1750E 00	0.5000E 00	0.1284E 02	0.4100E-01	0.1290E 01	0.6900E 00
593	0.3550E 00	0.1400E 00	0.5000E 00	0.6659E 01	0.4100E-01	0.1290E 01	0.6900E 00
594	0.2280E 00	0.2200E 00	0.5000E 00	0.1463E 02	0.1800E-01	0.1290E 01	0.6900E 00
595	0.2280E 00	0.1900E 00	0.5000E 00	0.1113E 02	0.1800E-01	0.1290E 01	0.6900E 00
596	0.2280E 00	0.1700E 00	0.5000E 00	0.8348E 01	0.1800E-01	0.1290E 01	0.6900E 00
597	0.5660E 00	0.4400E 00	0.6500E 00	0.3519E 02	0.1100E 00	0.1290E 01	0.6900E 00
598	0.5660E 00	0.4000E 00	0.6500E 00	0.2677E 02	0.1100E 00	0.1290E 01	0.6900E 00
599	0.5660E 00	0.3400E 00	0.6500E 00	0.2008E 02	0.1100E 00	0.1290E 01	0.6900E 00
600	0.5660E 00	0.2600E 00	0.6500E 00	0.1041E 02	0.1100E 00	0.1290E 01	0.6900E 00

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OBSV   SUBMER       U           H           P           X           W           L

601  0.5050E 00  0.4000E 00  0.6500E 00  0.3158E 02  0.4100E-01  0.1290E 01  0.6900E 00
602  0.5050E 00  0.3600E 00  0.6500E 00  0.2402E 02  0.4100E-01  0.1290E 01  0.6900E 00
603  0.5050E 00  0.3200E 00  0.6500E 00  0.1802E 02  0.4100E-01  0.1290E 01  0.6900E 00
604  0.5050E 00  0.2600E 00  0.6500E 00  0.9340E 01  0.4100E-01  0.1290E 01  0.6900E 00
605  0.3780E 00  0.3300E 00  0.6500E 00  0.2392E 02  0.1800E-01  0.1290E 01  0.6900E 00
606  0.3780E 00  0.2900E 00  0.6500E 00  0.1819E 02  0.1800E-01  0.1290E 01  0.6900E 00
607  0.3780E 00  0.2600E 00  0.6500E 00  0.1365E 02  0.1800E-01  0.1290E 01  0.6900E 00
608  0.3780E 00  0.2100E 00  0.6500E 00  0.7080E 01  0.1800E-01  0.1290E 01  0.6900E 00
609  0.3450E 00  0.3000E 00  0.6500E 00  0.2190E 02  0.2000E-01  0.1290E 01  0.6900E 00
610  0.3450E 00  0.2600E 00  0.6500E 00  0.1666E 02  0.2000E-01  0.1290E 01  0.6900E 00
611  0.3450E 00  0.2400E 00  0.6500E 00  0.1249E 02  0.2000E-01  0.1290E 01  0.6900E 00
612  0.3450E 00  0.1900E 00  0.6500E 00  0.6480E 01  0.2000E-01  0.1290E 01  0.6900E 00
613  0.7160E 00  0.5200E 00  0.8000E 00  0.4392E 02  0.1100E 00  0.1290E 01  0.6900E 00
614  0.7160E 00  0.4650E 00  0.8000E 00  0.3340E 02  0.1100E 00  0.1290E 01  0.6900E 00
615  0.7160E 00  0.4250E 00  0.8000E 00  0.2505E 02  0.1100E 00  0.1290E 01  0.6900E 00
616  0.7160E 00  0.3450E 00  0.8000E 00  0.1299E 02  0.1100E 00  0.1290E 01  0.6900E 00
617  0.7160E 00  0.3200E 00  0.8000E 00  0.9280E 01  0.1100E 00  0.1290E 01  0.6900E 00
618  0.6550E 00  0.5000E 00  0.8000E 00  0.4040E 02  0.4100E-01  0.1290E 01  0.6900E 00
619  0.6550E 00  0.4400E 00  0.8000E 00  0.3073E 02  0.4100E-01  0.1290E 01  0.6900E 00
620  0.6550E 00  0.4000E 00  0.8000E 00  0.2305E 02  0.4100E-01  0.1290E 01  0.6900E 00
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OBSV   SUBMER      U           H           P           X           W           L

621  0.6550E 00  0.3300E 00  0.8000E 00  0.1195E 02  0.4100E-01  0.1290E 01  0.6900E 00
622  0.6550E 00  0.3000E 00  0.8000E 00  0.8540E 01  0.4100E-01  0.1290E 01  0.6900E 00
623  0.5280E 00  0.4100E 00  0.8000E 00  0.3295E 02  0.1800E-01  0.1290E 01  0.6900E 00
624  0.5280E 00  0.3800E 00  0.8000E 00  0.2506E 02  0.1800E-01  0.1290E 01  0.6900E 00
625  0.5280E 00  0.3200E 00  0.8000E 00  0.1880E 02  0.1800E-01  0.1290E 01  0.6900E 00
626  0.5280E 00  0.2800E 00  0.8000E 00  0.9750E 01  0.1800E-01  0.1290E 01  0.6900E 00
627  0.5280E 00  0.2600E 00  0.8000E 00  0.6960E 01  0.1800E-01  0.1290E 01  0.6900E 00
628  0.4950E 00  0.3900E 00  0.8000E 00  0.3099E 02  0.2000E-01  0.1290E 01  0.6900E 00
629  0.4950E 00  0.3500E 00  0.8000E 00  0.2357E 02  0.2000E-01  0.1290E 01  0.6900E 00
630  0.4950E 00  0.3200E 00  0.8000E 00  0.1768E 02  0.2000E-01  0.1290E 01  0.6900E 00
631  0.4950E 00  0.2700E 00  0.8000E 00  0.9160E 01  0.2000E-01  0.1290E 01  0.6900E 00
632  0.4950E 00  0.2400E 00  0.8000E 00  0.6550E 01  0.2000E-01  0.1290E 01  0.6900E 00
633  0.3940E 00  0.3500E 00  0.8000E 00  0.2490E 02  0.2000E-01  0.1290E 01  0.6900E 00
634  0.3940E 00  0.3100E 00  0.8000E 00  0.1894E 02  0.2000E-01  0.1290E 01  0.6900E 00
635  0.3940E 00  0.2800E 00  0.8000E 00  0.1420E 02  0.2000E-01  0.1290E 01  0.6900E 00
636  0.3940E 00  0.2400E 00  0.8000E 00  0.7360E 01  0.2000E-01  0.1290E 01  0.6900E 00
637  0.3940E 00  0.2200E 00  0.8000E 00  0.5260E 01  0.2000E-01  0.1290E 01  0.6900E 00
638  0.8660E 00  0.5400E 00  0.9500E 00  0.5241E 02  0.1100E 00  0.1290E 01  0.6900E 00
639  0.8660E 00  0.5100E 00  0.9500E 00  0.3986E 02  0.1100E 00  0.1290E 01  0.6900E 00
640  0.8660E 00  0.4700E 00  0.9500E 00  0.2989E 02  0.1100E 00  0.1290E 01  0.6900E 00
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OBSV   SUBMER       U            H            P            X            W            L

641   0.8660E 00   0.4000E 00   0.9500E 00   0.1550E 02   0.1100E 00   0.1290E 01   0.6900E 00

642   0.8660E 00   0.3600E 00   0.9500E 00   0.1107E 02   0.1100E 00   0.1290E 01   0.6900E 00

643   0.8050E 00   0.5000E 00   0.9500E 00   0.4898E 02   0.4100E-01   0.1290E 01   0.6900E 00

644   0.8050E 00   0.4800E 00   0.9500E 00   0.3726E 02   0.4100E-01   0.1290E 01   0.6900E 00

645   0.8050E 00   0.4500E 00   0.9500E 00   0.2794E 02   0.4100E-01   0.1290E 01   0.6900E 00

646   0.8050E 00   0.3700E 00   0.9500E 00   0.1449E 02   0.4100E-01   0.1290E 01   0.6900E 00

647   0.8050E 00   0.3500E 00   0.9500E 00   0.1035E 02   0.4100E-01   0.1290E 01   0.6900E 00

648   0.6750E 00   0.4700E 00   0.9500E 00   0.4156E 02   0.2000E-01   0.1290E 01   0.6900E 00

649   0.6750E 00   0.4300E 00   0.9500E 00   0.3161E 02   0.2000E-01   0.1290E 01   0.6900E 00

650   0.6750E 00   0.3900E 00   0.9500E 00   0.2371E 02   0.2000E-01   0.1290E 01   0.6900E 00

651   0.6750E 00   0.3300E 00   0.9500E 00   0.1229E 02   0.2000E-01   0.1290E 01   0.6900E 00

652   0.6750E 00   0.3000E 00   0.9500E 00   0.8780E 01   0.2000E-01   0.1290E 01   0.6900E 00

653   0.6450E 00   0.4500E 00   0.9500E 00   0.3982E 02   0.2500E-01   0.1290E 01   0.6900E 00

654   0.6450E 00   0.4100E 00   0.9500E 00   0.3029E 02   0.2500E-01   0.1290E 01   0.6900E 00

655   0.6450E 00   0.3700E 00   0.9500E 00   0.2272E 02   0.2500E-01   0.1290E 01   0.6900E 00

656   0.6450E 00   0.3100E 00   0.9500E 00   0.1178E 02   0.2500E-01   0.1290E 01   0.6900E 00

657   0.6450E 00   0.2800E 00   0.9500E 00   0.8410E 01   0.2500E-01   0.1290E 01   0.6900E 00

658   0.5440E 00   0.4300E 00   0.9500E 00   0.3390E 02   0.2500E-01   0.1290E 01   0.6900E 00

659   0.5440E 00   0.4000E 00   0.9500E 00   0.2578E 02   0.2500E-01   0.1290E 01   0.6900E 00

660   0.5440E 00   0.3600E 00   0.9500E 00   0.1934E 02   0.2500E-01   0.1290E 01   0.6900E 00
```

OBSV	SUBMER	U	H	P	X	W	L
661	0.5440E 00	0.3000E 00	0.9500E 00	0.1003E 02	0.2500E-01	0.1290E 01	0.6900E 00
662	0.5440E 00	0.2700E 00	0.9500E 00	0.7160E 01	0.2500E-01	0.1290E 01	0.6900E 00
663	0.4670E 00	0.3900E 00	0.9500E 00	0.2931E 02	0.2500E-01	0.1290E 01	0.6900E 00
664	0.4670E 00	0.3500E 00	0.9500E 00	0.2229E 02	0.2500E-01	0.1290E 01	0.6900E 00
665	0.4670E 00	0.3100E 00	0.9500E 00	0.1672E 02	0.2500E-01	0.1290E 01	0.6900E 00
666	0.4670E 00	0.2600E 00	0.9500E 00	0.8670E 01	0.2500E-01	0.1290E 01	0.6900E 00
667	0.4670E 00	0.2400E 00	0.9500E 00	0.6190E 01	0.2500E-01	0.1290E 01	0.6900E 00
668	0.1016E 01	0.5200E 00	0.1100E 01	0.6067E 02	0.1100E 00	0.1290E 01	0.6900E 00
669	0.1016E 01	0.4900E 00	0.1100E 01	0.4614E 02	0.1100E 00	0.1290E 01	0.6900E 00
670	0.1016E 01	0.4600E 00	0.1100E 01	0.3461E 02	0.1100E 00	0.1290E 01	0.6900E 00
671	0.1016E 01	0.4000E 00	0.1100E 01	0.1794E 02	0.1100E 00	0.1290E 01	0.6900E 00
672	0.1016E 01	0.3800E 00	0.1100E 01	0.1282E 02	0.1100E 00	0.1290E 01	0.6900E 00
673	0.9550E 00	0.5100E 00	0.1100E 01	0.5733E 02	0.4100E-01	0.1290E 01	0.6900E 00
674	0.9550E 00	0.4900E 00	0.1100E 01	0.4361E 02	0.4100E-01	0.1290E 01	0.6900E 00
675	0.9550E 00	0.4700E 00	0.1100E 01	0.3270E 02	0.4100E-01	0.1290E 01	0.6900E 00
676	0.9550E 00	0.4000E 00	0.1100E 01	0.1696E 02	0.4100E-01	0.1290E 01	0.6900E 00
677	0.9550E 00	0.3800E 00	0.1100E 01	0.1211E 02	0.4100E-01	0.1290E 01	0.6900E 00
678	0.8280E 00	0.4900E 00	0.1100E 01	0.5028E 02	0.2000E-01	0.1290E 01	0.6900E 00
679	0.8280E 00	0.4700E 00	0.1100E 01	0.3824E 02	0.2000E-01	0.1290E 01	0.6900E 00
680	0.8280E 00	0.4400E 00	0.1100E 01	0.2868E 02	0.2000E-01	0.1290E 01	0.6900E 00

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OBSV   SUBMER      U           H           P           X           W           L

681  0.8280E 00  0.3800E 00  0.1100E 01  0.1487E 02  0.2000E-01  0.1290E 01  0.6900E 00
682  0.8280E 00  0.3600E 00  0.1100E 01  0.1062E 02  0.2000E-01  0.1290E 01  0.6900E 00
683  0.7950E 00  0.4800E 00  0.1100E 01  0.4842E 02  0.2500E-01  0.1290E 01  0.6900E 00
684  0.7950E 00  0.4600E 00  0.1100E 01  0.3683E 02  0.2500E-01  0.1290E 01  0.6900E 00
685  0.7950E 00  0.4300E 00  0.1100E 01  0.2762E 02  0.2500E-01  0.1290E 01  0.6900E 00
686  0.7950E 00  0.3600E 00  0.1100E 01  0.1432E 02  0.2500E-01  0.1290E 01  0.6900E 00
687  0.7950E 00  0.3400E 00  0.1100E 01  0.1023E 02  0.2500E-01  0.1290E 01  0.6900E 00
688  0.6940E 00  0.4500E 00  0.1100E 01  0.4266E 02  0.2500E-01  0.1290E 01  0.6900E 00
689  0.6940E 00  0.4250E 00  0.1100E 01  0.3244E 02  0.2500E-01  0.1290E 01  0.6900E 00
690  0.6940E 00  0.4000E 00  0.1100E 01  0.2433E 02  0.2500E-01  0.1290E 01  0.6900E 00
691  0.6940E 00  0.3400E 00  0.1100E 01  0.1262E 02  0.2500E-01  0.1290E 01  0.6900E 00
692  0.6940E 00  0.3200E 00  0.1100E 01  0.9010E 01  0.2500E-01  0.1290E 01  0.6900E 00
693  0.6170E 00  0.4100E 00  0.1100E 01  0.3820E 02  0.2500E-01  0.1290E 01  0.6900E 00
694  0.6170E 00  0.3900E 00  0.1100E 01  0.2905E 02  0.2500E-01  0.1290E 01  0.6900E 00
695  0.6170E 00  0.3700E 00  0.1100E 01  0.2179E 02  0.2500E-01  0.1290E 01  0.6900E 00
696  0.6170E 00  0.3100E 00  0.1100E 01  0.1130E 02  0.2500E-01  0.1290E 01  0.6900E 00
697  0.6170E 00  0.2900E 00  0.1100E 01  0.8070E 01  0.2500E-01  0.1290E 01  0.6900E 00
698  0.5410E 00  0.3800E 00  0.1100E 01  0.3372E 02  0.2500E-01  0.1290E 01  0.6900E 00
699  0.5410E 00  0.3600E 00  0.1100E 01  0.2565E 02  0.2500E-01  0.1290E 01  0.6900E 00
700  0.5410E 00  0.3400E 00  0.1100E 01  0.1924E 02  0.2500E-01  0.1290E 01  0.6900E 00
```

```
OBSV   SUBMER       U            H            P            X            W            L

701   0.5410E 00   0.2800E 00   0.1100E 01   0.9970E 01   0.2500E-01   0.1290E 01   0.6900E 00
702   0.5410E 00   0.2600E 00   0.1100E 01   0.7120E 01   0.2500E-01   0.1290E 01   0.6900E 00
703   0.4160E 00   0.2800E 00   0.5000E 00   0.2623E 02   0.1100E 00   0.1060E 01   0.6900E 00
704   0.4160E 00   0.2400E 00   0.5000E 00   0.1995E 02   0.1100E 00   0.1060E 01   0.6900E 00
705   0.4160E 00   0.2000E 00   0.5000E 00   0.1496E 02   0.1100E 00   0.1060E 01   0.6900E 00
706   0.4160E 00   0.1600E 00   0.5000E 00   0.7760E 01   0.1100E 00   0.1060E 01   0.6900E 00
707   0.3550E 00   0.2600E 00   0.5000E 00   0.2251E 02   0.4100E-01   0.1060E 01   0.6900E 00
708   0.3550E 00   0.2300E 00   0.5000E 00   0.1712E 02   0.4100E-01   0.1060E 01   0.6900E 00
709   0.3550E 00   0.1900E 00   0.5000E 00   0.1284E 02   0.4100E-01   0.1060E 01   0.6900E 00
710   0.3550E 00   0.1500E 00   0.5000E 00   0.6659E 01   0.4100E-01   0.1060E 01   0.6900E 00
711   0.2280E 00   0.2400E 00   0.5000E 00   0.1463E 02   0.1800E-01   0.1060E 01   0.6900E 00
712   0.2280E 00   0.2100E 00   0.5000E 00   0.1113E 02   0.1800E-01   0.1060E 01   0.6900E 00
713   0.2280E 00   0.1800E 00   0.5000E 00   0.8348E 01   0.1800E-01   0.1060E 01   0.6900E 00
714   0.5660E 00   0.4800E 00   0.6500E 00   0.3519E 02   0.1100E 00   0.1060E 01   0.6900E 00
715   0.5660E 00   0.4400E 00   0.6500E 00   0.2677E 02   0.1100E 00   0.1060E 01   0.6900E 00
716   0.5660E 00   0.3900E 00   0.6500E 00   0.2008E 02   0.1100E 00   0.1060E 01   0.6900E 00
717   0.5660E 00   0.3100E 00   0.6500E 00   0.1041E 02   0.1100E 00   0.1060E 01   0.6900E 00
718   0.5050E 00   0.4500E 00   0.6500E 00   0.3158E 02   0.4100E-01   0.1060E 01   0.6900E 00
719   0.5050E 00   0.4000E 00   0.6500E 00   0.2402E 02   0.4100E-01   0.1060E 01   0.6900E 00
720   0.5050E 00   0.3600E 00   0.6500E 00   0.1802E 02   0.4100E-01   0.1060E 01   0.6900E 00
```

