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# Pulp Consistency Correlation to Pressure Drop across a Static Mixer as a Possible Means of Consistency Measurement

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# PULP CONSISTENCY CORRELATION TO PRESSURE DROP ACROSS A STATIC MIXER AS A POSSIBLE MEANS OF CONSISTENCY MEASUREMENT

by

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ABSTRACT

The purpose of this project was to determine if pressure drop in a static mixer can be related to pulp consistency in the 2-4% range. If this relationship can be found, it would be possible to use the static mixer as a consistency sensor. Consistency measurement is one of the most difficult variables to measure and control in the pulp and paper mill. Any sensor which would improve reliability and accuracy of consistency measurement would be worthwhile.

The results of this project indicate that the use of pressure drop across a static mixer is not a practical method of consistency sensing. The device was very sensitive to flow rate variations, a fact which is difficult to compensate for with the static mixer. The mixer pressure drop also appeared to vary with pulp species.

Further work should be done in this area using equipment more suited for higher consistencies. More runs should be done for each species type. Also, a more precise type of pressure drop measurement should be devised. Finally, a better means of mixing the dilution water should be used in order to maintain a more uniform consistency in the stock chest.

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# INTRODUCTION

The purpose of this experiment was to determine the pressure drop characteristics of a pulp slurry across a static mixer installed in-line. It was hoped that a relationship between consistency and pressure drop could be found making it possible to develop a low cost and low maintenance consistency sensor for use in the paper industry.

## BACKGROUND DISCUSSION

### The Motionless Mixer

With the rapid growth of continuous process technology, much work has been done to develop continuous in-line mixing. Initial work in this area resulted in such solutions as using small mixing towers or horizontal mixing cylinders in-line with input and output piping to allow continuous flow through the unit. However, these units used inefficient mechanical agitator blades which consumed large amounts of energy and resulted in a poor degree of mixing. This early form in in-line mixing equipment was expensive, costly to install, and required frequent maintenance.

The next development was the introduction of the first generation in-line motionless mixers. These units used stationary baffles of continuous spirals inside the pipeline to cause the mixing action. They were less expensive and used a little less energy than mechanical mixers. However, the design of mixing elements created random flow patterns which resulted in nonuniform mixing. This problem could be corrected by using longer mixing units, but this resulted in higher energy costs.[1]

Motionless mixers are not new since a mixer with no moving parts was patented around 1895.[2] However, motionless mixers were not scientifically developed until the 1960's. The first commercially available unit was introduced by

Kenics Corporation in the late 1960's. Several other companies have since entered the market. These include Komax, Sulzer, E. T. Oakes, Lightnin Mixers, and Dynamix. The main difference between the various types of mixers is usually the shape of the mixing elements.[3,4] Different shaped elements, tube diameters, and tube lengths are selected depending upon the application.[1]

Motionless mixers have found uses in the entire range of process industries including the pulp and paper industry. The materials to be mixed are pumped through the mixer which contains the mixing elements. The elements split the incoming flow into smaller substreams, change the direction of the substreams, and then recombine the streams. This process will repeat at each mixer element. The number of substreams increases rapidly as the flow pases through the mixer. The mixing action is independent of flow rate and type of flow (turbulent or laminar flow). The performance of a motionless mixer can be accurately predicted for any given application.[5] The uses of motionless mixers are not limited to mixing as they have also been used as reactor units and heat exchangers.[4]

The advantages of motionless mixers include the ability to handle wide ranges and large ratios of viscosity, low cost, reduction of operating costs, and superior mixing. The only energy required is that needed to pump materials through the mixer. Maintenance costs are also reduced since no moving parts are involved.[4]

Even with all of these advantages, motionless mixers were slow in gaining acceptance in the process industries. But with rising energy costs and more use of continuous processes, the possibility of more mixing with less energy is becoming much more attractive. Today motionless mixers are found in nearly all of the process industries. Their main usage is for gas/liquid, liquid/liquid, and liquid/solid mixing in the synthetic fiber, plastics, petroleum, chemical, water treatment, food and pharmaceutical industries.[2] The petroleum and chemical industries show the greatest potential for the use of static mixers. Since it was the first commercially available motionless mixer, the Kenics Mixer has been used in more industrial applications than any other make.