OBSV	SUBMER	U	H	P	X	W	L
721	0.5050E 00	0.2900E 00	0.6500E 00	0.9340E 01	0.4100E-01	0.1060E 01	0.6900E 00
722	0.3780E 00	0.3600E 00	0.6500E 00	0.2392E 02	0.1800E-01	0.1060E 01	0.6900E 00
723	0.3780E 00	0.3200E 00	0.6500E 00	0.1819E 02	0.1800E-01	0.1060E 01	0.6900E 00
724	0.3780E 00	0.2900E 00	0.6500E 00	0.1365E 02	0.1800E-01	0.1060E 01	0.6900E 00
725	0.3780E 00	0.2400E 00	0.6500E 00	0.7080E 01	0.1800E-01	0.1060E 01	0.6900E 00
726	0.3450E 00	0.3400E 00	0.6500E 00	0.2190E 02	0.2000E-01	0.1060E 01	0.6900E 00
727	0.3450E 00	0.3050E 00	0.6500E 00	0.1666E 02	0.2000E-01	0.1060E 01	0.6900E 00
728	0.3450E 00	0.2700E 00	0.6500E 00	0.1249E 02	0.2000E-01	0.1060E 01	0.6900E 00
729	0.3450E 00	0.2200E 00	0.6500E 00	0.6480E 01	0.2000E-01	0.1060E 01	0.6900E 00
730	0.7160E 00	0.5200E 00	0.8000E 00	0.4392E 02	0.1100E 00	0.1060E 01	0.6900E 00
731	0.7160E 00	0.4800E 00	0.8000E 00	0.3340E 02	0.1100E 00	0.1060E 01	0.6900E 00
732	0.7160E 00	0.4400E 00	0.8000E 00	0.2505E 02	0.1100E 00	0.1060E 01	0.6900E 00
733	0.7160E 00	0.3600E 00	0.8000E 00	0.1299E 02	0.1100E 00	0.1060E 01	0.6900E 00
734	0.7160E 00	0.3100E 00	0.8000E 00	0.9280E 01	0.1100E 00	0.1060E 01	0.6900E 00
735	0.6550E 00	0.4800E 00	0.8000E 00	0.4040E 02	0.4100E-01	0.1060E 01	0.6900E 00
736	0.6550E 00	0.4500E 00	0.8000E 00	0.3073E 02	0.4100E-01	0.1060E 01	0.6900E 00
737	0.6550E 00	0.4000E 00	0.8000E 00	0.2305E 02	0.4100E-01	0.1060E 01	0.6900E 00
738	0.6550E 00	0.3300E 00	0.8000E 00	0.1195E 02	0.4100E-01	0.1060E 01	0.6900E 00
739	0.6550E 00	0.3000E 00	0.8000E 00	0.8540E 01	0.4100E-01	0.1060E 01	0.6900E 00
740	0.5280E 00	0.4200E 00	0.8000E 00	0.3295E 02	0.1800E-01	0.1060E 01	0.6900E 00

OBSV	SUBMER	U	H	P	X	W	L
741	0.5280E 00	0.3900E 00	0.8000E 00	0.2506E 02	0.1800E-01	0.1060E 01	0.6900E 00
742	0.5280E 00	0.3300E 00	0.8000E 00	0.1880E 02	0.1800E-01	0.1060E 01	0.6900E 00
743	0.5280E 00	0.3000E 00	0.8000E 00	0.9750E 01	0.1800E-01	0.1060E 01	0.6900E 00
744	0.5280E 00	0.2800E 00	0.8000E 00	0.6960E 01	0.1800E-01	0.1060E 01	0.6900E 00
745	0.4950E 00	0.3900E 00	0.8000E 00	0.3099E 02	0.2000E-01	0.1060E 01	0.6900E 00
746	0.4950E 00	0.3600E 00	0.8000E 00	0.2357E 02	0.2000E-01	0.1060E 01	0.6900E 00
747	0.4950E 00	0.3300E 00	0.8000E 00	0.1768E 02	0.2000E-01	0.1060E 01	0.6900E 00
748	0.4950E 00	0.2800E 00	0.8000E 00	0.9160E 01	0.2000E-01	0.1060E 01	0.6900E 00
749	0.4950E 00	0.2600E 00	0.8000E 00	0.6550E 01	0.2000E-01	0.1060E 01	0.6900E 00
750	0.3940E 00	0.3600E 00	0.8000E 00	0.2490E 02	0.2000E-01	0.1060E 01	0.6900E 00
751	0.3940E 00	0.3200E 00	0.8000E 00	0.1894E 02	0.2000E-01	0.1060E 01	0.6900E 00
752	0.3940E 00	0.2900E 00	0.8000E 00	0.1420E 02	0.2000E-01	0.1060E 01	0.6900E 00
753	0.3940E 00	0.2500E 00	0.8000E 00	0.7360E 01	0.2000E-01	0.1060E 01	0.6900E 00
754	0.3940E 00	0.2300E 00	0.8000E 00	0.5260E 01	0.2000E-01	0.1060E 01	0.6900E 00
755	0.8660E 00	0.4900E 00	0.9500E 00	0.5241E 02	0.1100E 00	0.1060E 01	0.6900E 00
756	0.8660E 00	0.4600E 00	0.9500E 00	0.3986E 02	0.1100E 00	0.1060E 01	0.6900E 00
757	0.8660E 00	0.4300E 00	0.9500E 00	0.2989E 02	0.1100E 00	0.1060E 01	0.6900E 00
758	0.8660E 00	0.3800E 00	0.9500E 00	0.1550E 02	0.1100E 00	0.1060E 01	0.6900E 00
759	0.8660E 00	0.3500E 00	0.9500E 00	0.1107E 02	0.1100E 00	0.1060E 01	0.6900E 00
760	0.8050E 00	0.4700E 00	0.9500E 00	0.4898E 02	0.4100E-01	0.1060E 01	0.6900E 00

```
OBSV   SUBMER       U           H           P           X            W           L

761  0.8050E 00  0.4400E 00  0.9500E 00  0.3726E 02  0.4100E-01  0.1060E 01  0.6900E 00
762  0.8050E 00  0.4100E 00  0.9500E 00  0.2794E 02  0.4100E-01  0.1060E 01  0.6900E 00
763  0.8050E 00  0.3600E 00  0.9500E 00  0.1449E 02  0.4100E-01  0.1060E 01  0.6900E 00
764  0.8050E 00  0.3400E 00  0.9500E 00  0.1035E 02  0.4100E-01  0.1060E 01  0.6900E 00
765  0.6750E 00  0.4500E 00  0.9500E 00  0.4156E 02  0.2000E-01  0.1060E 01  0.6900E 00
766  0.6750E 00  0.4200E 00  0.9500E 00  0.3161E 02  0.2000E-01  0.1060E 01  0.6900E 00
767  0.6750E 00  0.3800E 00  0.9500E 00  0.2371E 02  0.2000E-01  0.1060E 01  0.6900E 00
768  0.6750E 00  0.3200E 00  0.9500E 00  0.1229E 02  0.2000E-01  0.1060E 01  0.6900E 00
769  0.6750E 00  0.3000E 00  0.9500E 00  0.8780E 01  0.2000E-01  0.1060E 01  0.6900E 00
770  0.6450E 00  0.4300E 00  0.9500E 00  0.3982E 02  0.2500E-01  0.1060E 01  0.6900E 00
771  0.6450E 00  0.4050E 00  0.9500E 00  0.3029E 02  0.2500E-01  0.1060E 01  0.6900E 00
772  0.6450E 00  0.3700E 00  0.9500E 00  0.2272E 02  0.2500E-01  0.1060E 01  0.6900E 00
773  0.6450E 00  0.3100E 00  0.9500E 00  0.1178E 02  0.2500E-01  0.1060E 01  0.6900E 00
774  0.6450E 00  0.2800E 00  0.9500E 00  0.8410E 01  0.2500E-01  0.1060E 01  0.6900E 00
775  0.5440E 00  0.3900E 00  0.9500E 00  0.3390E 02  0.2500E-01  0.1060E 01  0.6900E 00
776  0.5440E 00  0.3600E 00  0.9500E 00  0.2578E 02  0.2500E-01  0.1060E 01  0.6900E 00
777  0.5440E 00  0.3300E 00  0.9500E 00  0.1934E 02  0.2500E-01  0.1060E 01  0.6900E 00
778  0.5440E 00  0.2800E 00  0.9500E 00  0.1003E 02  0.2500E-01  0.1060E 01  0.6900E 00
779  0.5440E 00  0.2600E 00  0.9500E 00  0.7160E 01  0.2500E-01  0.1060E 01  0.6900E 00
780  0.4670E 00  0.3600E 00  0.9500E 00  0.2931E 02  0.2500E-01  0.1060E 01  0.6900E 00
```

```
OBSV   SUBMER       U            H            P            X             W            L

781   0.4670E 00   0.3300E 00   0.9500E 00   0.2229E 02   0.2500E-01   0.1060E 01   0.6900E 00

782   0.4670E 00   0.3000E 00   0.9500E 00   0.1672E 02   0.2500E-01   0.1060E 01   0.6900E 00

783   0.4670E 00   0.2400E 00   0.9500E 00   0.8670E 01   0.2500E-01   0.1060E 01   0.6900E 00

784   0.4670E 00   0.2200E 00   0.9500E 00   0.6190E 01   0.2500E-01   0.1060E 01   0.6900E 00

785   0.1016E 01   0.4800E 00   0.1100E 01   0.6067E 02   0.1100E 00   0.1060E 01   0.6900E 00

786   0.1016E 01   0.4600E 00   0.1100E 01   0.4614E 02   0.1100E 00   0.1060E 01   0.6900E 00

787   0.1016E 01   0.4400E 00   0.1100E 01   0.3461E 02   0.1100E 00   0.1060E 01   0.6900E 00

788   0.1016E 01   0.3800E 00   0.1100E 01   0.1794E 02   0.1100E 00   0.1060E 01   0.6900E 00

789   0.1016E 01   0.3600E 00   0.1100E 01   0.1282E 02   0.1100E 00   0.1060E 01   0.6900E 00

790   0.9550E 00   0.4700E 00   0.1100E 01   0.5733E 02   0.4100E-01   0.1060E 01   0.6900E 00

791   0.9550E 00   0.4500E 00   0.1100E 01   0.4361E 02   0.4100E-01   0.1060E 01   0.6900E 00

792   0.9550E 00   0.4300E 00   0.1100E 01   0.3270E 02   0.4100E-01   0.1060E 01   0.6900E 00

793   0.9550E 00   0.3700E 00   0.1100E 01   0.1696E 02   0.4100E-01   0.1060E 01   0.6900E 00

794   0.9550E 00   0.3500E 00   0.1100E 01   0.1211E 02   0.4100E-01   0.1060E 01   0.6900E 00

795   0.8280E 00   0.4600E 00   0.1100E 01   0.5028E 02   0.2000E-01   0.1060E 01   0.6900E 00

796   0.8280E 00   0.4400E 00   0.1100E 01   0.3824E 02   0.2000E-01   0.1060E 01   0.6900E 00

797   0.8280E 00   0.4100E 00   0.1100E 01   0.2868E 02   0.2000E-01   0.1060E 01   0.6900E 00

798   0.8280E 00   0.3400E 00   0.1100E 01   0.1487E 02   0.2000E-01   0.1060E 01   0.6900E 00

799   0.8280E 00   0.3200E 00   0.1100E 01   0.1062E 02   0.2000E-01   0.1060E 01   0.6900E 00

800   0.7950E 00   0.4400E 00   0.1100E 01   0.4842E 02   0.2500E-01   0.1060E 01   0.6900E 00
```

```
OBSV   SUBMER       U            H            P            X            W            L

801   0.7950E 00   0.4200E 00   0.1100E 01   0.3683E 02   0.2500E-01   0.1060E 01   0.6900E 00
802   0.7950E 00   0.3900E 00   0.1100E 01   0.2762E 02   0.2500E-01   0.1060E 01   0.6900E 00
803   0.7950E 00   0.3200E 00   0.1100E 01   0.1432E 02   0.2500E-01   0.1060E 01   0.6900E 00
804   0.7950E 00   0.3000E 00   0.1100E 01   0.1023E 02   0.2500E-01   0.1060E 01   0.6900E 00
805   0.6940E 00   0.4100E 00   0.1100E 01   0.4266E 02   0.2500E-01   0.1060E 01   0.6900E 00
806   0.6940E 00   0.3900E 00   0.1100E 01   0.3244E 02   0.2500E-01   0.1060E 01   0.6900E 00
807   0.6940E 00   0.3600E 00   0.1100E 01   0.2433E 02   0.2500E-01   0.1060E 01   0.6900E 00
808   0.6940E 00   0.3000E 00   0.1100E 01   0.1262E 02   0.2500E-01   0.1060E 01   0.6900E 00
809   0.6940E 00   0.2800E 00   0.1100E 01   0.9010E 01   0.2500E-01   0.1060E 01   0.6900E 00
810   0.6170E 00   0.3900E 00   0.1100E 01   0.3820E 02   0.2500E-01   0.1060E 01   0.6900E 00
811   0.6170E 00   0.3600E 00   0.1100E 01   0.2905E 02   0.2500E-01   0.1060E 01   0.6900E 00
812   0.6170E 00   0.3400E 00   0.1100E 01   0.2179E 02   0.2500E-01   0.1060E 01   0.6900E 00
813   0.6170E 00   0.2800E 00   0.1100E 01   0.1130E 02   0.2500E-01   0.1060E 01   0.6900E 00
814   0.6170E 00   0.2600E 00   0.1100E 01   0.8070E 01   0.2500E-01   0.1060E 01   0.6900E 00
815   0.5410E 00   0.3650E 00   0.1100E 01   0.3372E 02   0.2500E-01   0.1060E 01   0.6900E 00
816   0.5410E 00   0.3400E 00   0.1100E 01   0.2565E 02   0.2500E-01   0.1060E 01   0.6900E 00
817   0.5410E 00   0.3200E 00   0.1100E 01   0.1924E 02   0.2500E-01   0.1060E 01   0.6900E 00
818   0.5410E 00   0.2600E 00   0.1100E 01   0.9970E 01   0.2500E-01   0.1060E 01   0.6900E 00
819   0.5410E 00   0.2400E 00   0.1100E 01   0.7120E 01   0.2500E-01   0.1060E 01   0.6900E 00
```

Appendix E

DIFFERENT RATES OF POWER CALCULATED FOR VARIOUS OPERATING CONDITIONS

Where, QOPERT=Air Flow Rate at the Operating Temperature and Pressure, m^3/s

QNORML=Air Flow Rate at the Standard Temperature and Pressure, m^3/s

QNML1 =Air Flow Rate at the Standard Temperature and Pressure, m^3/min

POWER1=Theoretical Power (Using Pressure Gauge Reading), KW

POWER2=Theoretical Power (Using Pressure Gauge Reading), Watts

POWER3=Theoretical Power (Using Submergence and Ignoring all the Losses), KW

POWER4=Theoretical Power (Using Submergence and Ignoring all the Losses), Watts

USEPWR=Useful Power, Watts

Note: The rate of power does not vary for different widths of the tank.

```
OBSERV    QOPERT       QNORML       POWER1       POWER2       POWER3       POWER4       QNML1        USEPWR

  1     0.6666E-02   0.6935E-02   0.7367E-01   0.7367E 02   0.2700E-01   0.2700E 02   0.4161E 00   0.2768E 02
  2     0.5033E-02   0.5236E-02   0.3755E-01   0.3755E 02   0.2039E-01   0.2039E 02   0.3142E 00   0.2090E 02
  3     0.3759E-02   0.3911E-02   0.2054E-01   0.2054E 02   0.1523E-01   0.1523E 02   0.2346E 00   0.1561E 02
  4     0.1940E-02   0.2018E-02   0.6011E-02   0.6011E 01   0.7858E-02   0.7858E 01   0.1211E 00   0.8055E 01
  5     0.6689E-02   0.6919E-02   0.7135E-01   0.7135E 02   0.2304E-01   0.2304E 02   0.4151E 00   0.2364E 02
  6     0.5047E-02   0.5220E-02   0.3411E-01   0.3411E 02   0.1738E-01   0.1738E 02   0.3132E 00   0.1783E 02
  7     0.3769E-02   0.3899E-02   0.1796E-01   0.1796E 02   0.1298E-01   0.1298E 02   0.2339E 00   0.1332E 02
  8     0.1946E-02   0.2013E-02   0.5336E-02   0.5336E 01   0.6704E-02   0.6704E 01   0.1208E 00   0.6878E 01
  9     0.6729E-02   0.6877E-02   0.6234E-01   0.6234E 02   0.1477E-01   0.1477E 02   0.4126E 00   0.1518E 02
 10     0.5076E-02   0.5188E-02   0.2725E-01   0.2725E 02   0.1114E-01   0.1114E 02   0.3113E 00   0.1145E 02
 11     0.3791E-02   0.3875E-02   0.1281E-01   0.1281E 02   0.8322E-02   0.8322E 01   0.2325E 00   0.8553E 01
 12     0.6618E-02   0.6981E-02   0.8277E-01   0.8277E 02   0.3680E-01   0.3680E 02   0.4188E 00   0.3765E 02
 13     0.4997E-02   0.5271E-02   0.4447E-01   0.4447E 02   0.2779E-01   0.2779E 02   0.3163E 00   0.2843E 02
 14     0.3733E-02   0.3937E-02   0.2573E-01   0.2573E 02   0.2076E-01   0.2076E 02   0.2362E 00   0.2124E 02
 15     0.1927E-02   0.2033E-02   0.9364E-02   0.9364E 01   0.1072E-01   0.1072E 02   0.1220E 00   0.1097E 02
 16     0.6640E-02   0.6965E-02   0.8045E-01   0.8045E 02   0.3283E-01   0.3283E 02   0.4179E 00   0.3361E 02
 17     0.5010E-02   0.5255E-02   0.4102E-01   0.4102E 02   0.2477E-01   0.2477E 02   0.3153E 00   0.2536E 02
 18     0.3745E-02   0.3928E-02   0.2441E-01   0.2441E 02   0.1851E-01   0.1851E 02   0.2357E 00   0.1896E 02
```

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OBSERV   QOPERT       QNORML       POWER1       POWER2       POWER3       POWER4       QNML1        USEPWR