## The Imco Dyna-Foil Mixer

The Dyna-foil Mixer consists of a cylindrical tube with a series of contoured vanes inserted across the tube diameter (Figure 1). The leading edges of adjacent vanes are oriented at $90^{o}$ to one another. The size and contour of the vanes are designed to give maximum mixing with minimum flow resistance. There are two mixing actions employed by the Dyna-Flow Mixer. These are flow splitting and acceleration/deceleration of the flow as it passes the vanes. These actions occur simultaneously in the mixer. As a result of these mixing actions, a condition of nearly plug flow exists in the mixer.[6]

Flow splitting occurs at the leading edge of each vane.

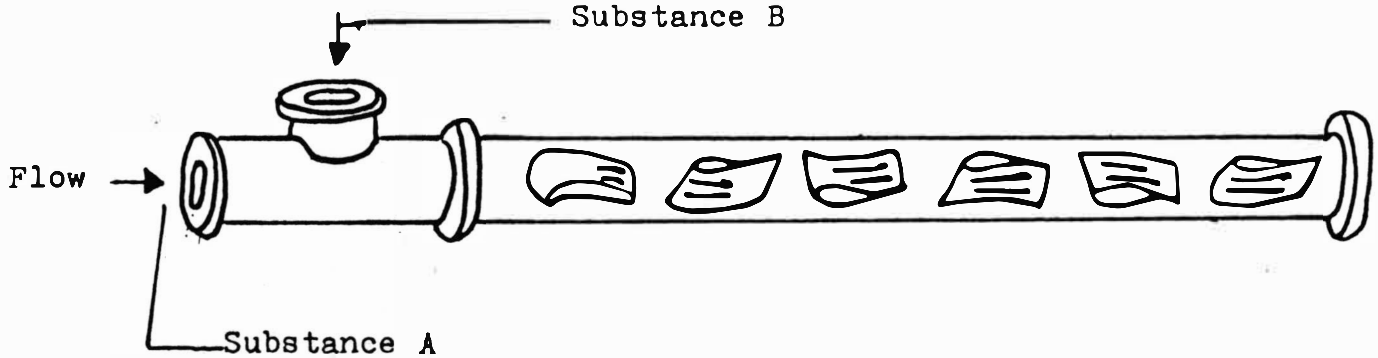



Figure 1
Positioning of mixing vanes in an Imco-Dyna-Foil Mixer.

This results in an exponential progression of flow division. This progression is given by the formula $S=2^n$, where S is the number of flow splits and n is the number of vanes in the mixer. For example, in a unit with 20 vanes, over 1 million ($2^{20}$) striations are created. The thickness of each striation is given by $D=D/2^n$, where D is the inside diameter of the pipe.

The amount of acceleration/deceleration is dependent upon particle position in the mixer with relation to the x-x axis (Figure 2). Since the vane surface area is constant while flow areas vary in size across the tube diameter, many different particle velocities are developed. This assures a maximum amount of fluid shear without high flow resistance.

The advantages of the Dyna-Foil Mixer include low energy consumption and the ability to induce fluid shear with minimum turbulence. The Dyna-Foil Mixer is available in carbon and stainless steel, alloy metals, glass, fiberglass, PVC, and other plastics.[6]

<u>Pressure Drop in the Static Mixer</u>

Since no moving parts are used in the static mixer, the only power required is that needed to overcome the frictional losses as reflected by pressure drop. The factors which influence the pressure drop in the mixer are flow velocity, consistency, pipe diameter, the number of elements, and the friction factor. These factors are related by the following equation for an empty pipe known as the