 19     0.1932E-02   0.2027E-02   0.8021E-02   0.8021E 01   0.9553E-02   0.9553E 01   0.1216E 00   0.9782E 01
 20     0.6683E-02   0.6928E-02   0.7360E-01   0.7360E 02   0.2454E-01   0.2454E 02   0.4157E 00   0.2517E 02
 21     0.5042E-02   0.5227E-02   0.3582E-01   0.3582E 02   0.1852E-01   0.1852E 02   0.3136E 00   0.1899E 02
 22     0.3764E-02   0.3901E-02   0.1797E-01   0.1797E 02   0.1382E-01   0.1382E 02   0.2341E 00   0.1418E 02
 23     0.1943E-02   0.2014E-02   0.5339E-02   0.5339E 01   0.7137E-02   0.7137E 01   0.1209E 00   0.7320E 01
 24     0.6694E-02   0.6917E-02   0.7134E-01   0.7134E 02   0.2239E-01   0.2239E 02   0.4150E 00   0.2298E 02
 25     0.5050E-02   0.5219E-02   0.3410E-01   0.3410E 02   0.1689E-01   0.1689E 02   0.3131E 00   0.1733E 02
 26     0.3769E-02   0.3895E-02   0.1668E-01   0.1668E 02   0.1261E-01   0.1261E 02   0.2337E 00   0.1294E 02
 27     0.1948E-02   0.2013E-02   0.5335E-02   0.5335E 01   0.6516E-02   0.6516E 01   0.1208E 00   0.6685E 01
 28     0.6570E-02   0.7026E-02   0.9191E-01   0.9191E 02   0.4662E-01   0.4662E 02   0.4216E 00   0.4761E 02
 29     0.4965E-02   0.5309E-02   0.5310E-01   0.5310E 02   0.3523E-01   0.3523E 02   0.3185E 00   0.3598E 02
 30     0.3706E-02   0.3963E-02   0.3093E-01   0.3093E 02   0.2630E-01   0.2630E 02   0.2378E 00   0.2686E 02
 31     0.1914E-02   0.2047E-02   0.1206E-01   0.1206E 02   0.1358E-01   0.1358E 02   0.1228E 00   0.1387E 02
 32     0.1365E-02   0.1460E-02   0.7667E-02   0.7667E 01   0.9688E-02   0.9688E 01   0.8759E-01   0.9893E 01
 33     0.6592E-02   0.7010E-02   0.8957E-01   0.8957E 02   0.4264E-01   0.4264E 02   0.4206E 00   0.4358E 02
 34     0.4978E-02   0.5294E-02   0.4964E-01   0.4964E 02   0.3220E-01   0.3220E 02   0.3176E 00   0.3291E 02
 35     0.3716E-02   0.3952E-02   0.2834E-01   0.2834E 02   0.2404E-01   0.2404E 02   0.2371E 00   0.2456E 02
 36     0.1919E-02   0.2041E-02   0.1072E-01   0.1072E 02   0.1241E-01   0.1241E 02   0.1224E 00   0.1268E 02
```

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OBSERV    QOPERT       QNORML       POWER1       POWER2       POWER3       POWER4       QNML1        USEPWR

 37     0.1370E-02   0.1457E-02   0.7180E-02   0.7180E 01   0.8860E-02   0.8860E 01   0.8739E-01   0.9054E 01

 38     0.6630E-02   0.6969E-02   0.8049E-01   0.8049E 02   0.3431E-01   0.3431E 02   0.4181E 00   0.3513E 02

 39     0.5003E-02   0.5259E-02   0.4104E-01   0.4104E 02   0.2589E-01   0.2589E 02   0.3155E 00   0.2650E 02

 40     0.3739E-02   0.3931E-02   0.2443E-01   0.2443E 02   0.1935E-01   0.1935E 02   0.2358E 00   0.1981E 02

 41     0.1930E-02   0.2028E-02   0.8026E-02   0.8026E 01   0.9987E-02   0.9987E 01   0.1217E 00   0.1022E 02

 42     0.1377E-02   0.1448E-02   0.5258E-02   0.5258E 01   0.7128E-02   0.7128E 01   0.8686E-01   0.7297E 01

 43     0.6640E-02   0.6959E-02   0.7823E-01   0.7823E 02   0.3216E-01   0.3216E 02   0.4175E 00   0.3293E 02

 44     0.5014E-02   0.5254E-02   0.4101E-01   0.4101E 02   0.2428E-01   0.2428E 02   0.3152E 00   0.2486E 02

 45     0.3745E-02   0.3924E-02   0.2313E-01   0.2313E 02   0.1814E-01   0.1814E 02   0.2355E 00   0.1857E 02

 46     0.1934E-02   0.2026E-02   0.8019E-02   0.8019E 01   0.9365E-02   0.9365E 01   0.1216E 00   0.9590E 01

 47     0.1379E-02   0.1445E-02   0.4778E-02   0.4778E 01   0.6680E-02   0.6680E 01   0.8673E-01   0.6840E 01

 48     0.6672E-02   0.6926E-02   0.7143E-01   0.7143E 02   0.2556E-01   0.2556E 02   0.4156E 00   0.2621E 02

 49     0.5037E-02   0.5229E-02   0.3584E-01   0.3584E 02   0.1930E-01   0.1930E 02   0.3138E 00   0.1979E 02

 50     0.3762E-02   0.3906E-02   0.1925E-01   0.1925E 02   0.1442E-01   0.1442E 02   0.2343E 00   0.1478E 02

 51     0.1941E-02   0.2015E-02   0.5342E-02   0.5342E 01   0.7438E-02   0.7438E 01   0.1209E 00   0.7627E 01

 52     0.1386E-02   0.1438E-02   0.3340E-02   0.3340E 01   0.5309E-02   0.5309E 01   0.8631E-01   0.5444E 01

 53     0.6524E-02   0.7071E-02   0.1011E 00   0.1011E 03   0.5648E-01   0.5648E 02   0.4243E 00   0.5756E 02

 54     0.4927E-02   0.5340E-02   0.5838E-01   0.5838E 02   0.4265E-01   0.4265E 02   0.3204E 00   0.4347E 02
```

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OBSERV     QOPERT       QNORML       POWER1       POWER2       POWER3       POWER4       QNML1        USEPWR

 55     0.3681E-02   0.3989E-02   0.3616E-01   0.3616E 02   0.3186E-01   0.3186E 02   0.2394E 00   0.3247E 02
 56     0.1899E-02   0.2059E-02   0.1411E-01   0.1411E 02   0.1644E-01   0.1644E 02   0.1235E 00   0.1676E 02
 57     0.1356E-02   0.1470E-02   0.9602E-02   0.9602E 01   0.1174E-01   0.1174E 02   0.8817E-01   0.1196E 02
 58     0.6545E-02   0.7056E-02   0.9873E-01   0.9873E 02   0.5249E-01   0.5249E 02   0.4233E 00   0.5354E 02
 59     0.4940E-02   0.5325E-02   0.5491E-01   0.5491E 02   0.3961E-01   0.3961E 02   0.3195E 00   0.4040E 02
 60     0.3690E-02   0.3978E-02   0.3356E-01   0.3356E 02   0.2959E-01   0.2959E 02   0.2387E 00   0.3018E 02
 61     0.1906E-02   0.2054E-02   0.1342E-01   0.1342E 02   0.1528E-01   0.1528E 02   0.1233E 00   0.1559E 02
 62     0.1360E-02   0.1466E-02   0.9112E-02   0.9112E 01   0.1091E-01   0.1091E 02   0.8798E-01   0.1113E 02
 63     0.6588E-02   0.7019E-02   0.9182E-01   0.9182E 02   0.4397E-01   0.4397E 02   0.4211E 00   0.4492E 02
 64     0.4971E-02   0.5296E-02   0.4967E-01   0.4967E 02   0.3318E-01   0.3318E 02   0.3178E 00   0.3390E 02
 65     0.3711E-02   0.3954E-02   0.2835E-01   0.2835E 02   0.2477E-01   0.2477E 02   0.2372E 00   0.2530E 02
 66     0.1916E-02   0.2042E-02   0.1072E-01   0.1072E 02   0.1279E-01   0.1279E 02   0.1225E 00   0.1307E 02
 67     0.1368E-02   0.1457E-02   0.7183E-02   0.7183E 01   0.9129E-02   0.9129E 01   0.8744E-01   0.9327E 01
 68     0.6597E-02   0.7009E-02   0.8955E-01   0.8955E 02   0.4199E-01   0.4199E 02   0.4205E 00   0.4292E 02
 69     0.4978E-02   0.5289E-02   0.4794E-01   0.4794E 02   0.3169E-01   0.3169E 02   0.3173E 00   0.3239E 02
 70     0.3718E-02   0.3951E-02   0.2833E-01   0.2833E 02   0.2367E-01   0.2367E 02   0.2370E 00   0.2419E 02
 71     0.1920E-02   0.2040E-02   0.1071E-01   0.1071E 02   0.1222E-01   0.1222E 02   0.1224E 00   0.1249E 02
 72     0.1370E-02   0.1455E-02   0.6703E-02   0.6703E 01   0.8719E-02   0.8719E 01   0.8731E-01   0.8912E 01
```

```
OBSERV    QOPERT       QNORML       POWER1       POWER2       POWER3       POWER4       QNML1        USEPWR
  73    0.6623E-02   0.6972E-02   0.8053E-01   0.8053E 02   0.3535E-01   0.3535E 02   0.4183E 00   0.3618E 02
  74    0.5001E-02   0.5264E-02   0.4275E-01   0.4275E 02   0.2669E-01   0.2669E 02   0.3159E 00   0.2732E 02
  75    0.3738E-02   0.3935E-02   0.2571E-01   0.2571E 02   0.1995E-01   0.1995E 02   0.2361E 00   0.2042E 02
  76    0.1928E-02   0.2029E-02   0.8029E-02   0.8029E 01   0.1029E-01   0.1029E 02   0.1217E 00   0.1053E 02
  77    0.1376E-02   0.1448E-02   0.5260E-02   0.5260E 01   0.7344E-02   0.7344E 01   0.8690E-01   0.7516E 01
  78    0.6648E-02   0.6949E-02   0.7597E-01   0.7597E 02   0.3032E-01   0.3032E 02   0.4169E 00   0.3107E 02
  79    0.5020E-02   0.5247E-02   0.3929E-01   0.3929E 02   0.2290E-01   0.2290E 02   0.3148E 00   0.2346E 02
  80    0.3747E-02   0.3916E-02   0.2057E-01   0.2057E 02   0.1709E-01   0.1709E 02   0.2350E 00   0.1751E 02
  81    0.1935E-02   0.2022E-02   0.6684E-02   0.6684E 01   0.8824E-02   0.8824E 01   0.1213E 00   0.9040E 01
  82    0.1380E-02   0.1442E-02   0.3823E-02   0.3823E 01   0.6294E-02   0.6294E 01   0.8654E-01   0.6448E 01
  83    0.6474E-02   0.7111E-02   0.1081E 00   0.1081E 03   0.6632E-01   0.6632E 02   0.4267E 00   0.6746E 02
  84    0.4893E-02   0.5374E-02   0.6538E-01   0.6538E 02   0.5012E-01   0.5012E 02   0.3225E 00   0.5098E 02
  85    0.3653E-02   0.4012E-02   0.4013E-01   0.4013E 02   0.3742E-01   0.3742E 02   0.2407E 00   0.3806E 02
  86    0.1887E-02   0.2072E-02   0.1683E-01   0.1683E 02   0.1932E-01   0.1932E 02   0.1243E 00   0.1966E 02
  87    0.1347E-02   0.1479E-02   0.1155E-01   0.1155E 02   0.1379E-01   0.1379E 02   0.8875E-01   0.1403E 02
  88    0.6495E-02   0.7096E-02   0.1057E 00   0.1057E 03   0.6232E-01   0.6232E 02   0.4258E 00   0.6344E 02
  89    0.4906E-02   0.5359E-02   0.6190E-01   0.6190E 02   0.4707E-01   0.4707E 02   0.3216E 00   0.4792E 02
  90    0.3665E-02   0.4004E-02   0.3879E-01   0.3879E 02   0.3516E-01   0.3516E 02   0.2402E 00   0.3580E 02
```

```
OBSERV    QOPERT      QNORML      POWER1      POWER2      POWER3      POWER4      QNML1       USEPWR

  91    0.1891E-02  0.2066E-02  0.1547E-01  0.1547E 02  0.1815E-01  0.1815E 02  0.1240E 00  0.1847E 02
  92    0.1350E-02  0.1475E-02  0.1058E-01  0.1058E 02  0.1295E-01  0.1295E 02  0.8849E-01  0.1319E 02
  93    0.6536E-02  0.7060E-02  0.9879E-01  0.9879E 02  0.5398E-01  0.5398E 02  0.4236E 00  0.5504E 02
  94    0.4936E-02  0.5331E-02  0.5664E-01  0.5664E 02  0.4076E-01  0.4076E 02  0.3199E 00  0.4157E 02
  95    0.3685E-02  0.3980E-02  0.3358E-01  0.3358E 02  0.3043E-01  0.3043E 02  0.2388E 00  0.3103E 02
  96    0.1903E-02  0.2055E-02  0.1343E-01  0.1343E 02  0.1572E-01  0.1572E 02  0.1233E 00  0.1602E 02
  97    0.1358E-02  0.1467E-02  0.9118E-02  0.9118E 01  0.1122E-01  0.1122E 02  0.8803E-01  0.1144E 02
  98    0.6541E-02  0.7045E-02  0.9430E-01  0.9430E 02  0.5177E-01  0.5177E 02  0.4227E 00  0.5281E 02
  99    0.4940E-02  0.5320E-02  0.5321E-01  0.5321E 02  0.3910E-01  0.3910E 02  0.3192E 00  0.3988E 02
 100    0.3687E-02  0.3971E-02  0.3100E-01  0.3100E 02  0.2919E-01  0.2919E 02  0.2383E 00  0.2977E 02
 101    0.1906E-02  0.2052E-02  0.1275E-01  0.1275E 02  0.1508E-01  0.1508E 02  0.1231E 00  0.1539E 02
 102    0.1360E-02  0.1465E-02  0.8635E-02  0.8635E 01  0.1077E-01  0.1077E 02  0.8789E-01  0.1098E 02
 103    0.6576E-02  0.7017E-02  0.8966E-01  0.8966E 02  0.4517E-01  0.4517E 02  0.4210E 00  0.4614E 02
 104    0.4962E-02  0.5296E-02  0.4800E-01  0.4800E 02  0.3409E-01  0.3409E 02  0.3177E 00  0.3482E 02
 105    0.3707E-02  0.3956E-02  0.2837E-01  0.2837E 02  0.2546E-01  0.2546E 02  0.2373E 00  0.2601E 02
 106    0.1914E-02  0.2043E-02  0.1073E-01  0.1073E 02  0.1315E-01  0.1315E 02  0.1226E 00  0.1343E 02
 107    0.1365E-02  0.1457E-02  0.6711E-02  0.6711E 01  0.9379E-02  0.9379E 01  0.8742E-01  0.9579E 01
 108    0.6600E-02  0.6994E-02  0.8509E-01  0.8509E 02  0.4013E-01  0.4013E 02  0.4197E 00  0.4103E 02
```

```
OBSERV    QOPERT      QNORML      POWER1      POWER2      POWER3      POWER4      QNML1       USEPWR

109     0.4980E-02  0.5278E-02  0.4453E-01  0.4453E 02  0.3028E-01  0.3028E 02  0.3167E 00  0.3096E 02

110     0.3720E-02  0.3942E-02  0.2576E-01  0.2576E 02  0.2262E-01  0.2262E 02  0.2365E 00  0.2313E 02

111     0.1920E-02  0.2034E-02  0.8711E-02  0.8711E 01  0.1167E-01  0.1167E 02  0.1221E 00  0.1193E 02

112     0.1370E-02  0.1452E-02  0.5746E-02  0.5746E 01  0.8331E-02  0.8331E 01  0.8713E-01  0.8518E 01

113     0.6624E-02  0.6971E-02  0.8052E-01  0.8052E 02  0.3516E-01  0.3516E 02  0.4183E 00  0.3598E 02

114     0.4998E-02  0.5260E-02  0.4106E-01  0.4106E 02  0.2653E-01  0.2653E 02  0.3156E 00  0.2715E 02

115     0.3734E-02  0.3929E-02  0.2316E-01  0.2316E 02  0.1982E-01  0.1982E 02  0.2358E 00  0.2028E 02

116     0.1928E-02  0.2029E-02  0.8029E-02  0.8029E 01  0.1023E-01  0.1023E 02  0.1217E 00  0.1047E 02

117     0.1376E-02  0.1448E-02  0.5259E-02  0.5259E 01  0.7304E-02  0.7304E 01  0.8689E-01  0.7475E 01
```

Appendix F

VARIOUS OPERATING CONDITIONS FOR WHICH DIMENSIONLESS FACTORS WERE CALCULATED

Where SUBMER=Depth of Water Above the Diffusers, m

QOBSD = Observed Air Flow Rate (Rotameter Reading), SCFM

PRGARD= Observed Pressure Gauge Reading, psig

For different widths of the tank, SUBMER, QOBSD and PRGARD readings did not change. Only the horizontal velocities changed along the depth for different widths of the tank.

OBSERV	SUBMER	QOBSD	PRGARD
1	0.4160E 00	0.1420E 02	0.1650E 01
2	0.4160E 00	0.1080E 02	0.1100E 01
3	0.4160E 00	0.8100E 01	0.8000E 00
4	0.4160E 00	0.4200E 01	0.4500E 00
5	0.3550E 00	0.1420E 02	0.1600E 01
6	0.3550E 00	0.1080E 02	0.1000E 01
7	0.3550E 00	0.8100E 01	0.7000E 00
8	0.3550E 00	0.4200E 01	0.4000E 00
9	0.2280E 00	0.1420E 02	0.1400E 01
10	0.2280E 00	0.1080E 02	0.8000E 00
11	0.2280E 00	0.8100E 01	0.5000E 00
12	0.5660E 00	0.1420E 02	0.1850E 01
13	0.5660E 00	0.1080E 02	0.1300E 01
14	0.5660E 00	0.8100E 01	0.1000E 01
15	0.5660E 00	0.4200E 01	0.7000E 00
16	0.5050E 00	0.1420E 02	0.1800E 01
17	0.5050E 00	0.1080E 02	0.1200E 01
18	0.5050E 00	0.8100E 01	0.9500E 00
19	0.5050E 00	0.4200E 01	0.6000E 00
20	0.3780E 00	0.1420E 02	0.1650E 01
21	0.3780E 00	0.1080E 02	0.1050E 01
22	0.3780E 00	0.8100E 01	0.7000E 00
23	0.3780E 00	0.4200E 01	0.4000E 00
24	0.3450E 00	0.1420E 02	0.1600E 01
25	0.3450E 00	0.1080E 02	0.1000E 01

OBSERV	SUBMER	QOBSD	PRGARD
26	0.3450E 00	0.8100E 01	0.6500E 00
27	0.3450E 00	0.4200E 01	0.4000E 00
28	0.7160E 00	0.1420E 02	0.2050E 01
29	0.7160E 00	0.1080E 02	0.1550E 01
30	0.7160E 00	0.8100E 01	0.1200E 01
31	0.7160E 00	0.4200E 01	0.9000E 00
32	0.7160E 00	0.3000E 01	0.8000E 00
33	0.6550E 00	0.1420E 02	0.2000E 01
34	0.6550E 00	0.1080E 02	0.1450E 01
35	0.6550E 00	0.8100E 01	0.1100E 01
36	0.6550E 00	0.4200E 01	0.8000E 00
37	0.6550E 00	0.3000E 01	0.7500E 00
38	0.5280E 00	0.1420E 02	0.1800E 01
39	0.5280E 00	0.1080E 02	0.1200E 01
40	0.5280E 00	0.8100E 01	0.9500E 00
41	0.5280E 00	0.4200E 01	0.6000E 00
42	0.5280E 00	0.3000E 01	0.5500E 00
43	0.4950E 00	0.1420E 02	0.1750E 01
44	0.4950E 00	0.1080E 02	0.1200E 01
45	0.4950E 00	0.8100E 01	0.9000E 00
46	0.4950E 00	0.4200E 01	0.6000E 00
47	0.4950E 00	0.3000E 01	0.5000E 00
48	0.3940E 00	0.1420E 02	0.1600E 01
49	0.3940E 00	0.1080E 02	0.1050E 01
50	0.3940E 00	0.8100E 01	0.7500E 00

OBSERV	SUBMER	QOBSD	PRGARD
51	0.3940E 00	0.4200E 01	0.4000E 00
52	0.3940E 00	0.3000E 01	0.3500E 00
53	0.8660E 00	0.1420E 02	0.2250E 01
54	0.8660E 00	0.1080E 02	0.1700E 01
55	0.8660E 00	0.8100E 01	0.1400E 01
56	0.8660E 00	0.4200E 01	0.1050E 01
57	0.8660E 00	0.3000E 01	0.1000E 01
58	0.8050E 00	0.1420E 02	0.2200E 01
59	0.8050E 00	0.1080E 02	0.1600E 01
60	0.8050E 00	0.8100E 01	0.1300E 01
61	0.8050E 00	0.4200E 01	0.1000E 01
62	0.8050E 00	0.3000E 01	0.9500E 00
63	0.6750E 00	0.1420E 02	0.2050E 01
64	0.6750E 00	0.1080E 02	0.1450E 01
65	0.6750E 00	0.8100E 01	0.1100E 01
66	0.6750E 00	0.4200E 01	0.8000E 00
67	0.6750E 00	0.3000E 01	0.7500E 00
68	0.6450E 00	0.1420E 02	0.2000E 01
69	0.6450E 00	0.1080E 02	0.1400E 01
70	0.6450E 00	0.8100E 01	0.1100E 01
71	0.6450E 00	0.4200E 01	0.8000E 00
72	0.6450E 00	0.3000E 01	0.7000E 00
73	0.5440E 00	0.1420E 02	0.1800E 01
74	0.5440E 00	0.1080E 02	0.1250E 01
75	0.5440E 00	0.8100E 01	0.1000E 01

OBSERV	SUBMER	QOBSD	PRGARD
76	0.5440E 00	0.4200E 01	0.6000E 00
77	0.5440E 00	0.3000E 01	0.5500E 00
78	0.4670E 00	0.1420E 02	0.1700E 01
79	0.4670E 00	0.1080E 02	0.1150E 01
80	0.4670E 00	0.8100E 01	0.8000E 00
81	0.4670E 00	0.4200E 01	0.5000E 00
82	0.4670E 00	0.3000E 01	0.4000E 00
83	0.1016E 01	0.1420E 02	0.2400E 01
84	0.1016E 01	0.1080E 02	0.1900E 01
85	0.1016E 01	0.8100E 01	0.1550E 01
86	0.1016E 01	0.4200E 01	0.1250E 01
87	0.1016E 01	0.3000E 01	0.1200E 01
88	0.9550E 00	0.1420E 02	0.2350E 01
89	0.9550E 00	0.1080E 02	0.1800E 01
90	0.9550E 00	0.8100E 01	0.1500E 01
91	0.9550E 00	0.4200E 01	0.1150E 01
92	0.9550E 00	0.3000E 01	0.1100E 01
93	0.8280E 00	0.1420E 02	0.2200E 01
94	0.8280E 00	0.1080E 02	0.1650E 01
95	0.8280E 00	0.8100E 01	0.1300E 01
96	0.8280E 00	0.4200E 01	0.1000E 01
97	0.8280E 00	0.3000E 01	0.9500E 00
98	0.7950E 00	0.1420E 02	0.2100E 01
99	0.7950E 00	0.1080E 02	0.1550E 01
100	0.7950E 00	0.8100E 01	0.1200E 01