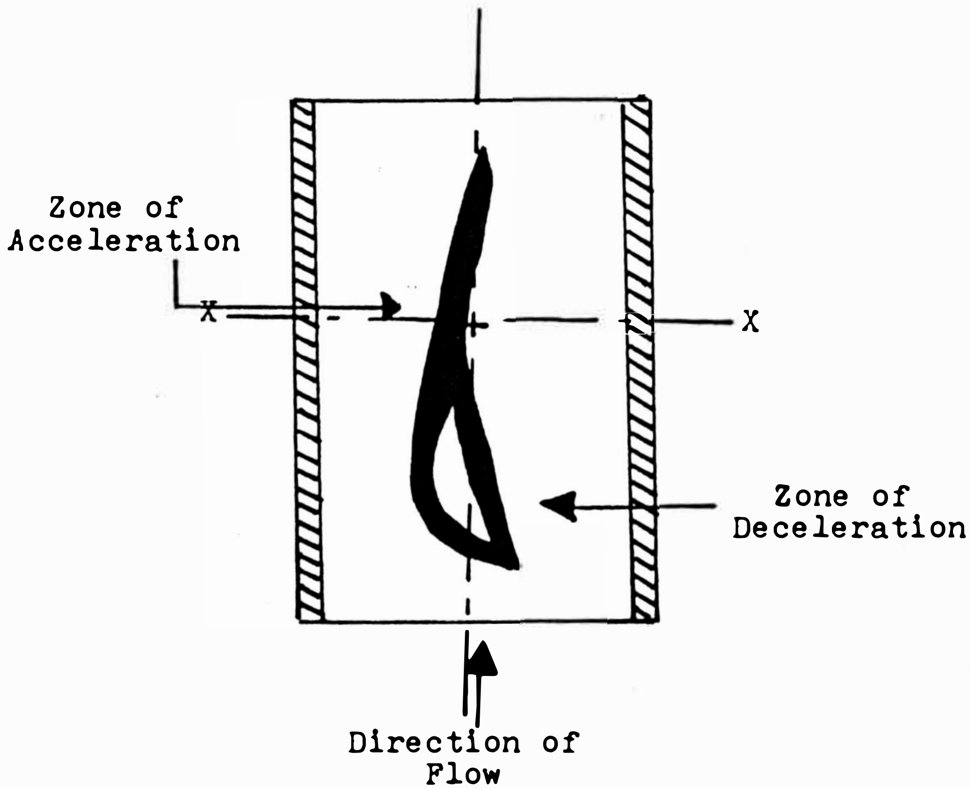



Figure 2
Zones of acceleration and
deceleration in the Imco Dyna-Foil Mixer.

Darcy equation.[7]

$$P = \frac{f \times L \times \rho \times V^2}{12 \times D\ 2gc} = \frac{(2.15 \times 10^{-4}) f \times L \times \rho \times Q^2}{D^5}$$

$$= \frac{(1.35 \times 10^{-2}) f \times L \times S.G.Q \times Q^2}{\rho D^5}$$

where:
- p = pressure drop (lbs./ft.$^2$)
- $\rho$ = density of the fluid (lbs./ft.$^3$)
- f = friction factor (dimensionless)
- L = length of pipe (ft.)
- V = flow velocity (ft./sec.)
- $g_c$ = gravitational constant (32.17 ft./sec.$^2$)
- D = inside diameter of the pipe (inches)
- Q = volumetric flow rate (gal./min.)
- S.G. = specific gravity
- W = mass flow rate

Darcy friction factor is defined as $f = 64/N_{Re}$ for laminar flow. The pressure drop in a static mixer of the same length and diameter as the empty pipe in the Darcy equation is found by multiplying the empty pipe pressure drop by a factor of K ($\Delta P_{mixer} = K \Delta P_{pipe}$). The K factor is a function of the mixer geometry and the Reynolds number. Values of K for various flow conditions have been determined experimentally by Kenic Corporation and the University of Massachusetts. These values are available in graphs and tables from Kenics. Actual values for pressure drop in the mixer have been determined by Kenics, but are proprietary information and are not available.

Once the pressure drop has been determined, power loss can also be calculated easily (theoretical horsepower =

.262 $P_{mixer}$ x $ft.^3$/sec. flow rate). In turbulent flow the pressure drop across the static mixer is 40-200 times that of an equivalent length and diameter of smooth pipe. In general, energy consumption of the static mixer is one order of magnitude (1/10) less than the consumption of a dynamic mixer designed to do the same job.[5]

Consistency Measurement in the 2-6% Range

Within the pulp and paper industry, one of the single most important measurements is that of pulp slurry consistency. Pulp consistency is one of the main controlling factors for the efficient operation of several processes in the pulp and paper mill.

Pulp consistency is defined as the percentage, by weight, of bone dry fiber to total weight of a pulp slurry sample. Today, howver, no supplier has been able to produce a consistency transmitter which actually reports consistency based on this definition. All present day consistency transmitters measure consistency indirectly by correlating another pulp slurry property that varies with consistency. The property used should not be greatly affected by flow velocity, degree of refining, temperature, pH, or pulp type. A modern consistency sensor, developed in 1928, was based on this principle. The sensing element, known as Kalle's Finger, influences an electrical contact as the changing consistency changes the shear forces on the finger. This in turn signals a controller which will modulate the dilution valve. The dilution valve controls the flow of dilution water to the

pipeline in order to maintain a constant consistency.[8]

In the 1950's another type of transmitter was developed based on the principle of apparent viscosity. A specially designed cone was rotated in the pulp slurry by a water injection system. Apparent viscosity is the most commonly used basis for consistency measurement. Types of measurement based on apparent viscosity may include pure surface friction (flow resistance in a pipe), internal friction (torque of an agitator turned in the stock), and/or shearing force (a force generated on a rod shearing the stock). Consistency mesurement is carried out under pressurized conditions in a stock pipe or in an open vessel connected to the stock line.[8]

Factors Interfering With Consistency Measurement

Each type of pulp will give a different consistency reading even though their actual consistencies, by definition, are equal. Type of pulping, species, and degree and type of refining will all case slight variations in consistency readings. Other factors which will influence consistency readings are the amount of additives (fillers, etc.), temperature, pressure, air content, and pH.[9]

Sampling Type Devices

The sampling type of consistency transmitter operates by removing a sample from the process stream, measuring its consistency, and returning the sample to the stock stream. There are two types of sample devices, pressurized

and atmospheric (open-box). For a long time, the open-box sensor was the most commonly used. This type of transmitter senses consistency in one of two ways. One type uses a two-compartment box. A constant head in the upper compartment is maintained by a wier. This compartment feeds a constant flow through an orifice into a standpipe in front of the box. The pressure head required to pass this flow through a viscosity tube into the lower compartment is the measurement related to consistency (Figure 3).

The second type of this kind of device obtains a sample in much the same way as the above sensor. The sensor used is a motor driven feeler paddle The force required to turn the feeler agitator at a given speed is a function of consistency of the pulp slurry. Both of these systems transmit a signal to a dilution water valve.

The pressurized sample system is used when flow in the main stock line exceeds the measuring capacity of the sensing element. This type of sensor operates in much the same way as the open-box type of sensor. The pressurized box will prevent an excess amount of stock from entering the sensing unit. All sampling type consistency sensors return the pulp sample to the process stream or to a stock chest.[10,11]

Full Stream Sensors

Full stream consistency sensors essentially measure a 100% sample with the sensing element operating in the main stream. There are two types of full stream transmit-