```
OBSERV     SUBMER          QOBSD           PRGARD

101        0.7950E 00      0.4200E 01      0.9500E 00

102        0.7950E 00      0.3000E 01      0.9000E 00

103        0.6940E 00      0.1420E 02      0.2000E 01

104        0.6940E 00      0.1080E 02      0.1400E 01

105        0.6940E 00      0.8100E 01      0.1100E 01

106        0.6940E 00      0.4200E 01      0.8000E 00

107        0.6940E 00      0.3000E 01      0.7000E 00

108        0.6170E 00      0.1420E 02      0.1900E 01

109        0.6170E 00      0.1080E 02      0.1300E 01

110        0.6170E 00      0.8100E 01      0.1000E 01

111        0.6170E 00      0.4200E 01      0.6500E 00

112        0.6170E 00      0.3000E 01      0.6000E 00

113        0.5410E 00      0.1420E 02      0.1800E 01

114        0.5410E 00      0.1080E 02      0.1200E 01

115        0.5410E 00      0.8100E 01      0.9000E 00

116        0.5410E 00      0.4200E 01      0.6000E 00

117        0.5410E 00      0.3000E 01      0.5500E 00
```

Appendix G

VARIOUS DIMENSIONLESS FACTORS FOR DIFFERENT OPERATING CONDITIONS

Where F1 = Velocity Factor

F2 = Power Factor

F3 = Width Factor

F4 = Depth Factor

F5 = Submergence Factor

OBSV	F1	F2	F3	F4	F5
1	0.7485E 05	0.1378E 17	0.4880E 01	0.1069E 05	0.8320E 00
2	0.6487E 05	0.1041E 17	0.4880E 01	0.1069E 05	0.8320E 00
3	0.5489E 05	0.7774E 16	0.4880E 01	0.1069E 05	0.8320E 00
4	0.3493E 05	0.4009E 16	0.4880E 01	0.1069E 05	0.8320E 00
5	0.6986E 05	0.1177E 17	0.4880E 01	0.1069E 05	0.7100E 00
6	0.5988E 05	0.8879E 16	0.4880E 01	0.1069E 05	0.7100E 00
7	0.4990E 05	0.6633E 16	0.4880E 01	0.1069E 05	0.7100E 00
8	0.2994E 05	0.3425E 16	0.4880E 01	0.1069E 05	0.7100E 00
9	0.6487E 05	0.7560E 16	0.4880E 01	0.1069E 05	0.4560E 00
10	0.5489E 05	0.5702E 16	0.4880E 01	0.1069E 05	0.4560E 00
11	0.4491E 05	0.4259E 16	0.4880E 01	0.1069E 05	0.4560E 00
12	0.1557E 06	0.2437E 17	0.3754E 01	0.1390E 05	0.8708E 00
13	0.1362E 06	0.1841E 17	0.3754E 01	0.1390E 05	0.8708E 00
14	0.1168E 06	0.1375E 17	0.3754E 01	0.1390E 05	0.8708E 00
15	0.9082E 05	0.7102E 16	0.3754E 01	0.1390E 05	0.8708E 00
16	0.1427E 06	0.2176E 17	0.3754E 01	0.1390E 05	0.7769E 00
17	0.1297E 06	0.1642E 17	0.3754E 01	0.1390E 05	0.7769E 00
18	0.1103E 06	0.1227E 17	0.3754E 01	0.1390E 05	0.7769E 00
19	0.8433E 05	0.6332E 16	0.3754E 01	0.1390E 05	0.7769E 00
20	0.1168E 06	0.1630E 17	0.3754E 01	0.1390E 05	0.5815E 00

```
OBSV    F1             F2             F3            F4            F5

21   0.1038E 06    0.1229E 17    0.3754E 01    0.1390E 05    0.5815E 00
22   0.9082E 05    0.9180E 16    0.3754E 01    0.1390E 05    0.5815E 00
23   0.6487E 05    0.4739E 16    0.3754E 01    0.1390E 05    0.5815E 00
24   0.1103E 06    0.1488E 17    0.3754E 01    0.1390E 05    0.5308E 00
25   0.9730E 05    0.1122E 17    0.3754E 01    0.1390E 05    0.5308E 00
26   0.7784E 05    0.8377E 16    0.3754E 01    0.1390E 05    0.5308E 00
27   0.5190E 05    0.4331E 16    0.3754E 01    0.1390E 05    0.5308E 00
28   0.2475E 06    0.3794E 17    0.3050E 01    0.1710E 05    0.8950E 00
29   0.2315E 06    0.2867E 17    0.3050E 01    0.1710E 05    0.8950E 00
30   0.2076E 06    0.2140E 17    0.3050E 01    0.1710E 05    0.8950E 00
31   0.1597E 06    0.1105E 17    0.3050E 01    0.1710E 05    0.8950E 00
32   0.1437E 06    0.7880E 16    0.3050E 01    0.1710E 05    0.8950E 00
33   0.2395E 06    0.3472E 17    0.3050E 01    0.1710E 05    0.8187E 00
34   0.2156E 06    0.2622E 17    0.3050E 01    0.1710E 05    0.8187E 00
35   0.1836E 06    0.1957E 17    0.3050E 01    0.1710E 05    0.8187E 00
36   0.1437E 06    0.1010E 17    0.3050E 01    0.1710E 05    0.8187E 00
37   0.1198E 06    0.7211E 16    0.3050E 01    0.1710E 05    0.8187E 00
38   0.1916E 06    0.2799E 17    0.3050E 01    0.1710E 05    0.6600E 00
39   0.1756E 06    0.2112E 17    0.3050E 01    0.1710E 05    0.6600E 00
40   0.1597E 06    0.1578E 17    0.3050E 01    0.1710E 05    0.6600E 00
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```
OBSV    F1            F2            F3            F4            F5

 41   0.1198E 06    0.8143E 16    0.3050E 01    0.1710E 05    0.6600E 00
 42   0.9581E 05    0.5817E 16    0.3050E 01    0.1710E 05    0.6600E 00
 43   0.1756E 06    0.2624E 17    0.3050E 01    0.1710E 05    0.6187E 00
 44   0.1597E 06    0.1981E 17    0.3050E 01    0.1710E 05    0.6187E 00
 45   0.1437E 06    0.1480E 17    0.3050E 01    0.1710E 05    0.6187E 00
 46   0.1118E 06    0.7641E 16    0.3050E 01    0.1710E 05    0.6187E 00
 47   0.8782E 05    0.5450E 16    0.3050E 01    0.1710E 05    0.6187E 00
 48   0.1597E 06    0.2088E 17    0.3050E 01    0.1710E 05    0.4925E 00
 49   0.1437E 06    0.1577E 17    0.3050E 01    0.1710E 05    0.4925E 00
 50   0.1277E 06    0.1178E 17    0.3050E 01    0.1710E 05    0.4925E 00
 51   0.1038E 06    0.6080E 16    0.3050E 01    0.1710E 05    0.4925E 00
 52   0.7984E 05    0.4335E 16    0.3050E 01    0.1710E 05    0.4925E 00
 53   0.3413E 06    0.5446E 17    0.2568E 01    0.2031E 05    0.9116E 00
 54   0.3129E 06    0.4113E 17    0.2568E 01    0.2031E 05    0.9116E 00
 55   0.2844E 06    0.3072E 17    0.2568E 01    0.2031E 05    0.9116E 00
 56   0.2275E 06    0.1586E 17    0.2568E 01    0.2031E 05    0.9116E 00
 57   0.1991E 06    0.1132E 17    0.2568E 01    0.2031E 05    0.9116E 00
 58   0.3224E 06    0.5066E 17    0.2568E 01    0.2031E 05    0.8474E 00
 59   0.2844E 06    0.3823E 17    0.2568E 01    0.2031E 05    0.8474E 00
 60   0.2465E 06    0.2856E 17    0.2568E 01    0.2031E 05    0.8474E 00
```

```
OBSV     F1            F2            F3            F4            F5

 61  0.1991E 06    0.1475E 17    0.2568E 01    0.2031E 05    0.8474E 00
 62  0.1801E 06    0.1053E 17    0.2568E 01    0.2031E 05    0.8474E 00
 63  0.2844E 06    0.4250E 17    0.2568E 01    0.2031E 05    0.7105E 00
 64  0.2560E 06    0.3208E 17    0.2568E 01    0.2031E 05    0.7105E 00
 65  0.2275E 06    0.2394E 17    0.2568E 01    0.2031E 05    0.7105E 00
 66  0.1801E 06    0.1237E 17    0.2568E 01    0.2031E 05    0.7105E 00
 67  0.1517E 06    0.8828E 16    0.2568E 01    0.2031E 05    0.7105E 00
 68  0.2655E 06    0.4061E 17    0.2568E 01    0.2031E 05    0.6789E 00
 69  0.2465E 06    0.3116E 17    0.2568E 01    0.2031E 05    0.6789E 00
 70  0.2181E 06    0.2289E 17    0.2568E 01    0.2031E 05    0.6789E 00
 71  0.1707E 06    0.1182E 17    0.2568E 01    0.2031E 05    0.6789E 00
 72  0.1327E 06    0.8431E 16    0.2568E 01    0.2031E 05    0.6789E 00
 73  0.2560E 06    0.3423E 17    0.2568E 01    0.2031E 05    0.5726E 00
 74  0.2370E 06    0.2585E 17    0.2568E 01    0.2031E 05    0.5726E 00
 75  0.2086E 06    0.1932E 17    0.2568E 01    0.2031E 05    0.5726E 00
 76  0.1422E 06    0.9964E 16    0.2568E 01    0.2031E 05    0.5726E 00
 77  0.1138E 06    0.7115E 16    0.2568E 01    0.2031E 05    0.5726E 00
 78  0.2465E 06    0.2940E 17    0.2568E 01    0.2031E 05    0.4916E 00
 79  0.2275E 06    0.2220E 17    0.2568E 01    0.2031E 05    0.4916E 00
 80  0.1896E 06    0.1647E 17    0.2568E 01    0.2031E 05    0.4916E 00
```

OBSV	F1	F2	F3	F4	F5
81	0.1327E 06	0.8554E 16	0.2568E 01	0.2031E 05	0.4916E 00
82	0.9481E 05	0.6103E 16	0.2568E 01	0.2031E 05	0.4916E 00
83	0.4281E 06	0.7391E 17	0.2218E 01	0.2352E 05	0.9236E 00
84	0.3952E 06	0.5585E 17	0.2218E 01	0.2352E 05	0.9236E 00
85	0.3623E 06	0.4170E 17	0.2218E 01	0.2352E 05	0.9236E 00
86	0.2854E 06	0.2154E 17	0.2218E 01	0.2352E 05	0.9236E 00
87	0.2635E 06	0.1537E 17	0.2218E 01	0.2352E 05	0.9236E 00
88	0.3952E 06	0.6951E 17	0.2218E 01	0.2352E 05	0.8682E 00
89	0.3623E 06	0.5250E 17	0.2218E 01	0.2352E 05	0.8682E 00
90	0.3293E 06	0.3922E 17	0.2218E 01	0.2352E 05	0.8682E 00
91	0.2635E 06	0.2024E 17	0.2218E 01	0.2352E 05	0.8682E 00
92	0.2305E 06	0.1445E 17	0.2218E 01	0.2352E 05	0.8682E 00
93	0.3623E 06	0.6030E 17	0.2218E 01	0.2352E 05	0.7527E 00
94	0.3293E 06	0.4554E 17	0.2218E 01	0.2352E 05	0.7527E 00
95	0.2964E 06	0.3400E 17	0.2218E 01	0.2352E 05	0.7527E 00
96	0.2196E 06	0.1755E 17	0.2218E 01	0.2352E 05	0.7527E 00
97	0.1866E 06	0.1253E 17	0.2218E 01	0.2352E 05	0.7527E 00
98	0.3293E 06	0.5786E 17	0.2218E 01	0.2352E 05	0.7227E 00
99	0.3074E 06	0.4369E 17	0.2218E 01	0.2352E 05	0.7227E 00
100	0.2744E 06	0.3262E 17	0.2218E 01	0.2352E 05	0.7227E 00

```
OBSV    F1             F2             F3             F4             F5

101  0.2086E 06    0.1686E 17    0.2218E 01    0.2352E 05    0.7227E 00
102  0.1756E 06    0.1203E 17    0.2218E 01    0.2352E 05    0.7227E 00
103  0.3184E 06    0.5055E 17    0.2218E 01    0.2352E 05    0.6309E 00
104  0.2854E 06    0.3815E 17    0.2218E 01    0.2352E 05    0.6309E 00
105  0.2525E 06    0.2850E 17    0.2218E 01    0.2352E 05    0.6309E 00
106  0.1976E 06    0.1471E 17    0.2218E 01    0.2352E 05    0.6309E 00
107  0.1647E 06    0.1050E 17    0.2218E 01    0.2352E 05    0.6309E 00
108  0.2964E 06    0.4495E 17    0.2218E 01    0.2352E 05    0.5609E 00
109  0.2744E 06    0.3392E 17    0.2218E 01    0.2352E 05    0.5609E 00
110  0.2415E 06    0.2534E 17    0.2218E 01    0.2352E 05    0.5609E 00
111  0.1756E 06    0.1307E 17    0.2218E 01    0.2352E 05    0.5609E 00
112  0.1537E 06    0.9335E 16    0.2218E 01    0.2352E 05    0.5609E 00
113  0.2744E 06    0.3942E 17    0.2218E 01    0.2352E 05    0.4918E 00
114  0.2525E 06    0.2975E 17    0.2218E 01    0.2352E 05    0.4918E 00
115  0.2305E 06    0.2222E 17    0.2218E 01    0.2352E 05    0.4918E 00
116  0.1537E 06    0.1147E 17    0.2218E 01    0.2352E 05    0.4918E 00
117  0.1317E 06    0.8195E 16    0.2218E 01    0.2352E 05    0.4918E 00
118  0.8483E 05    0.1306E 17    0.4420E 01    0.1069E 05    0.8320E 00
119  0.7485E 05    0.9935E 16    0.4420E 01    0.1069E 05    0.8320E 00
120  0.6487E 05    0.7450E 16    0.4420E 01    0.1069E 05    0.8320E 00
```

OBSV	F1	F2	F3	F4	F5
121	0.3992E 05	0.3864E 16	0.4420E 01	0.1069E 05	0.8320E 00
122	0.7984E 05	0.1121E 17	0.4420E 01	0.1069E 05	0.7100E 00
123	0.6986E 05	0.8526E 16	0.4420E 01	0.1069E 05	0.7100E 00
124	0.5988E 05	0.6394E 16	0.4420E 01	0.1069E 05	0.7100E 00
125	0.3992E 05	0.3316E 16	0.4420E 01	0.1069E 05	0.7100E 00
126	0.7485E 05	0.7286E 16	0.4420E 01	0.1069E 05	0.4560E 00
127	0.6238E 05	0.5543E 16	0.4420E 01	0.1069E 05	0.4560E 00
128	0.5489E 05	0.4157E 16	0.4420E 01	0.1069E 05	0.4560E 00
129	0.1687E 06	0.2278E 17	0.3400E 01	0.1390E 05	0.8708E 00
130	0.1492E 06	0.1733E 17	0.3400E 01	0.1390E 05	0.8708E 00
131	0.1362E 06	0.1300E 17	0.3400E 01	0.1390E 05	0.8708E 00
132	0.1038E 06	0.6739E 16	0.3400E 01	0.1390E 05	0.8708E 00
133	0.1622E 06	0.2044E 17	0.3400E 01	0.1390E 05	0.7769E 00
134	0.1427E 06	0.1555E 17	0.3400E 01	0.1390E 05	0.7769E 00
135	0.1297E 06	0.1167E 17	0.3400E 01	0.1390E 05	0.7769E 00
136	0.9730E 05	0.6047E 16	0.3400E 01	0.1390E 05	0.7769E 00
137	0.1362E 06	0.1549E 17	0.3400E 01	0.1390E 05	0.5815E 00
138	0.1168E 06	0.1178E 17	0.3400E 01	0.1390E 05	0.5815E 00
139	0.1038E 06	0.8837E 16	0.3400E 01	0.1390E 05	0.5815E 00
140	0.7784E 05	0.4584E 16	0.3400E 01	0.1390E 05	0.5815E 00

```
OBSV     F1            F2            F3            F4            F5

141  0.1233E 06   0.1418E 17   0.3400E 01   0.1390E 05   0.5308E 00
142  0.1103E 06   0.1079E 17   0.3400E 01   0.1390E 05   0.5308E 00
143  0.9082E 05   0.8086E 16   0.3400E 01   0.1390E 05   0.5308E 00
144  0.5838E 05   0.4195E 16   0.3400E 01   0.1390E 05   0.5308E 00
145  0.2715E 06   0.3500E 17   0.2762E 01   0.1710E 05   0.8950E 00
146  0.2475E 06   0.2661E 17   0.2762E 01   0.1710E 05   0.8950E 00
147  0.2236E 06   0.1996E 17   0.2762E 01   0.1710E 05   0.8950E 00
148  0.1756E 06   0.1035E 17   0.2762E 01   0.1710E 05   0.8950E 00
149  0.1517E 06   0.7394E 16   0.2762E 01   0.1710E 05   0.8950E 00
150  0.2555E 06   0.3219E 17   0.2762E 01   0.1710E 05   0.8187E 00
151  0.2236E 06   0.2449E 17   0.2762E 01   0.1710E 05   0.8187E 00
152  0.1996E 06   0.1837E 17   0.2762E 01   0.1710E 05   0.8187E 00
153  0.1517E 06   0.9522E 16   0.2762E 01   0.1710E 05   0.8187E 00
154  0.1277E 06   0.6805E 16   0.2762E 01   0.1710E 05   0.8187E 00
155  0.2236E 06   0.2625E 17   0.2762E 01   0.1710E 05   0.6600E 00
156  0.1996E 06   0.1997E 17   0.2762E 01   0.1710E 05   0.6600E 00
157  0.1677E 06   0.1498E 17   0.2762E 01   0.1710E 05   0.6600E 00
158  0.1277E 06   0.7769E 16   0.2762E 01   0.1710E 05   0.6600E 00
159  0.1038E 06   0.5546E 16   0.2762E 01   0.1710E 05   0.6600E 00
160  0.2076E 06   0.2469E 17   0.2762E 01   0.1710E 05   0.6187E 00
```

OBSV	F1	F2	F3	F4	F5
161	0.1916E 06	0.1878E 17	0.2762E 01	0.1710E 05	0.6187E 00
162	0.1597E 06	0.1409E 17	0.2762E 01	0.1710E 05	0.6187E 00
163	0.1198E 06	0.7299E 16	0.2762E 01	0.1710E 05	0.6187E 00
164	0.9581E 05	0.5219E 16	0.2762E 01	0.1710E 05	0.6187E 00
165	0.1916E 06	0.1984E 17	0.2762E 01	0.1710E 05	0.4925E 00
166	0.1756E 06	0.1509E 17	0.2762E 01	0.1710E 05	0.4925E 00
167	0.1517E 06	0.1131E 17	0.2762E 01	0.1710E 05	0.4925E 00
168	0.1118E 06	0.5864E 16	0.2762E 01	0.1710E 05	0.4925E 00
169	0.8782E 05	0.4191E 16	0.2762E 01	0.1710E 05	0.4925E 00
170	0.3792E 06	0.4959E 17	0.2326E 01	0.2031E 05	0.9116E 00
171	0.3413E 06	0.3772E 17	0.2326E 01	0.2031E 05	0.9116E 00
172	0.3129E 06	0.2828E 17	0.2326E 01	0.2031E 05	0.9116E 00
173	0.2560E 06	0.1467E 17	0.2326E 01	0.2031E 05	0.9116E 00
174	0.2275E 06	0.1047E 17	0.2326E 01	0.2031E 05	0.9116E 00
175	0.3318E 06	0.4635E 17	0.2326E 01	0.2031E 05	0.8474E 00
176	0.3081E 06	0.3526E 17	0.2326E 01	0.2031E 05	0.8474E 00
177	0.2655E 06	0.2644E 17	0.2326E 01	0.2031E 05	0.8474E 00
178	0.2181E 06	0.1371E 17	0.2326E 01	0.2031E 05	0.8474E 00
179	0.1991E 06	0.9793E 16	0.2326E 01	0.2031E 05	0.8474E 00
180	0.3129E 06	0.3932E 17	0.2326E 01	0.2031E 05	0.7105E 00

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OBSV    F1            F2            F3            F4            F5

181   0.2844E 06    0.2991E 17    0.2326E 01    0.2031E 05    0.7105E 00
182   0.2465E 06    0.2243E 17    0.2326E 01    0.2031E 05    0.7105E 00
183   0.1991E 06    0.1163E 17    0.2326E 01    0.2031E 05    0.7105E 00
184   0.1659E 06    0.8308E 16    0.2326E 01    0.2031E 05    0.7105E 00
185   0.2987E 06    0.3768E 17    0.2326E 01    0.2031E 05    0.6789E 00
186   0.2655E 06    0.2866E 17    0.2326E 01    0.2031E 05    0.6789E 00
187   0.2275E 06    0.2150E 17    0.2326E 01    0.2031E 05    0.6789E 00
188   0.1849E 06    0.1115E 17    0.2326E 01    0.2031E 05    0.6789E 00
189   0.1517E 06    0.7958E 16    0.2326E 01    0.2031E 05    0.6789E 00
190   0.2749E 06    0.3208E 17    0.2326E 01    0.2031E 05    0.5726E 00
191   0.2465E 06    0.2439E 17    0.2326E 01    0.2031E 05    0.5726E 00
192   0.2181E 06    0.1830E 17    0.2326E 01    0.2031E 05    0.5726E 00
193   0.1707E 06    0.9490E 16    0.2326E 01    0.2031E 05    0.5726E 00
194   0.1422E 06    0.6775E 16    0.2326E 01    0.2031E 05    0.5726E 00
195   0.2465E 06    0.2773E 17    0.2326E 01    0.2031E 05    0.4916E 00
196   0.2275E 06    0.2109E 17    0.2326E 01    0.2031E 05    0.4916E 00
197   0.1991E 06    0.1582E 17    0.2326E 01    0.2031E 05    0.4916E 00
198   0.1612E 06    0.8204E 16    0.2326E 01    0.2031E 05    0.4916E 00
199   0.1327E 06    0.5857E 16    0.2326E 01    0.2031E 05    0.4916E 00
200   0.4940E 06    0.6647E 17    0.2009E 01    0.2352E 05    0.9236E 00
```

OBSV	F1	F2	F3	F4	F5
201	0.4611E 06	0.5055E 17	0.2009E 01	0.2352E 05	0.9236E 00
202	0.4172E 06	0.3792E 17	0.2009E 01	0.2352E 05	0.9236E 00
203	0.3513E 06	0.1966E 17	0.2009E 01	0.2352E 05	0.9236E 00
204	0.3293E 06	0.1405E 17	0.2009E 01	0.2352E 05	0.9236E 00
205	0.4611E 06	0.6281E 17	0.2009E 01	0.2352E 05	0.8682E 00
206	0.4281E 06	0.4778E 17	0.2009E 01	0.2352E 05	0.8682E 00
207	0.3952E 06	0.3583E 17	0.2009E 01	0.2352E 05	0.8682E 00
208	0.3293E 06	0.1858E 17	0.2009E 01	0.2352E 05	0.8682E 00
209	0.3074E 06	0.1327E 17	0.2009E 01	0.2352E 05	0.8682E 00
210	0.4281E 06	0.5509E 17	0.2009E 01	0.2352E 05	0.7527E 00
211	0.3952E 06	0.4190E 17	0.2009E 01	0.2352E 05	0.7527E 00
212	0.3513E 06	0.3142E 17	0.2009E 01	0.2352E 05	0.7527E 00
213	0.2744E 06	0.1629E 17	0.2009E 01	0.2352E 05	0.7527E 00
214	0.2525E 06	0.1164E 17	0.2009E 01	0.2352E 05	0.7527E 00
215	0.3952E 06	0.5305E 17	0.2009E 01	0.2352E 05	0.7227E 00
216	0.3623E 06	0.4035E 17	0.2009E 01	0.2352E 05	0.7227E 00
217	0.3293E 06	0.3026E 17	0.2009E 01	0.2352E 05	0.7227E 00
218	0.2635E 06	0.1569E 17	0.2009E 01	0.2352E 05	0.7227E 00
219	0.2415E 06	0.1121E 17	0.2009E 01	0.2352E 05	0.7227E 00
220	0.3733E 06	0.4674E 17	0.2009E 01	0.2352E 05	0.6309E 00

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OBSV    F1            F2            F3            F4            F5

221     0.3513E 06    0.3554E 17    0.2009E 01    0.2352E 05    0.6309E 00
222     0.3184E 06    0.2666E 17    0.2009E 01    0.2352E 05    0.6309E 00
223     0.2415E 06    0.1383E 17    0.2009E 01    0.2352E 05    0.6309E 00
224     0.2196E 06    0.9871E 16    0.2009E 01    0.2352E 05    0.6309E 00
225     0.3513E 06    0.4185E 17    0.2009E 01    0.2352E 05    0.5609E 00
226     0.3293E 06    0.3183E 17    0.2009E 01    0.2352E 05    0.5609E 00
227     0.3074E 06    0.2387E 17    0.2009E 01    0.2352E 05    0.5609E 00
228     0.2305E 06    0.1238E 17    0.2009E 01    0.2352E 05    0.5609E 00
229     0.2086E 06    0.8842E 16    0.2009E 01    0.2352E 05    0.5609E 00
230     0.3293E 06    0.3694E 17    0.2009E 01    0.2352E 05    0.4918E 00
231     0.3074E 06    0.2810E 17    0.2009E 01    0.2352E 05    0.4918E 00
232     0.2854E 06    0.2108E 17    0.2009E 01    0.2352E 05    0.4918E 00
233     0.2196E 06    0.1092E 17    0.2009E 01    0.2352E 05    0.4918E 00
234     0.1976E 06    0.7801E 16    0.2009E 01    0.2352E 05    0.4918E 00
235     0.8982E 05    0.1306E 17    0.3960E 01    0.1069E 05    0.8320E 00
236     0.7984E 05    0.9935E 16    0.3960E 01    0.1069E 05    0.8320E 00
237     0.6986E 05    0.7450E 16    0.3960E 01    0.1069E 05    0.8320E 00
238     0.4241E 05    0.3864E 16    0.3960E 01    0.1069E 05    0.8320E 00
239     0.8733E 05    0.1121E 17    0.3960E 01    0.1069E 05    0.7100E 00
240     0.7485E 05    0.8526E 16    0.3960E 01    0.1069E 05    0.7100E 00
```

OBSV	F1	F2	F3	F4	F5
241	0.6736E 05	0.6394E 16	0.3960E 01	0.1069E 05	0.7100E 00
242	0.3992E 05	0.3316E 16	0.3960E 01	0.1069E 05	0.7100E 00
243	0.8234E 05	0.7286E 16	0.3960E 01	0.1069E 05	0.4560E 00
244	0.7235E 05	0.5543E 16	0.3960E 01	0.1069E 05	0.4560E 00
245	0.6487E 05	0.4157E 16	0.3960E 01	0.1069E 05	0.4560E 00
246	0.2011E 06	0.2278E 17	0.3046E 01	0.1390E 05	0.8708E 00
247	0.1816E 06	0.1733E 17	0.3046E 01	0.1390E 05	0.8708E 00
248	0.1557E 06	0.1300E 17	0.3046E 01	0.1390E 05	0.8708E 00
249	0.1168E 06	0.6739E 16	0.3046E 01	0.1390E 05	0.8708E 00
250	0.1816E 06	0.2044E 17	0.3046E 01	0.1390E 05	0.7769E 00
251	0.1622E 06	0.1555E 17	0.3046E 01	0.1390E 05	0.7769E 00
252	0.1427E 06	0.1167E 17	0.3046E 01	0.1390E 05	0.7769E 00
253	0.1038E 06	0.6047E 16	0.3046E 01	0.1390E 05	0.7769E 00
254	0.1460E 06	0.1549E 17	0.3046E 01	0.1390E 05	0.5815E 00
255	0.1233E 06	0.1178E 17	0.3046E 01	0.1390E 05	0.5815E 00
256	0.1103E 06	0.8837E 16	0.3046E 01	0.1390E 05	0.5815E 00
257	0.9082E 05	0.4584E 16	0.3046E 01	0.1390E 05	0.5815E 00
258	0.1297E 06	0.1418E 17	0.3046E 01	0.1390E 05	0.5308E 00
259	0.1168E 06	0.1079E 17	0.3046E 01	0.1390E 05	0.5308E 00
260	0.1038E 06	0.8086E 16	0.3046E 01	0.1390E 05	0.5308E 00

OBSV	F1	F2	F3	F4	F5
261	0.7136E 05	0.4195E 16	0.3046E 01	0.1390E 05	0.5308E 00
262	0.2874E 06	0.3500E 17	0.2475E 01	0.1710E 05	0.8950E 00
263	0.2555E 06	0.2661E 17	0.2475E 01	0.1710E 05	0.8950E 00
264	0.2395E 06	0.1996E 17	0.2475E 01	0.1710E 05	0.8950E 00
265	0.1916E 06	0.1035E 17	0.2475E 01	0.1710E 05	0.8950E 00
266	0.1597E 06	0.7394E 16	0.2475E 01	0.1710E 05	0.8950E 00
267	0.2715E 06	0.3219E 17	0.2475E 01	0.1710E 05	0.8187E 00
268	0.2395E 06	0.2449E 17	0.2475E 01	0.1710E 05	0.8187E 00
269	0.2236E 06	0.1837E 17	0.2475E 01	0.1710E 05	0.8187E 00
270	0.1756E 06	0.9522E 16	0.2475E 01	0.1710E 05	0.8187E 00
271	0.1437E 06	0.6805E 16	0.2475E 01	0.1710E 05	0.8187E 00
272	0.2555E 06	0.2625E 17	0.2475E 01	0.1710E 05	0.6600E 00
273	0.2315E 06	0.1997E 17	0.2475E 01	0.1710E 05	0.6600E 00
274	0.2156E 06	0.1498E 17	0.2475E 01	0.1710E 05	0.6600E 00
275	0.1677E 06	0.7769E 16	0.2475E 01	0.1710E 05	0.6600E 00
276	0.1357E 06	0.5546E 16	0.2475E 01	0.1710E 05	0.6600E 00
277	0.2395E 06	0.2469E 17	0.2475E 01	0.1710E 05	0.6187E 00
278	0.2236E 06	0.1878E 17	0.2475E 01	0.1710E 05	0.6187E 00
279	0.1996E 06	0.1409E 17	0.2475E 01	0.1710E 05	0.6187E 00
280	0.1597E 06	0.7299E 16	0.2475E 01	0.1710E 05	0.6187E 00

OBSV	F1	F2	F3	F4	F5
281	0.1277E 06	0.5219E 16	0.2475E 01	0.1710E 05	0.6187E 00
282	0.2236E 06	0.1984E 17	0.2475E 01	0.1710E 05	0.4925E 00
283	0.2076E 06	0.1509E 17	0.2475E 01	0.1710E 05	0.4925E 00
284	0.1916E 06	0.1131E 17	0.2475E 01	0.1710E 05	0.4925E 00
285	0.1437E 06	0.5864E 16	0.2475E 01	0.1710E 05	0.4925E 00
286	0.1118E 06	0.4191E 16	0.2475E 01	0.1710E 05	0.4925E 00
287	0.3887E 06	0.4959E 17	0.2084E 01	0.2031E 05	0.9116E 00
288	0.3508E 06	0.3772E 17	0.2084E 01	0.2031E 05	0.9116E 00
289	0.3224E 06	0.2828E 17	0.2084E 01	0.2031E 05	0.9116E 00
290	0.2749E 06	0.1467E 17	0.2084E 01	0.2031E 05	0.9116E 00
291	0.2465E 06	0.1047E 17	0.2084E 01	0.2031E 05	0.9116E 00
292	0.3413E 06	0.4635E 17	0.2084E 01	0.2031E 05	0.8474E 00
293	0.3129E 06	0.3526E 17	0.2084E 01	0.2031E 05	0.8474E 00
294	0.2844E 06	0.2644E 17	0.2084E 01	0.2031E 05	0.8474E 00
295	0.2370E 06	0.1371E 17	0.2084E 01	0.2031E 05	0.8474E 00
296	0.2181E 06	0.9793E 16	0.2084E 01	0.2031E 05	0.8474E 00
297	0.3224E 06	0.3932E 17	0.2084E 01	0.2031E 05	0.7105E 00
298	0.2939E 06	0.2991E 17	0.2084E 01	0.2031E 05	0.7105E 00
299	0.2655E 06	0.2243E 17	0.2084E 01	0.2031E 05	0.7105E 00
300	0.2086E 06	0.1163E 17	0.2084E 01	0.2031E 05	0.7105E 00

OBSV	F1	F2	F3	F4	F5
301	0.1896E 06	0.8308E 16	0.2084E 01	0.2031E 05	0.7103E 00
302	0.3034E 06	0.3768E 17	0.2084E 01	0.2031E 05	0.6789E 00
303	0.2844E 06	0.2866E 17	0.2084E 01	0.2031E 05	0.6789E 00
304	0.2560E 06	0.2150E 17	0.2084E 01	0.2031E 05	0.6789E 00
305	0.1991E 06	0.1115E 17	0.2084E 01	0.2031E 05	0.6789E 00
306	0.1801E 06	0.7958E 16	0.2084E 01	0.2031E 05	0.6789E 00
307	0.2892E 06	0.3208E 17	0.2084E 01	0.2031E 05	0.5726E 00
308	0.2655E 06	0.2439E 17	0.2084E 01	0.2031E 05	0.5726E 00
309	0.2465E 06	0.1830E 17	0.2084E 01	0.2031E 05	0.5726E 00
310	0.1801E 06	0.9490E 16	0.2084E 01	0.2031E 05	0.5726E 00
311	0.1612E 06	0.6775E 16	0.2084E 01	0.2031E 05	0.5726E 00
312	0.2655E 06	0.2773E 17	0.2084E 01	0.2031E 05	0.4916E 00
313	0.2465E 06	0.2109E 17	0.2084E 01	0.2031E 05	0.4916E 00
314	0.2275E 06	0.1582E 17	0.2084E 01	0.2031E 05	0.4916E 00
315	0.1707E 06	0.8204E 16	0.2084E 01	0.2031E 05	0.4916E 00
316	0.1517E 06	0.5857E 16	0.2084E 01	0.2031E 05	0.4916E 00
317	0.5160E 06	0.6647E 17	0.1800E 01	0.2352E 05	0.9236E 00
318	0.4940E 06	0.5055E 17	0.1800E 01	0.2352E 05	0.9236E 00
319	0.4611E 06	0.3792E 17	0.1800E 01	0.2352E 05	0.9236E 00
320	0.3952E 06	0.1966E 17	0.1800E 01	0.2352E 05	0.9236E 00

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OBSV     F1              F2              F3              F4              F5


321  0.3623E 06    0.1405E 17    0.1800E 01    0.2352E 05    0.9236E 00

322  0.4940E 06    0.6281E 17    0.1800E 01    0.2352E 05    0.8682E 00

323  0.4611E 06    0.4778E 17    0.1800E 01    0.2352E 05    0.8682E 00

324  0.4281E 06    0.3583E 17    0.1800E 01    0.2352E 05    0.8682E 00

325  0.3513E 06    0.1858E 17    0.1800E 01    0.2352E 05    0.8682E 00

326  0.3293E 06    0.1327E 17    0.1800E 01    0.2352E 05    0.8682E 00

327  0.4611E 06    0.5509E 17    0.1800E 01    0.2352E 05    0.7527E 00

328  0.4391E 06    0.4190E 17    0.1800E 01    0.2352E 05    0.7527E 00

329  0.4062E 06    0.3142E 17    0.1800E 01    0.2352E 05    0.7527E 00

330  0.3293E 06    0.1629E 17    0.1800E 01    0.2352E 05    0.7527E 00

331  0.3074E 06    0.1164E 17    0.1800E 01    0.2352E 05    0.7527E 00

332  0.4501E 06    0.5305E 17    0.1800E 01    0.2352E 05    0.7227E 00

333  0.4281E 06    0.4035E 17    0.1800E 01    0.2352E 05    0.7227E 00

334  0.3952E 06    0.3026E 17    0.1800E 01    0.2352E 05    0.7227E 00

335  0.3184E 06    0.1569E 17    0.1800E 01    0.2352E 05    0.7227E 00

336  0.2964E 06    0.1121E 17    0.1800E 01    0.2352E 05    0.7227E 00

337  0.4281E 06    0.4674E 17    0.1800E 01    0.2352E 05    0.6309E 00

338  0.3952E 06    0.3554E 17    0.1800E 01    0.2352E 05    0.6309E 00

339  0.3623E 06    0.2666E 17    0.1800E 01    0.2352E 05    0.6309E 00

340  0.2854E 06    0.1383E 17    0.1800E 01    0.2352E 05    0.6309E 00
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OBSV	F1	F2	F3	F4	F5
341	0.2635E 06	0.9871E 16	0.1800E 01	0.2352E 05	0.6309E 00
342	0.3952E 06	0.4185E 17	0.1800E 01	0.2352E 05	0.5609E 00
343	0.3733E 06	0.3183E 17	0.1800E 01	0.2352E 05	0.5609E 00
344	0.3403E 06	0.2387E 17	0.1800E 01	0.2352E 05	0.5609E 00
345	0.2744E 06	0.1238E 17	0.1800E 01	0.2352E 05	0.5609E 00
346	0.2525E 06	0.8842E 16	0.1800E 01	0.2352E 05	0.5609E 00
347	0.3733E 06	0.3694E 17	0.1800E 01	0.2352E 05	0.4918E 00
348	0.3513E 06	0.2810E 17	0.1800E 01	0.2352E 05	0.4918E 00
349	0.3184E 06	0.2108E 17	0.1800E 01	0.2352E 05	0.4918E 00
350	0.2525E 06	0.1092E 17	0.1800E 01	0.2352E 05	0.4918E 00
351	0.2305E 06	0.7801E 16	0.1800E 01	0.2352E 05	0.4918E 00
352	0.1048E 06	0.1306E 17	0.3500E 01	0.1069E 05	0.8320E 00
353	0.9481E 05	0.9935E 16	0.3500E 01	0.1069E 05	0.8320E 00
354	0.7235E 05	0.7450E 16	0.3500E 01	0.1069E 05	0.8320E 00
355	0.4491E 05	0.3864E 16	0.3500E 01	0.1069E 05	0.8320E 00
356	0.9980E 05	0.1121E 17	0.3500E 01	0.1069E 05	0.7100E 00
357	0.8982E 05	0.8526E 16	0.3500E 01	0.1069E 05	0.7100E 00
358	0.6986E 05	0.6394E 16	0.3500E 01	0.1069E 05	0.7100E 00
359	0.4241E 05	0.3316E 16	0.3500E 01	0.1069E 05	0.7100E 00
360	0.8982E 05	0.7286E 16	0.3500E 01	0.1069E 05	0.4560E 00

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OBSV     F1             F2             F3             F4             F5

361  0.7984E 05    0.5543E 16    0.3500E 01    0.1069E 05    0.4560E 00
362  0.6986E 05    0.4157E 16    0.3500E 01    0.1069E 05    0.4560E 00
363  0.2335E 06    0.2278E 17    0.2692E 01    0.1390E 05    0.8708E 00
364  0.2011E 06    0.1733E 17    0.2692E 01    0.1390E 05    0.8708E 00
365  0.1751E 06    0.1300E 17    0.2692E 01    0.1390E 05    0.8708E 00
366  0.1362E 06    0.6739E 16    0.2692E 01    0.1390E 05    0.8708E 00
367  0.2108E 06    0.2044E 17    0.2692E 01    0.1390E 05    0.7769E 00
368  0.1687E 06    0.1555E 17    0.2692E 01    0.1390E 05    0.7769E 00
369  0.1362E 06    0.1167E 17    0.2692E 01    0.1390E 05    0.7769E 00
370  0.1070E 06    0.6047E 16    0.2692E 01    0.1390E 05    0.7769E 00
371  0.1816E 06    0.1549E 17    0.2692E 01    0.1390E 05    0.5815E 00
372  0.1492E 06    0.1178E 17    0.2692E 01    0.1390E 05    0.5815E 00
373  0.1297E 06    0.8837E 16    0.2692E 01    0.1390E 05    0.5815E 00
374  0.1038E 06    0.4584E 16    0.2692E 01    0.1390E 05    0.5815E 00
375  0.1622E 06    0.1418E 17    0.2692E 01    0.1390E 05    0.5308E 00
376  0.1427E 06    0.1079E 17    0.2692E 01    0.1390E 05    0.5308E 00
377  0.1233E 06    0.8086E 16    0.2692E 01    0.1390E 05    0.5308E 00
378  0.9730E 05    0.4195E 16    0.2692E 01    0.1390E 05    0.5308E 00
379  0.3194E 06    0.3500E 17    0.2187E 01    0.1710E 05    0.8950E 00
380  0.2954E 06    0.2661E 17    0.2187E 01    0.1710E 05    0.8950E 00
```