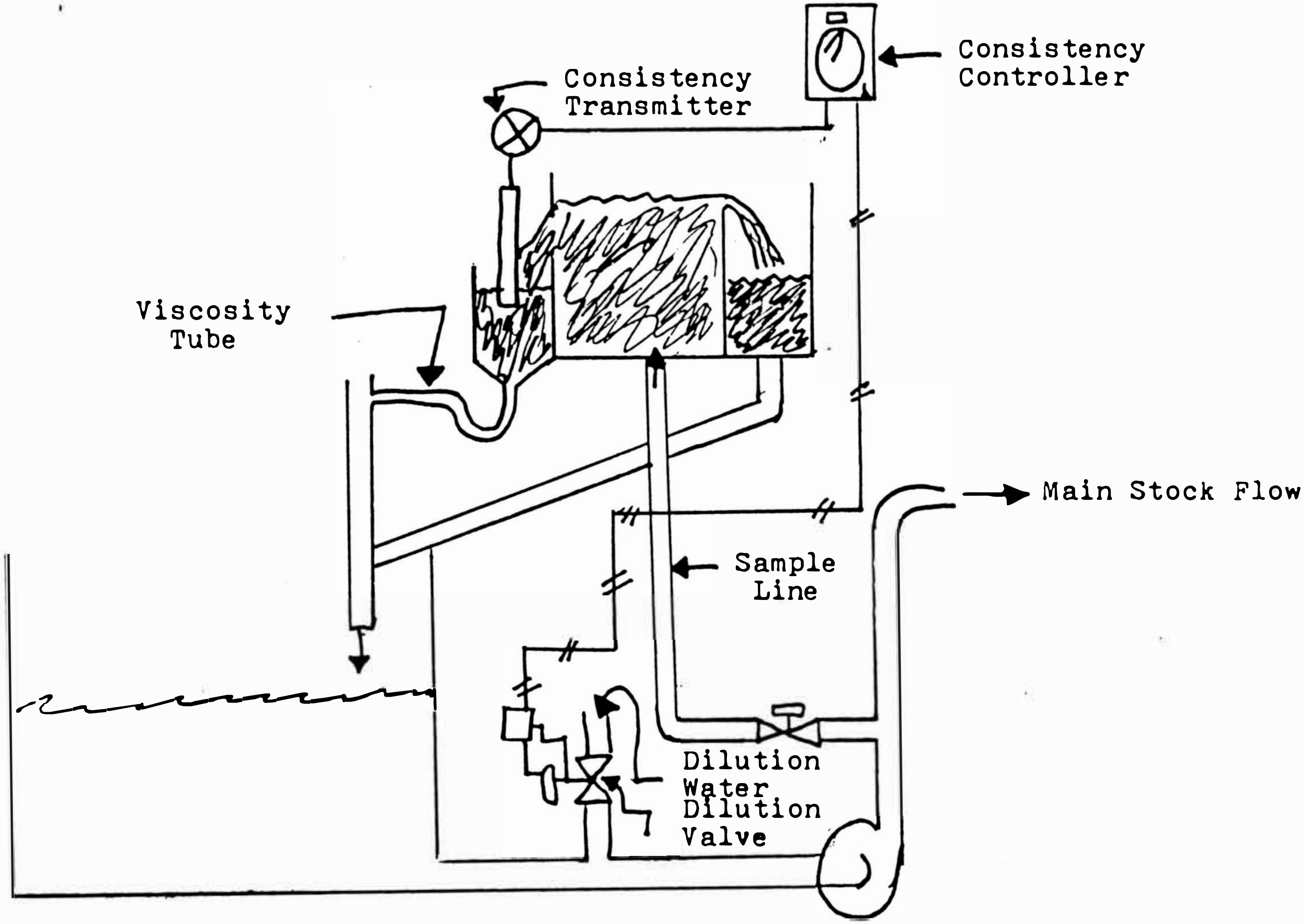



Figure 3
An example of an open box type consistency control system.

ters: atmospheric (open-box) and pressurized (in-line). A common open-box full stream sensor is very similar to the rotating sensor sampling type except that the full flow of the stock line flows through the box. Other similar types of sensors measure friction loss across a flow restriction. Pressurized devices are used directly in the pipeline. This method of installation is the most often used in newer pulp and paper mill installations. The main advantage of this sensor is that since the device is placed in the pipeline, it can be placed close to the point of dilution. This fact helps to greatly reduce time lags inherent to flow-box type sensors. The in-line system also permits the design of completely closed stock systems. This allows for a reduction of pulp aeration, fiber bundles, and piping costs required for flow-box type devices. Pressurized (in-line) devices are the most common today. They measure the shear forces on disks, paddles, impellers, cones, spheres, restrictions, or they measure head loss through a length of pipe. There are two types of pressurized in-line consistency sensors: those which use a rotating or moving body in the pulp stream and those which use a stationary sensing element in the pulp stream.[10,11]

The rotating element in-line unit typically uses a flat circular plate with involute ribs on the surface. The torque required to turn the plate at a constant speed will increase with increasing consistency. The torque signal is sensed by either an electronic or pneumatic bridge which

in turn produces a signal which the controller uses to adjust the dilution water valve. Other types of rotating sensor devices operate on much the same principles varying only in design of the sensor element and method of converting the torque measurement to a transmission signal correlated to consistency.

Pressurized in-line stationary element consistency devices differ in design of sensing elements as well as in principles used to detect consistency changes. Sensing element signals may be either pneumatic or electronic.

An example of a pneumatic consistency transmitter of this type utilizes a shear float in the pulp stream as the sensing element. The element consists of a round shaft with cylindrical fingers projecting from it. As consistency increases, the force exerted on the sensor increases. This force is transmitted to a pneumatic transmitter which signals the controller.[10]

An electronic version of this type of sensor uses a stainless steel probe which contains four strain gauges which form a resistance bridge. The resistance of the bridge will change as the forces on the sensor change. These force changes are caused by changes in consistency. The change in resistance causes a voltage input to an a.c. potentiometer consistency recorder controller which in turn controls the dilution valve.[11]

## The Scimitar Blade Consistency Sensor

In England, in 1963, work was begun to develop a new

concept of in-line pressurized consistency meter. The concept involved was that of apparent viscosity. At that time a very dependable differential pressure sensor using a very stable force balance transmitting mechanism was commercially available for detection of low level forces in pipelines. Designers felt that an in-line drag plate could be developed which, when placed in the pulp stream, would sense forces related to apparent viscosity. By combining these two instruments it was felt that a consistency sensor of good sensitivity and stability could be developed.

This idea was supported by data obtained in pipeline pressure drop studies. Newtonian fluids flowing in a pipeline experience a pressure drop which provides a measure of forces exerted by the fluid at the pipe wall. These forces are related to viscosity. From this it was concluded that similar forces could be produced on the surface of a thin plate in the pulp flow if its sides were parallel to the flow. However, with pulp stock, which is a non-Newtonian fluid, the nature of the forces are not easily defined. Experience has shown that there is an empirical relationship between these forces (related to apparent viscosity) and consistency. Researchers found that with a properly designed plate, it was possible to relate the forces directly to consistency. Since the plate had some thickness to it, additional forces acted upon it where the pulp struck the front of the plate. This force, due to flow velocity, had to be eliminated because it was not possible to correlate these

forces to consistency when velocity was changing. The forces along the flat sides of the plate could, however, be related to consistency. The lateral forces were also not sensitive to changes in velocity under normal condition. As a result of this research the first successful Scimitar Blade consistency detector was produced and made available to industry in 1964.

Under typical operating conditions, two types of forces act on the blade (Figure 4). The first type of force, which acts on the sides of the blade, is caused by the fibers as they flow by. The second type of force acts on the frontal surface of the blade and on the tail of the blade. These forces act perpendicularly on their respective surfaces and are the primary forces causing pressure drop. By proper proportioning of the blade dimensions, these two perpendicular forces cancel one another, leaving only the side forces to be detected. These forces cause a moment around the Elgioloy seal pivot. The moment is transmitted to a flapper-nozzle assembly on the outside of the pipe. If a change in the moment occurs due to a consistency change, it will cause a change in the flapper-nozzle relationship. This in turn causes equivalent changes in both the relay output and feedback pressures. The feedback force causes the flapper-nozzle relationship to be restored as well as producing an output signal equal to the feedback pressure needed to balance the new moment on the blade. The transmitter output is a function of the moment on the blade which is in turn a function of consistency. This type of consistency

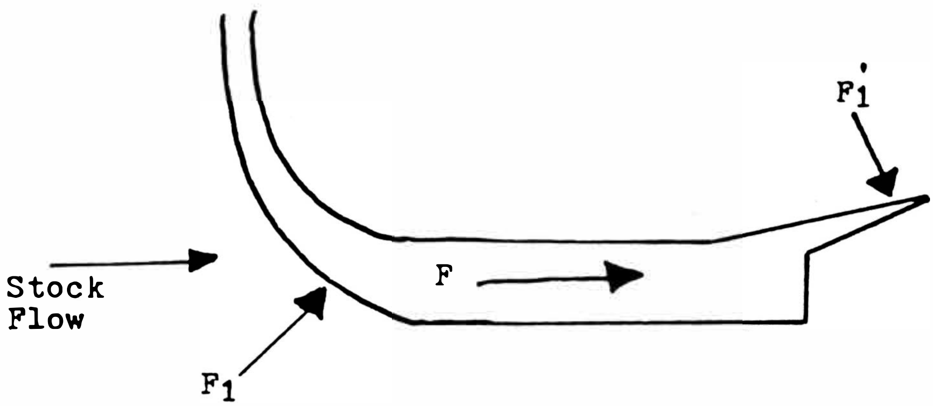



Figure 4
Forces acting on a Scimitar Blade consistency sensor in a pulp stock line.

mesurements is probably the most commonly used in the paper industry in the middle consistency range. It is not used much in the low consistency range since the forces exerted by the pulp fibers on the sides of the blade are too small to accurately detected.

Most other consistency sensors used in this consistency range are based on the same principle, varying in the design sensor. Some use a rotating sensor, but all are based on the principle of shear stress changing with pulp consistency as this has been found to be the most reliable.[10]

Rheological Properties of Pulp Slurries

The medium of a fiber suspension is water. Water is a Newtonian fluid with a very low viscosity which will flow in a pipeline with low pressure drop. Flow of water under mill conditions is nearly always turbulent due to the high flow velocities involved. Pulp slurries behave quite differently than water. Under some conditions, the flow resistance of a pulp slurry is less than that of water. This is because the fiber content of such a slurry reduces turbulence in the flow stream which makes flow more laminar and reduces flow resistance. As the fiber content of a pulp slurry increases, it tends to become pseudoplastic. This condition is caused by entanglement of the pulp fibers which form a three-dimensional network. Pseudoplastic behavior occurs at between 0.5% and 1.5% and up to about 8% depending upon pulp type and flow rate. It is this range that is the most desirable for consistency measurement. Slurries above

8% consistency behave much differently as they become very thick and difficult to handle.

Pseudoplastic slurries are made up of non-homogeneous fiber network of flocs and small lumps. This network binds the suspension which inhibits turbulence. At low flow rates, pulp slurries exhibit plug flow characteristics because the water acts as a lubricant along the inner walls of the pipe. Turbulent flow will occur in pulp slurries if the flow rate is high enough. Flow resistance of a pulp slurry in a pipe is influenced by consistency, flow rate, pipe size, quality of the pipe surface, temperature, and pulp type. The flow rate at which turbulent flow will occur depends upon the consistency of the slurry and the type of pulp being used.[9]

## EXPERIMENTAL PROCEDURE

In determining the pressure drop of a pulp slurry across an Imco Static Mixer, three types of pulp were used. These were an unrefined hardwood, a refined (400CSF) softwood, and an unrefined softwood. The procedure used for each pulp type follows.