OBSV	F1	F2	F3	F4	F5
381	0.2715E 06	0.1996E 17	0.2187E 01	0.1710E 05	0.8950E 00
382	0.2236E 06	0.1035E 17	0.2187E 01	0.1710E 05	0.8950E 00
383	0.1916E 06	0.7394E 16	0.2187E 01	0.1710E 05	0.8950E 00
384	0.3034E 06	0.3219E 17	0.2187E 01	0.1710E 05	0.8187E 00
385	0.2794E 06	0.2449E 17	0.2187E 01	0.1710E 05	0.8187E 00
386	0.2475E 06	0.1837E 17	0.2187E 01	0.1710E 05	0.8187E 00
387	0.1996E 06	0.9522E 16	0.2187E 01	0.1710E 05	0.8187E 00
388	0.1756E 06	0.6805E 16	0.2187E 01	0.1710E 05	0.8187E 00
389	0.2914E 06	0.2625E 17	0.2187E 01	0.1710E 05	0.6600E 00
390	0.2715E 06	0.1997E 17	0.2187E 01	0.1710E 05	0.6600E 00
391	0.2315E 06	0.1498E 17	0.2187E 01	0.1710E 05	0.6600E 00
392	0.1916E 06	0.7769E 16	0.2187E 01	0.1710E 05	0.6600E 00
393	0.1677E 06	0.5546E 16	0.2187E 01	0.1710E 05	0.6600E 00
394	0.2794E 06	0.2469E 17	0.2187E 01	0.1710E 05	0.6187E 00
395	0.2555E 06	0.1878E 17	0.2187E 01	0.1710E 05	0.6187E 00
396	0.2236E 06	0.1409E 17	0.2187E 01	0.1710E 05	0.6187E 00
397	0.1836E 06	0.7299E 16	0.2187E 01	0.1710E 05	0.6187E 00
398	0.1597E 06	0.5219E 16	0.2187E 01	0.1710E 05	0.6187E 00
399	0.2635E 06	0.1984E 17	0.2187E 01	0.1710E 05	0.4925E 00
400	0.2315E 06	0.1509E 17	0.2187E 01	0.1710E 05	0.4925E 00

```
OBSV    F1            F2            F3            F4            F5

401   0.2076E 06    0.1131E 17    0.2187E 01    0.1710E 05    0.4925E 00
402   0.1677E 06    0.5864E 16    0.2187E 01    0.1710E 05    0.4925E 00
403   0.1517E 06    0.4191E 16    0.2187E 01    0.1710E 05    0.4925E 00
404   0.4172E 06    0.4959E 17    0.1842E 01    0.2031E 05    0.9116E 00
405   0.3887E 06    0.3772E 17    0.1842E 01    0.2031E 05    0.9116E 00
406   0.3603E 06    0.2828E 17    0.1842E 01    0.2031E 05    0.9116E 00
407   0.3034E 06    0.1467E 17    0.1842E 01    0.2031E 05    0.9116E 00
408   0.2702E 06    0.1047E 17    0.1842E 01    0.2031E 05    0.9116E 00
409   0.3792E 06    0.4635E 17    0.1842E 01    0.2031E 05    0.8474E 00
410   0.3413E 06    0.3526E 17    0.1842E 01    0.2031E 05    0.8474E 00
411   0.3129E 06    0.2644E 17    0.1842E 01    0.2031E 05    0.8474E 00
412   0.2655E 06    0.1371E 17    0.1842E 01    0.2031E 05    0.8474E 00
413   0.2370E 06    0.9793E 16    0.1842E 01    0.2031E 05    0.8474E 00
414   0.3413E 06    0.3932E 17    0.1842E 01    0.2031E 05    0.7105E 00
415   0.3129E 06    0.2991E 17    0.1842E 01    0.2031E 05    0.7105E 00
416   0.2844E 06    0.2243E 17    0.1842E 01    0.2031E 05    0.7105E 00
417   0.2370E 06    0.1163E 17    0.1842E 01    0.2031E 05    0.7105E 00
418   0.2181E 06    0.8308E 16    0.1842E 01    0.2031E 05    0.7105E 00
419   0.3224E 06    0.3768E 17    0.1842E 01    0.2031E 05    0.6789E 00
420   0.3034E 06    0.2866E 17    0.1842E 01    0.2031E 05    0.6789E 00
```

OBSV	F1	F2	F3	F4	F5
421	0.2749E 06	0.2150E 17	0.1842E 01	0.2031E 05	0.6789E 00
422	0.2275E 06	0.1115E 17	0.1842E 01	0.2031E 05	0.6789E 00
423	0.2086E 06	0.7958E 16	0.1842E 01	0.2031E 05	0.6789E 00
424	0.3034E 06	0.3208E 17	0.1842E 01	0.2031E 05	0.5726E 00
425	0.2844E 06	0.2439E 17	0.1842E 01	0.2031E 05	0.5726E 00
426	0.2655E 06	0.1830E 17	0.1842E 01	0.2031E 05	0.5726E 00
427	0.2275E 06	0.9490E 16	0.1842E 01	0.2031E 05	0.5726E 00
428	0.1991E 06	0.6775E 16	0.1842E 01	0.2031E 05	0.5726E 00
429	0.2939E 06	0.2773E 17	0.1842E 01	0.2031E 05	0.4916E 00
430	0.2749E 06	0.2109E 17	0.1842E 01	0.2031E 05	0.4916E 00
431	0.2512E 06	0.1582E 17	0.1842E 01	0.2031E 05	0.4916E 00
432	0.2181E 06	0.8204E 16	0.1842E 01	0.2031E 05	0.4916E 00
433	0.1896E 06	0.5857E 16	0.1842E 01	0.2031E 05	0.4916E 00
434	0.5379E 06	0.6647E 17	0.1591E 01	0.2352E 05	0.9236E 00
435	0.5050E 06	0.5055E 17	0.1591E 01	0.2352E 05	0.9236E 00
436	0.4721E 06	0.3792E 17	0.1591E 01	0.2352E 05	0.9236E 00
437	0.4062E 06	0.1966E 17	0.1591E 01	0.2352E 05	0.9236E 00
438	0.3842E 06	0.1405E 17	0.1591E 01	0.2352E 05	0.9236E 00
439	0.5050E 06	0.6281E 17	0.1591E 01	0.2352E 05	0.8682E 00
440	0.4830E 06	0.4778E 17	0.1591E 01	0.2352E 05	0.8682E 00

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OBSV    F1            F2            F3            F4            F5

441   0.4501E 06    0.3583E 17    0.1591E 01    0.2352E 05    0.8682E 00
442   0.3733E 06    0.1858E 17    0.1591E 01    0.2352E 05    0.8682E 00
443   0.3513E 06    0.1327E 17    0.1591E 01    0.2352E 05    0.8682E 00
444   0.4721E 06    0.5509E 17    0.1591E 01    0.2352E 05    0.7527E 00
445   0.4501E 06    0.4190E 17    0.1591E 01    0.2352E 05    0.7527E 00
446   0.4172E 06    0.3142E 17    0.1591E 01    0.2352E 05    0.7527E 00
447   0.3513E 06    0.1629E 17    0.1591E 01    0.2352E 05    0.7527E 00
448   0.3293E 06    0.1164E 17    0.1591E 01    0.2352E 05    0.7527E 00
449   0.4611E 06    0.5305E 17    0.1591E 01    0.2352E 05    0.7227E 00
450   0.4391E 06    0.4035E 17    0.1591E 01    0.2352E 05    0.7227E 00
451   0.4062E 06    0.3026E 17    0.1591E 01    0.2352E 05    0.7227E 00
452   0.3293E 06    0.1569E 17    0.1591E 01    0.2352E 05    0.7227E 00
453   0.3074E 06    0.1121E 17    0.1591E 01    0.2352E 05    0.7227E 00
454   0.4391E 06    0.4674E 17    0.1591E 01    0.2352E 05    0.6309E 00
455   0.4172E 06    0.3554E 17    0.1591E 01    0.2352E 05    0.6309E 00
456   0.3842E 06    0.2666E 17    0.1591E 01    0.2352E 05    0.6309E 00
457   0.3074E 06    0.1383E 17    0.1591E 01    0.2352E 05    0.6309E 00
458   0.2854E 06    0.9871E 16    0.1591E 01    0.2352E 05    0.6309E 00
459   0.4172E 06    0.4185E 17    0.1591E 01    0.2352E 05    0.5609E 00
460   0.3952E 06    0.3183E 17    0.1591E 01    0.2352E 05    0.5609E 00
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OBSV     F1            F2            F3            F4            F5


461   0.3623E 06    0.2387E 17    0.1591E 01    0.2352E 05    0.5609E 00

462   0.2964E 06    0.1238E 17    0.1591E 01    0.2352E 05    0.5609E 00

463   0.2744E 06    0.8842E 16    0.1591E 01    0.2352E 05    0.5609E 00

464   0.3952E 06    0.3694E 17    0.1591E 01    0.2352E 05    0.4918E 00

465   0.3733E 06    0.2810E 17    0.1591E 01    0.2352E 05    0.4918E 00

466   0.3403E 06    0.2108E 17    0.1591E 01    0.2352E 05    0.4918E 00

467   0.2854E 06    0.1092E 17    0.1591E 01    0.2352E 05    0.4918E 00

468   0.2525E 06    0.7801E 16    0.1591E 01    0.2352E 05    0.4918E 00

469   0.1148E 06    0.1306E 17    0.3040E 01    0.1069E 05    0.8320E 00

470   0.9980E 05    0.9935E 16    0.3040E 01    0.1069E 05    0.8320E 00

471   0.8234E 05    0.7450E 16    0.3040E 01    0.1069E 05    0.8320E 00

472   0.6487E 05    0.3864E 16    0.3040E 01    0.1069E 05    0.8320E 00

473   0.1098E 06    0.1121E 17    0.3040E 01    0.1069E 05    0.7100E 00

474   0.9481E 05    0.8526E 16    0.3040E 01    0.1069E 05    0.7100E 00

475   0.7984E 05    0.6394E 16    0.3040E 01    0.1069E 05    0.7100E 00

476   0.5988E 05    0.3316E 16    0.3040E 01    0.1069E 05    0.7100E 00

477   0.9980E 05    0.7286E 16    0.3040E 01    0.1069E 05    0.4560E 00

478   0.8733E 05    0.5543E 16    0.3040E 01    0.1069E 05    0.4560E 00

479   0.5988E 05    0.4157E 16    0.3040E 01    0.1069E 05    0.4560E 00

480   0.2725E 06    0.2278E 17    0.2338E 01    0.1390E 05    0.8708E 00
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OBSV    F1            F2            F3            F4            F5

481  0.2400E 06   0.1733E 17   0.2338E 01   0.1390E 05   0.8708E 00
482  0.2076E 06   0.1300E 17   0.2338E 01   0.1390E 05   0.8708E 00
483  0.1622E 06   0.6739E 16   0.2338E 01   0.1390E 05   0.8708E 00
484  0.2335E 06   0.2044E 17   0.2338E 01   0.1390E 05   0.7769E 00
485  0.2076E 06   0.1555E 17   0.2338E 01   0.1390E 05   0.7769E 00
486  0.1687E 06   0.1167E 17   0.2338E 01   0.1390E 05   0.7769E 00
487  0.1427E 06   0.6047E 16   0.2338E 01   0.1390E 05   0.7769E 00
488  0.2011E 06   0.1549E 17   0.2338E 01   0.1390E 05   0.5815E 00
489  0.1816E 06   0.1178E 17   0.2338E 01   0.1390E 05   0.5815E 00
490  0.1557E 06   0.8837E 16   0.2338E 01   0.1390E 05   0.5815E 00
491  0.1168E 06   0.4584E 16   0.2338E 01   0.1390E 05   0.5815E 00
492  0.1751E 06   0.1418E 17   0.2338E 01   0.1390E 05   0.5308E 00
493  0.1557E 06   0.1079E 17   0.2338E 01   0.1390E 05   0.5308E 00
494  0.1427E 06   0.8086E 16   0.2338E 01   0.1390E 05   0.5308E 00
495  0.1103E 06   0.4195E 16   0.2338E 01   0.1390E 05   0.5308E 00
496  0.3673E 06   0.3500E 17   0.1900E 01   0.1710E 05   0.8950E 00
497  0.3353E 06   0.2661E 17   0.1900E 01   0.1710E 05   0.8950E 00
498  0.3194E 06   0.1996E 17   0.1900E 01   0.1710E 05   0.8950E 00
499  0.2555E 06   0.1035E 17   0.1900E 01   0.1710E 05   0.8950E 00
500  0.2236E 06   0.7394E 16   0.1900E 01   0.1710E 05   0.8950E 00
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OBSV	F1	F2	F3	F4	F5
501	0.3513E 06	0.3219E 17	0.1900E 01	0.1710E 05	0.8187E 00
502	0.3194E 06	0.2449E 17	0.1900E 01	0.1710E 05	0.8187E 00
503	0.2874E 06	0.1837E 17	0.1900E 01	0.1710E 05	0.8187E 00
504	0.2395E 06	0.9522E 16	0.1900E 01	0.1710E 05	0.8187E 00
505	0.2076E 06	0.6805E 16	0.1900E 01	0.1710E 05	0.8187E 00
506	0.3114E 06	0.2625E 17	0.1900E 01	0.1710E 05	0.6600E 00
507	0.2874E 06	0.1997E 17	0.1900E 01	0.1710E 05	0.6600E 00
508	0.2475E 06	0.1498E 17	0.1900E 01	0.1710E 05	0.6600E 00
509	0.2076E 06	0.7769E 16	0.1900E 01	0.1710E 05	0.6600E 00
510	0.1916E 06	0.5546E 16	0.1900E 01	0.1710E 05	0.6600E 00
511	0.2954E 06	0.2469E 17	0.1900E 01	0.1710E 05	0.6187E 00
512	0.2715E 06	0.1878E 17	0.1900E 01	0.1710E 05	0.6187E 00
513	0.2395E 06	0.1409E 17	0.1900E 01	0.1710E 05	0.6187E 00
514	0.1956E 06	0.7299E 16	0.1900E 01	0.1710E 05	0.6187E 00
515	0.1796E 06	0.5219E 16	0.1900E 01	0.1710E 05	0.6187E 00
516	0.2715E 06	0.1984E 17	0.1900E 01	0.1710E 05	0.4925E 00
517	0.2395E 06	0.1509E 17	0.1900E 01	0.1710E 05	0.4925E 00
518	0.2156E 06	0.1131E 17	0.1900E 01	0.1710E 05	0.4925E 00
519	0.1756E 06	0.5864E 16	0.1900E 01	0.1710E 05	0.4925E 00
520	0.1597E 06	0.4191E 16	0.1900E 01	0.1710E 05	0.4925E 00