Two hundred pounds (bone dry) of pulp were slurried at as high a consistency as possible in the Western Michigan University Pilot Plant Valley Beater. Some dilution was necessary in order to pump the stock from the beater to the stock chest. The hardwood pulp was pumped to the chest at 4.25%, the refined softwood at 3.25%, and the unrefined softwood at 3.0%. Problems encountered with pumping the softwood pulps were due to the long fiber length of the softwood pulp, dewatering of the softwood pulp in the pipeline, and the inability of the pump used to pump high consistency pulps, especially softwoods.

The pulp slurry in the stock chest was pumped through the Imco Static Mixer. Two, two-foot sections, each two inches in diameter, of Imco Mixer were used as the presure drop section of the pipeline (Figure 6). Pressure was measured at the inlet and outlet of the mixer. Due to incorrect placement of the pressure tap on the inlet side of the mixer by the piping contractor, the inlet pressure readings had to be corrected to a two inch diameter pipe from the

pressure values obtained from the tap placed on the three inch pipe. The equation used for this correction are given in Appendix 1 of this report.

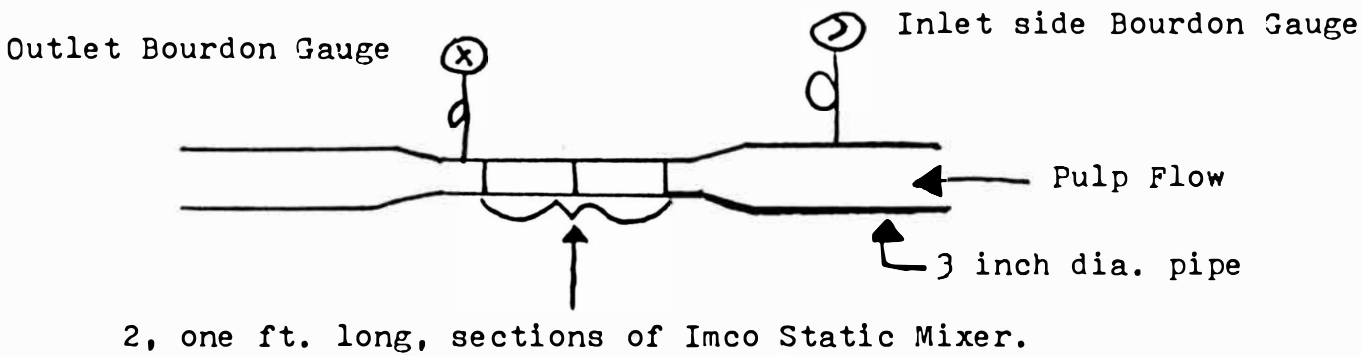
At the starting consistency, flow rates were controlled by adjustment of a butterfly valve placed before the mixer. This valving setup gave rather poor control of the flow rate. Therefore, as the data will show, repeatability of flow rates at a given consistency was not very good. The maximum flow rate obtained increased as consistency went down for all three pulp types used. Flow rates were determined by filling a five gallon pail from the open ended pipe returning the pulp to the stock chest and timing how long it took to fill the pail.

After checking the pressure drop at various flow rates at the initial consistency, the consistency was reduced by 0.25% and the changing of flow rates and recording of pressure readings was repeated. Consistency was checked manually for each consistency change. Consistency reduction was accomplished by adding water at a known flow rate from a hose so as to add the calculated amount of dilution water needed. This sequence of dilution in 0.25% steps and changing flow rates to obtain pressure drops was repeated at each interval down to 2.0% for each pulp type.