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OBSV     F1            F2            F3            F4            F5


521   0.4361E 06   0.4959E 17   0.1600E 01   0.2031E 05   0.9116E 00
522   0.4077E 06   0.3772E 17   0.1600E 01   0.2031E 05   0.9116E 00
523   0.3792E 06   0.2828E 17   0.1600E 01   0.2031E 05   0.9116E 00
524   0.3224E 06   0.1467E 17   0.1600E 01   0.2031E 05   0.9116E 00
525   0.3034E 06   0.1047E 17   0.1600E 01   0.2031E 05   0.9116E 00
526   0.4077E 06   0.4635E 17   0.1600E 01   0.2031E 05   0.8474E 00
527   0.3792E 06   0.3526E 17   0.1600E 01   0.2031E 05   0.8474E 00
528   0.3508E 06   0.2644E 17   0.1600E 01   0.2031E 05   0.8474E 00
529   0.3034E 06   0.1371E 17   0.1600E 01   0.2031E 05   0.8474E 00
530   0.2844E 06   0.9793E 16   0.1600E 01   0.2031E 05   0.8474E 00
531   0.3792E 06   0.3932E 17   0.1600E 01   0.2031E 05   0.7105E 00
532   0.3603E 06   0.2991E 17   0.1600E 01   0.2031E 05   0.7105E 00
533   0.3224E 06   0.2243E 17   0.1600E 01   0.2031E 05   0.7105E 00
534   0.2749E 06   0.1163E 17   0.1600E 01   0.2031E 05   0.7105E 00
535   0.2560E 06   0.8308E 16   0.1600E 01   0.2031E 05   0.7105E 00
536   0.3603E 06   0.3768E 17   0.1600E 01   0.2031E 05   0.6789E 00
537   0.3413E 06   0.2866E 17   0.1600E 01   0.2031E 05   0.6789E 00
538   0.3034E 06   0.2150E 17   0.1600E 01   0.2031E 05   0.6789E 00
539   0.2560E 06   0.1115E 17   0.1600E 01   0.2031E 05   0.6789E 00
540   0.2370E 06   0.7958E 16   0.1600E 01   0.2031E 05   0.6789E 00
```

OBSV	F1	F2	F3	F4	F5
541	0.3413E 06	0.3208E 17	0.1600E 01	0.2031E 05	0.5726E 00
542	0.3224E 06	0.2439E 17	0.1600E 01	0.2031E 05	0.5726E 00
543	0.2939E 06	0.1830E 17	0.1600E 01	0.2031E 05	0.5726E 00
544	0.2465E 06	0.9490E 16	0.1600E 01	0.2031E 05	0.5726E 00
545	0.2275E 06	0.6775E 16	0.1600E 01	0.2031E 05	0.5726E 00
546	0.3129E 06	0.2773E 17	0.1600E 01	0.2031E 05	0.4916E 00
547	0.2892E 06	0.2109E 17	0.1600E 01	0.2031E 05	0.4916E 00
548	0.2655E 06	0.1582E 17	0.1600E 01	0.2031E 05	0.4916E 00
549	0.2275E 06	0.8204E 16	0.1600E 01	0.2031E 05	0.4916E 00
550	0.1991E 06	0.5857E 16	0.1600E 01	0.2031E 05	0.4916E 00
551	0.5818E 06	0.6647E 17	0.1382E 01	0.2352E 05	0.9236E 00
552	0.5599E 06	0.5055E 17	0.1382E 01	0.2352E 05	0.9236E 00
553	0.5269E 06	0.3792E 17	0.1382E 01	0.2352E 05	0.9236E 00
554	0.4501E 06	0.1966E 17	0.1382E 01	0.2352E 05	0.9236E 00
555	0.4172E 06	0.1405E 17	0.1382E 01	0.2352E 05	0.9236E 00
556	0.5489E 06	0.6281E 17	0.1382E 01	0.2352E 05	0.8682E 00
557	0.5269E 06	0.4778E 17	0.1382E 01	0.2352E 05	0.8682E 00
558	0.5050E 06	0.3583E 17	0.1382E 01	0.2352E 05	0.8682E 00
559	0.4281E 06	0.1858E 17	0.1382E 01	0.2352E 05	0.8682E 00
560	0.3952E 06	0.1327E 17	0.1382E 01	0.2352E 05	0.8682E 00

OBSV	F1	F2	F3	F4	F5
561	0.5160E 06	0.5509E 17	0.1382E 01	0.2352E 05	0.7527E 00
562	0.4830E 06	0.4190E 17	0.1382E 01	0.2352E 05	0.7527E 00
563	0.4611E 06	0.3142E 17	0.1382E 01	0.2352E 05	0.7527E 00
564	0.3842E 06	0.1629E 17	0.1382E 01	0.2352E 05	0.7527E 00
565	0.3623E 06	0.1164E 17	0.1382E 01	0.2352E 05	0.7527E 00
566	0.4885E 06	0.5305E 17	0.1382E 01	0.2352E 05	0.7227E 00
567	0.4611E 06	0.4035E 17	0.1382E 01	0.2352E 05	0.7227E 00
568	0.4281E 06	0.3026E 17	0.1382E 01	0.2352E 05	0.7227E 00
569	0.3623E 06	0.1569E 17	0.1382E 01	0.2352E 05	0.7227E 00
570	0.3403E 06	0.1121E 17	0.1382E 01	0.2352E 05	0.7227E 00
571	0.4721E 06	0.4674E 17	0.1382E 01	0.2352E 05	0.6309E 00
572	0.4501E 06	0.3554E 17	0.1382E 01	0.2352E 05	0.6309E 00
573	0.4172E 06	0.2666E 17	0.1382E 01	0.2352E 05	0.6309E 00
574	0.3513E 06	0.1383E 17	0.1382E 01	0.2352E 05	0.6309E 00
575	0.3293E 06	0.9871E 16	0.1382E 01	0.2352E 05	0.6309E 00
576	0.4281E 06	0.4185E 17	0.1382E 01	0.2352E 05	0.5609E 00
577	0.4062E 06	0.3183E 17	0.1382E 01	0.2352E 05	0.5609E 00
578	0.3733E 06	0.2387E 17	0.1382E 01	0.2352E 05	0.5609E 00
579	0.3074E 06	0.1238E 17	0.1382E 01	0.2352E 05	0.5609E 00
580	0.2854E 06	0.8842E 16	0.1382E 01	0.2352E 05	0.5609E 00

OBSV	F1	F2	F3	F4	F5
581	0.4062E 06	0.3694E 17	0.1382E 01	0.2352E 05	0.4918E 00
582	0.3842E 06	0.2810E 17	0.1382E 01	0.2352E 05	0.4918E 00
583	0.3623E 06	0.2108E 17	0.1382E 01	0.2352E 05	0.4918E 00
584	0.2964E 06	0.1092E 17	0.1382E 01	0.2352E 05	0.4918E 00
585	0.2744E 06	0.7801E 16	0.1382E 01	0.2352E 05	0.4918E 00
586	0.1198E 06	0.1306E 17	0.2580E 01	0.1069E 05	0.8320E 00
587	0.1048E 06	0.9935E 16	0.2580E 01	0.1069E 05	0.8320E 00
588	0.8982E 05	0.7450E 16	0.2580E 01	0.1069E 05	0.8320E 00
589	0.7235E 05	0.3864E 16	0.2580E 01	0.1069E 05	0.8320E 00
590	0.1148E 06	0.1121E 17	0.2580E 01	0.1069E 05	0.7100E 00
591	0.9980E 05	0.8526E 16	0.2580E 01	0.1069E 05	0.7100E 00
592	0.8733E 05	0.6394E 16	0.2580E 01	0.1069E 05	0.7100E 00
593	0.6986E 05	0.3316E 16	0.2580E 01	0.1069E 05	0.7100E 00
594	0.1098E 06	0.7286E 16	0.2580E 01	0.1069E 05	0.4560E 00
595	0.9481E 05	0.5543E 16	0.2580E 01	0.1069E 05	0.4560E 00
596	0.8483E 05	0.4157E 16	0.2580E 01	0.1069E 05	0.4560E 00
597	0.2854E 06	0.2278E 17	0.1985E 01	0.1390E 05	0.8708E 00
598	0.2595E 06	0.1733E 17	0.1985E 01	0.1390E 05	0.8708E 00
599	0.2206E 06	0.1300E 17	0.1985E 01	0.1390E 05	0.8708E 00
600	0.1687E 06	0.6739E 16	0.1985E 01	0.1390E 05	0.8708E 00

OBSV	F1	F2	F3	F4	F5
601	0.2595E 06	0.2044E 17	0.1985E 01	0.1390E 05	0.7769E 00
602	0.2335E 06	0.1555E 17	0.1985E 01	0.1390E 05	0.7769E 00
603	0.2076E 06	0.1167E 17	0.1985E 01	0.1390E 05	0.7769E 00
604	0.1687E 06	0.6047E 16	0.1985E 01	0.1390E 05	0.7769E 00
605	0.2141E 06	0.1549E 17	0.1985E 01	0.1390E 05	0.5815E 00
606	0.1881E 06	0.1178E 17	0.1985E 01	0.1390E 05	0.5815E 00
607	0.1687E 06	0.8837E 16	0.1985E 01	0.1390E 05	0.5815E 00
608	0.1362E 06	0.4584E 16	0.1985E 01	0.1390E 05	0.5815E 00
609	0.1946E 06	0.1418E 17	0.1985E 01	0.1390E 05	0.5308E 00
610	0.1687E 06	0.1079E 17	0.1985E 01	0.1390E 05	0.5308E 00
611	0.1557E 06	0.8086E 16	0.1985E 01	0.1390E 05	0.5308E 00
612	0.1233E 06	0.4195E 16	0.1985E 01	0.1390E 05	0.5308E 00
613	0.4152E 06	0.3500E 17	0.1612E 01	0.1710E 05	0.8950E 00
614	0.3713E 06	0.2661E 17	0.1612E 01	0.1710E 05	0.8950E 00
615	0.3393E 06	0.1996E 17	0.1612E 01	0.1710E 05	0.8950E 00
616	0.2754E 06	0.1035E 17	0.1612E 01	0.1710E 05	0.8950E 00
617	0.2555E 06	0.7394E 16	0.1612E 01	0.1710E 05	0.8950E 00
618	0.3992E 06	0.3219E 17	0.1612E 01	0.1710E 05	0.8187E 00
619	0.3513E 06	0.2449E 17	0.1612E 01	0.1710E 05	0.8187E 00
620	0.3194E 06	0.1837E 17	0.1612E 01	0.1710E 05	0.8187E 00

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OBSV     F1            F2            F3            F4            F5

621   0.2635E 06    0.9522E 16    0.1612E 01    0.1710E 05    0.8187E 00
622   0.2395E 06    0.6805E 16    0.1612E 01    0.1710E 05    0.8187E 00
623   0.3273E 06    0.2625E 17    0.1612E 01    0.1710E 05    0.6600E 00
624   0.3034E 06    0.1997E 17    0.1612E 01    0.1710E 05    0.6600E 00
625   0.2555E 06    0.1498E 17    0.1612E 01    0.1710E 05    0.6600E 00
626   0.2236E 06    0.7769E 16    0.1612E 01    0.1710E 05    0.6600E 00
627   0.2076E 06    0.5546E 16    0.1612E 01    0.1710E 05    0.6600E 00
628   0.3114E 06    0.2469E 17    0.1612E 01    0.1710E 05    0.6187E 00
629   0.2794E 06    0.1878E 17    0.1612E 01    0.1710E 05    0.6187E 00
630   0.2555E 06    0.1409E 17    0.1612E 01    0.1710E 05    0.6187E 00
631   0.2156E 06    0.7299E 16    0.1612E 01    0.1710E 05    0.6187E 00
632   0.1916E 06    0.5219E 16    0.1612E 01    0.1710E 05    0.6187E 00
633   0.2794E 06    0.1984E 17    0.1612E 01    0.1710E 05    0.4925E 00
634   0.2475E 06    0.1509E 17    0.1612E 01    0.1710E 05    0.4925E 00
635   0.2236E 06    0.1131E 17    0.1612E 01    0.1710E 05    0.4925E 00
636   0.1916E 06    0.5864E 16    0.1612E 01    0.1710E 05    0.4925E 00
637   0.1756E 06    0.4191E 16    0.1612E 01    0.1710E 05    0.4925E 00
638   0.5120E 06    0.4959E 17    0.1358E 01    0.2031E 05    0.9116E 00
639   0.4835E 06    0.3772E 17    0.1358E 01    0.2031E 05    0.9116E 00
640   0.4456E 06    0.2828E 17    0.1358E 01    0.2031E 05    0.9116E 00
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OBSV    F1            F2            F3            F4            F5


641   0.3792E 06    0.1467E 17    0.1358E 01    0.2031E 05    0.9116E 00

642   0.3413E 06    0.1047E 17    0.1358E 01    0.2031E 05    0.9116E 00

643   0.4740E 06    0.4635E 17    0.1358E 01    0.2031E 05    0.8474E 00

644   0.4551E 06    0.3526E 17    0.1358E 01    0.2031E 05    0.8474E 00

645   0.4266E 06    0.2644E 17    0.1358E 01    0.2031E 05    0.8474E 00

646   0.3508E 06    0.1371E 17    0.1358E 01    0.2031E 05    0.8474E 00

647   0.3318E 06    0.9793E 16    0.1358E 01    0.2031E 05    0.8474E 00

648   0.4456E 06    0.3932E 17    0.1358E 01    0.2031E 05    0.7105E 00

649   0.4077E 06    0.2991E 17    0.1358E 01    0.2031E 05    0.7105E 00

650   0.3698E 06    0.2243E 17    0.1358E 01    0.2031E 05    0.7105E 00

651   0.3129E 06    0.1163E 17    0.1358E 01    0.2031E 05    0.7105E 00

652   0.2844E 06    0.8308E 16    0.1358E 01    0.2031E 05    0.7105E 00

653   0.4266E 06    0.3768E 17    0.1358E 01    0.2031E 05    0.6789E 00

654   0.3887E 06    0.2866E 17    0.1358E 01    0.2031E 05    0.6789E 00

655   0.3508E 06    0.2150E 17    0.1358E 01    0.2031E 05    0.6789E 00

656   0.2939E 06    0.1115E 17    0.1358E 01    0.2031E 05    0.6789E 00

657   0.2655E 06    0.7958E 16    0.1358E 01    0.2031E 05    0.6789E 00

658   0.4077E 06    0.3208E 17    0.1358E 01    0.2031E 05    0.5726E 00

659   0.3792E 06    0.2439E 17    0.1358E 01    0.2031E 05    0.5726E 00

660   0.3413E 06    0.1830E 17    0.1358E 01    0.2031E 05    0.5726E 00
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OBSV	F1	F2	F3	F4	F5
661	0.2844E 06	0.9490E 16	0.1358E 01	0.2031E 05	0.5726E 00
662	0.2560E 06	0.6775E 16	0.1358E 01	0.2031E 05	0.5726E 00
663	0.3698E 06	0.2773E 17	0.1358E 01	0.2031E 05	0.4916E 00
664	0.3318E 06	0.2109E 17	0.1358E 01	0.2031E 05	0.4916E 00
665	0.2939E 06	0.1582E 17	0.1358E 01	0.2031E 05	0.4916E 00
666	0.2465E 06	0.8204E 16	0.1358E 01	0.2031E 05	0.4916E 00
667	0.2275E 06	0.5857E 16	0.1358E 01	0.2031E 05	0.4916E 00
668	0.5709E 06	0.6647E 17	0.1173E 01	0.2352E 05	0.9236E 00
669	0.5379E 06	0.5055E 17	0.1173E 01	0.2352E 05	0.9236E 00
670	0.5050E 06	0.3792E 17	0.1173E 01	0.2352E 05	0.9236E 00
671	0.4391E 06	0.1966E 17	0.1173E 01	0.2352E 05	0.9236E 00
672	0.4172E 06	0.1405E 17	0.1173E 01	0.2352E 05	0.9236E 00
673	0.5599E 06	0.6281E 17	0.1173E 01	0.2352E 05	0.8682E 00
674	0.5379E 06	0.4778E 17	0.1173E 01	0.2352E 05	0.8682E 00
675	0.5160E 06	0.3583E 17	0.1173E 01	0.2352E 05	0.8682E 00
676	0.4391E 06	0.1858E 17	0.1173E 01	0.2352E 05	0.8682E 00
677	0.4172E 06	0.1327E 17	0.1173E 01	0.2352E 05	0.8682E 00
678	0.5379E 06	0.5509E 17	0.1173E 01	0.2352E 05	0.7527E 00
679	0.5160E 06	0.4190E 17	0.1173E 01	0.2352E 05	0.7527E 00
680	0.4830E 06	0.3142E 17	0.1173E 01	0.2352E 05	0.7527E 00

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OBSV   F1           F2           F3           F4           F5

681    0.4172E 06   0.1629E 17   0.1173E 01   0.2352E 05   0.7527E 00
682    0.3952E 06   0.1164E 17   0.1173E 01   0.2352E 05   0.7527E 00
683    0.5269E 06   0.5305E 17   0.1173E 01   0.2352E 05   0.7227E 00
684    0.5050E 06   0.4035E 17   0.1173E 01   0.2352E 05   0.7227E 00
685    0.4721E 06   0.3026E 17   0.1173E 01   0.2352E 05   0.7227E 00
686    0.3952E 06   0.1569E 17   0.1173E 01   0.2352E 05   0.7227E 00
687    0.3733E 06   0.1121E 17   0.1173E 01   0.2352E 05   0.7227E 00
688    0.4940E 06   0.4674E 17   0.1173E 01   0.2352E 05   0.6309E 00
689    0.4666E 06   0.3554E 17   0.1173E 01   0.2352E 05   0.6309E 00
690    0.4391E 06   0.2666E 17   0.1173E 01   0.2352E 05   0.6309E 00
691    0.3733E 06   0.1383E 17   0.1173E 01   0.2352E 05   0.6309E 00
692    0.3513E 06   0.9871E 16   0.1173E 01   0.2352E 05   0.6309E 00
693    0.4501E 06   0.4185E 17   0.1173E 01   0.2352E 05   0.5609E 00
694    0.4281E 06   0.3183E 17   0.1173E 01   0.2352E 05   0.5609E 00
695    0.4062E 06   0.2387E 17   0.1173E 01   0.2352E 05   0.5609E 00
696    0.3403E 06   0.1238E 17   0.1173E 01   0.2352E 05   0.5609E 00
697    0.3184E 06   0.8842E 16   0.1173E 01   0.2352E 05   0.5609E 00
698    0.4172E 06   0.3694E 17   0.1173E 01   0.2352E 05   0.4918E 00
699    0.3952E 06   0.2810E 17   0.1173E 01   0.2352E 05   0.4918E 00
700    0.3733E 06   0.2108E 17   0.1173E 01   0.2352E 05   0.4918E 00
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OBSV    F1           F2           F3           F4           F5

701  0.3074E 06   0.1092E 17   0.1173E 01   0.2352E 05   0.4918E 00
702  0.2854E 06   0.7801E 16   0.1173E 01   0.2352E 05   0.4918E 00
703  0.1397E 06   0.1306E 17   0.2120E 01   0.1069E 05   0.8320E 00
704  0.1198E 06   0.9935E 16   0.2120E 01   0.1069E 05   0.8320E 00
705  0.9980E 05   0.7450E 16   0.2120E 01   0.1069E 05   0.8320E 00
706  0.7984E 05   0.3864E 16   0.2120E 01   0.1069E 05   0.8320E 00
707  0.1297E 06   0.1121E 17   0.2120E 01   0.1069E 05   0.7100E 00
708  0.1148E 06   0.8526E 16   0.2120E 01   0.1069E 05   0.7100E 00
709  0.9481E 05   0.6394E 16   0.2120E 01   0.1069E 05   0.7100E 00
710  0.7485E 05   0.3316E 16   0.2120E 01   0.1069E 05   0.7100E 00
711  0.1198E 06   0.7286E 16   0.2120E 01   0.1069E 05   0.4560E 00
712  0.1048E 06   0.5543E 16   0.2120E 01   0.1069E 05   0.4560E 00
713  0.8982E 05   0.4157E 16   0.2120E 01   0.1069E 05   0.4560E 00
714  0.3114E 06   0.2278E 17   0.1631E 01   0.1390E 05   0.8708E 00
715  0.2854E 06   0.1733E 17   0.1631E 01   0.1390E 05   0.8708E 00
716  0.2530E 06   0.1300E 17   0.1631E 01   0.1390E 05   0.8708E 00
717  0.2011E 06   0.6739E 16   0.1631E 01   0.1390E 05   0.8708E 00
718  0.2919E 06   0.2044E 17   0.1631E 01   0.1390E 05   0.7769E 00
719  0.2595E 06   0.1555E 17   0.1631E 01   0.1390E 05   0.7769E 00
720  0.2335E 06   0.1167E 17   0.1631E 01   0.1390E 05   0.7769E 00
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OBSV     F1            F2            F3            F4            F5


721   0.1881E 06    0.6047E 16    0.1631E 01    0.1390E 05    0.7769E 00

722   0.2335E 06    0.1549E 17    0.1631E 01    0.1390E 05    0.5815E 00

723   0.2076E 06    0.1178E 17    0.1631E 01    0.1390E 05    0.5815E 00

724   0.1881E 06    0.8837E 16    0.1631E 01    0.1390E 05    0.5815E 00

725   0.1557E 06    0.4584E 16    0.1631E 01    0.1390E 05    0.5815E 00

726   0.2206E 06    0.1418E 17    0.1631E 01    0.1390E 05    0.5308E 00

727   0.1979E 06    0.1079E 17    0.1631E 01    0.1390E 05    0.5308E 00

728   0.1751E 06    0.8086E 16    0.1631E 01    0.1390E 05    0.5308E 00

729   0.1427E 06    0.4195E 16    0.1631E 01    0.1390E 05    0.5308E 00

730   0.4152E 06    0.3500E 17    0.1325E 01    0.1710E 05    0.8950E 00

731   0.3832E 06    0.2661E 17    0.1325E 01    0.1710E 05    0.8950E 00

732   0.3513E 06    0.1996E 17    0.1325E 01    0.1710E 05    0.8950E 00

733   0.2874E 06    0.1035E 17    0.1325E 01    0.1710E 05    0.8950E 00

734   0.2475E 06    0.7394E 16    0.1325E 01    0.1710E 05    0.8950E 00

735   0.3832E 06    0.3219E 17    0.1325E 01    0.1710E 05    0.8187E 00

736   0.3593E 06    0.2449E 17    0.1325E 01    0.1710E 05    0.8187E 00

737   0.3194E 06    0.1837E 17    0.1325E 01    0.1710E 05    0.8187E 00

738   0.2635E 06    0.9522E 16    0.1325E 01    0.1710E 05    0.8187E 00

739   0.2395E 06    0.6805E 16    0.1325E 01    0.1710E 05    0.8187E 00

740   0.3353E 06    0.2625E 17    0.1325E 01    0.1710E 05    0.6600E 00
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OBSV    F1           F2           F3           F4           F5

741   0.3114E 06   0.1997E 17   0.1325E 01   0.1710E 05   0.6600E 00
742   0.2635E 06   0.1498E 17   0.1325E 01   0.1710E 05   0.6600E 00
743   0.2395E 06   0.7769E 16   0.1325E 01   0.1710E 05   0.6600E 00
744   0.2236E 06   0.5546E 16   0.1325E 01   0.1710E 05   0.6600E 00
745   0.3114E 06   0.2469E 17   0.1325E 01   0.1710E 05   0.6187E 00
746   0.2874E 06   0.1878E 17   0.1325E 01   0.1710E 05   0.6187E 00
747   0.2635E 06   0.1409E 17   0.1325E 01   0.1710E 05   0.6187E 00
748   0.2236E 06   0.7299E 16   0.1325E 01   0.1710E 05   0.6187E 00
749   0.2076E 06   0.5219E 16   0.1325E 01   0.1710E 05   0.6187E 00
750   0.2874E 06   0.1984E 17   0.1325E 01   0.1710E 05   0.4925E 00
751   0.2555E 06   0.1509E 17   0.1325E 01   0.1710E 05   0.4925E 00
752   0.2315E 06   0.1131E 17   0.1325E 01   0.1710E 05   0.4925E 00
753   0.1996E 06   0.5864E 16   0.1325E 01   0.1710E 05   0.4925E 00
754   0.1836E 06   0.4191E 16   0.1325E 01   0.1710E 05   0.4925E 00
755   0.4646E 06   0.4959E 17   0.1116E 01   0.2031E 05   0.9116E 00
756   0.4361E 06   0.3772E 17   0.1116E 01   0.2031E 05   0.9116E 00
757   0.4077E 06   0.2828E 17   0.1116E 01   0.2031E 05   0.9116E 00
758   0.3603E 06   0.1467E 17   0.1116E 01   0.2031E 05   0.9116E 00
759   0.3318E 06   0.1047E 17   0.1116E 01   0.2031E 05   0.9116E 00
760   0.4456E 06   0.4635E 17   0.1116E 01   0.2031E 05   0.8474E 00
```

OBSV	F1	F2	F3	F4	F5
761	0.4172E 06	0.3526E 17	0.1116E 01	0.2031E 05	0.8474E 00
762	0.3887E 06	0.2644E 17	0.1116E 01	0.2031E 05	0.8474E 00
763	0.3413E 06	0.1371E 17	0.1116E 01	0.2031E 05	0.8474E 00
764	0.3224E 06	0.9793E 16	0.1116E 01	0.2031E 05	0.8474E 00
765	0.4266E 06	0.3932E 17	0.1116E 01	0.2031E 05	0.7105E 00
766	0.3982E 06	0.2991E 17	0.1116E 01	0.2031E 05	0.7105E 00
767	0.3603E 06	0.2243E 17	0.1116E 01	0.2031E 05	0.7105E 00
768	0.3034E 06	0.1163E 17	0.1116E 01	0.2031E 05	0.7105E 00
769	0.2844E 06	0.8308E 16	0.1116E 01	0.2031E 05	0.7105E 00
770	0.4077E 06	0.3768E 17	0.1116E 01	0.2031E 05	0.6789E 00
771	0.3840E 06	0.2866E 17	0.1116E 01	0.2031E 05	0.6789E 00
772	0.3508E 06	0.2150E 17	0.1116E 01	0.2031E 05	0.6789E 00
773	0.2939E 06	0.1115E 17	0.1116E 01	0.2031E 05	0.6789E 00
774	0.2655E 06	0.7958E 16	0.1116E 01	0.2031E 05	0.6789E 00
775	0.3698E 06	0.3208E 17	0.1116E 01	0.2031E 05	0.5726E 00
776	0.3413E 06	0.2439E 17	0.1116E 01	0.2031E 05	0.5726E 00
777	0.3129E 06	0.1830E 17	0.1116E 01	0.2031E 05	0.5726E 00
778	0.2655E 06	0.9490E 16	0.1116E 01	0.2031E 05	0.5726E 00
779	0.2465E 06	0.6775E 16	0.1116E 01	0.2031E 05	0.5726E 00
780	0.3413E 06	0.2773E 17	0.1116E 01	0.2031E 05	0.4916E 00

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OBSV     F1            F2            F3            F4            F5


781  0.3129E 06   0.2109E 17   0.1116E 01   0.2031E 05   0.4916E 00

782  0.2844E 06   0.1582E 17   0.1116E 01   0.2031E 05   0.4916E 00

783  0.2275E 06   0.8204E 16   0.1116E 01   0.2031E 05   0.4916E 00

784  0.2086E 06   0.5857E 16   0.1116E 01   0.2031E 05   0.4916E 00

785  0.5269E 06   0.6647E 17   0.9636E 00   0.2352E 05   0.9236E 00

786  0.5050E 06   0.5055E 17   0.9636E 00   0.2352E 05   0.9236E 00

787  0.4830E 06   0.3792E 17   0.9636E 00   0.2352E 05   0.9236E 00

788  0.4172E 06   0.1966E 17   0.9636E 00   0.2352E 05   0.9236E 00

789  0.3952E 06   0.1405E 17   0.9636E 00   0.2352E 05   0.9236E 00

790  0.5160E 06   0.6281E 17   0.9636E 00   0.2352E 05   0.8682E 00

791  0.4940E 06   0.4778E 17   0.9636E 00   0.2352E 05   0.8682E 00

792  0.4721E 06   0.3583E 17   0.9636E 00   0.2352E 05   0.8682E 00

793  0.4062E 06   0.1858E 17   0.9636E 00   0.2352E 05   0.8682E 00

794  0.3842E 06   0.1327E 17   0.9636E 00   0.2352E 05   0.8682E 00

795  0.5050E 06   0.5509E 17   0.9636E 00   0.2352E 05   0.7527E 00

796  0.4830E 06   0.4190E 17   0.9636E 00   0.2352E 05   0.7527E 00

797  0.4501E 06   0.3142E 17   0.9636E 00   0.2352E 05   0.7527E 00

798  0.3733E 06   0.1629E 17   0.9636E 00   0.2352E 05   0.7527E 00

799  0.3513E 06   0.1164E 17   0.9636E 00   0.2352E 05   0.7527E 00

800  0.4830E 06   0.5305E 17   0.9636E 00   0.2352E 05   0.7227E 00
```

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OBSV     F1            F2            F3            F4            F5


801   0.4611E 06    0.4035E 17    0.9636E 00    0.2352E 05    0.7227E 00
802   0.4281E 06    0.3026E 17    0.9636E 00    0.2352E 05    0.7227E 00
803   0.3513E 06    0.1569E 17    0.9636E 00    0.2352E 05    0.7227E 00
804   0.3293E 06    0.1121E 17    0.9636E 00    0.2352E 05    0.7227E 00
805   0.4501E 06    0.4674E 17    0.9636E 00    0.2352E 05    0.6309E 00
806   0.4281E 06    0.3554E 17    0.9636E 00    0.2352E 05    0.6309E 00
807   0.3952E 06    0.2666E 17    0.9636E 00    0.2352E 05    0.6309E 00
808   0.3293E 06    0.1383E 17    0.9636E 00    0.2352E 05    0.6309E 00
809   0.3074E 06    0.9871E 16    0.9636E 00    0.2352E 05    0.6309E 00
810   0.4281E 06    0.4185E 17    0.9636E 00    0.2352E 05    0.5609E 00
811   0.3952E 06    0.3183E 17    0.9636E 00    0.2352E 05    0.5609E 00
812   0.3733E 06    0.2387E 17    0.9636E 00    0.2352E 05    0.5609E 00
813   0.3074E 06    0.1238E 17    0.9636E 00    0.2352E 05    0.5609E 00
814   0.2854E 06    0.8842E 16    0.9636E 00    0.2352E 05    0.5609E 00
815   0.4007E 06    0.3694E 17    0.9636E 00    0.2352E 05    0.4918E 00
816   0.3733E 06    0.2810E 17    0.9636E 00    0.2352E 05    0.4918E 00
817   0.3513E 06    0.2108E 17    0.9636E 00    0.2352E 05    0.4918E 00
818   0.2854E 06    0.1092E 17    0.9636E 00    0.2352E 05    0.4918E 00
819   0.2635E 06    0.7801E 16    0.9636E 00    0.2352E 05    0.4918E 00
```

APPENDIX H

NOMENCLATURE

A	Area of cross section, m^2
B_s	Equation constant
C_d	Drag coefficient
c & m	Correlation constants
D	Diameter of tank, m
d	Particle size or sphere diameter, m
d_s	Particle mean size, m
$\frac{du}{dy}$	Velocity gradient at a depth y, sec^{-1}
$\frac{du}{dx}$	Rate of shear or velocity gradient, sec^{-1}
d_{75}	Size for which 75% of the bed material is finer, mm
f	Darcy-Weisbach friction factor
F	Shear force, N
F_1	Velocity factor
F_2	Power factor
F_3	Width factor
F_4	Depth factor
F_5	Submergence factor
g	Acceleration due to gravity, m/s^2
h	Depth of the water above the diffuser (submergence), m

h_f	Head loss, m
H	Liquid depth, m
k	An empirical constant
k_1	A constant with dimensions of viscosity
k_s	Roughness height, m
L	Length of channel reach, m
L_1	Tank length, m
m	Constant
M	Torque, dynes - cm
n	A dimensionless constant with a value less than one
P	Rate of power consumption, kw
P_1	Absolute inlet pressure, atmosphere
P_2	Absolute Outlet pressure, atmosphere
P_e	Wetted perimeter
P_{atm}	Atmospheric pressure, 101.3 kN/m^2 or 14.7 psia
P_{gage}	Pressure gage reading, kN/m^2 or psig
P_{rota}	Pressure for which the rotameter was calibrated, 101.3 kN/m^2 or 14.7 psia
Q_{al}	Air flow rate under atmospheric pressure and at 20°C m^3/min
Q_{rota}	Observed air flow rate (reading from rotameter), m^3/s or cfm
Q_{STP}	Air flow rate under standard conditions, m^3/s, 20°C and 101.3 kN/m^2 or cfm 20° C and 14.7 psia

R	Hydraulic mean radius, m
R_b	Radius of the spindle, cm
R_c	Radius of the container, cm
R_e	Reynolds number
R_g	Gas constant, 8.314J/g. mol.
S	Slope of channel
S_f	Slope factor
S_s	Specific gravity of the particles or sphere
t_1	Time parameter with dimensions of time, sec.
T_i	Inlet temperature of air
t_{max}	Mixing time, s
T_{opc}	Operating temperature, °K
T_{STP}	Standard temperature for which the roameter was calibrated. 293.15°K
u	Point velocity at any depth y, m/s
u_m	Mean velocity, m/s
u' & v'	Components of the fluctuating velocity in x and y directions, respectively
U_*	Friction or shear velocity, m/s
U_{*c}	Critical shear or friction velocity, m/s
$\forall$	Volume of tank, m^3
V_c	Critical velocity to start scour of particles, m/s

V_{mc}	Competent mean velocity, ,/s
V_s	Settling or fall velocity, m/s
V_{sur}	Surface Velocity, m/sec
v	Linear velocity at any distance r, m/s
W	Air mass flow rate, kg/s
W_g	Weight of a grain, kg.
X	Distance of diffusers from the sidewall of the tank, m.
y	Distance from the bed or depth of flow, m
y_m	Depth at which the point velocity is equal to the mean velocity, m/s
β	An experimental constant
γ or γ_f	Specific weight of fluid or water, N/m^3
δ	Thickness of laminar sub layer
κ	Von Karman Universal constant, 0.4
ℓ	Prandtl mixing length
μ	Fluid dynamic viscosity, H.S/m^2
μ'	Viscosity parameter with dimensions of viscosity, poise
$\mu'(\frac{du}{dx})$	Non-Newtonian viscosity at shear rate of $\frac{du}{dx}$
μ_p	Plastic viscosity, N.S/m^2
ν	Kinematic viscosity, m^2/s
ω	Angular velocity radians/s

θ	Angle of repose
ρ or ρ^{s}_{f}	Fluid or water mass density, kg/m^3
ρ_s	Bed material mass density, kg/m^3
τ	Shear stress at any depth, N/m^2
τ_ℓ	Laminar or viscous shear stress, N/m^2
τ_o	Bed shear stress, N/m^2
τ_{oc}	Critical bed shear stress, N/m^2
τ_t	Turbulent shear stress, M/m^2
τ_y	Yield stress, N/m^2 or dynes/cm^2
γ'_s	Specific weight of bed material in the fluid, N/m^3
γ_s	Specific weight of bed material, N/m^3

Appendix I

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VITA AUCTORIS

The author was born on December 11, 1955 in Jabalpur, India. In June of 1976, he was graduated from the Government Engineering College, University of Jabalpur, with his Bachelor's Degree in Civil Engineering. In August of the same year he accepted a position as a Site Engineer with a Government contractor to work on the construction of ammunition magazines in defence installations.

In August, 1977 he entered the Asian Institute of Technology (Bangkok) after being awarded a United Kingdom Government scholarship to pursue his graduate studies. His efforts led to a Masters Degree in Environmental Engineering, specializing in water and wastewater engineering, in 1979.

After working for a short while on various research projects, he returned to India, and subsequently joined the Council of Scientific and Industrial Research as a Pool Officer. During this period, he was involved in both teaching and research activities. In December of 1979, he accepted a position with the Central Board for the Prevention and Control of Water Pollution as an Assistant Environmental Engineer, where he was involved in pollution surveys of various rivers and industries.

He emigrated to Canada in January of 1981, and enrolled in a programme leading to his degree of Doctor of Philosophy in Civil Engineering at the University of Windsor.