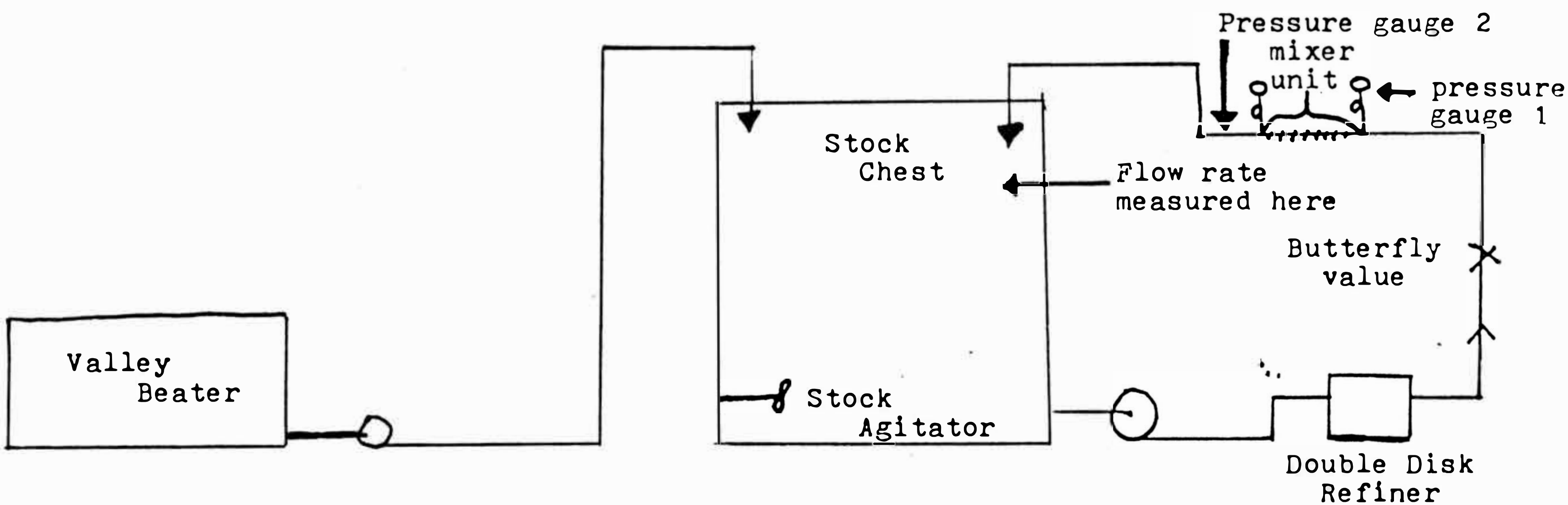
Pressure readings were taken by using Bourden type pressure gauges. These gauges have a water filled tube placed between the pressure gauge and the stock line. The water filled line prevents pulp from entering the pressure gauges

Figure 6

Mixer Unit Detail




Stock Flow System



and ruining them. The gauge on the inlet side of the mixer was a 0-30 psi gauge with 1 psi increments. The outlet gauge was a 0-10 psi gauge with 0.1 psi increments.

Some problems were encountered with the setup used in this expeiment. The worst problem, as mentioned before, was pumping the stock from the beater to the stock chest. Pumping the stock through the mixer unit was also a problem at consistency levels above 3.5% (3.0% with softwood). The butterfly valves that were used for flow control gave poor control and made exact duplication of flow rates nearly impossible. Another problem encountered was that with the piping system available, the pulp had to be pumped through a double disk refiner (not running) before passing through the mixer. When the pulp slurry passed through the refiner, it would tend to plug up the refiner and greatly restrict the flow. This was especially true with the higher consistencies. Another problem was that of obtaining an even consistency throughout the stock chest. With the amount of pulp used, levels in the stock chest were low enough that the stock agitator in the chest could not fully mix the stock with the dilution water. This condition made exact determination of consistency very difficult as samples taken from various places in the chest would often vary by 0.5% or more. For this reason, some of the consistency intervals had to be skipped.

A fourth run, using a refined hardwood, had been planned, but the pump motor on the Valley Beater burned out and made the final trial impossible.

## PRESENTATION OF DATA

The following data represents the results of the experiment attempting to correlate pressure drop across a Imco Dyna-Foil Mixer to consistency. The data was graphed in the following way for each of the pulp types: first, the data was graphed to show the relationship between pressure drop and flow rate at the various consistencies tested and secondly, the data for each pulp type was graphed to show the relationship between pressure drop and consistency at various flow rates. In graphing, it was assumed that the change between data points was linear. Included in the Appendix are tables which contain the raw data points.

The data for the unrefined hardwood pulp runs are the most complete obtained in this experiment. The graph showing the relationship between flow rate and pressure drop (Figure 7) clearly shows an increase in pressure drop as flow rate increases. For example, at 2.50% consistency and a flow rate of 120 gpm, a pressure drop of 7.7 psi occurs, while at the same consistency but at a flow rate of 42.2 gpm, the pressure drop is only 2.6 psi. There is only one instance where this result is not seen. That is in the 2.25% curve where the pressure drop decreases from 4.9 to 4.2 psi as flow rate increases from 56.6 gpm to 85.5 gpm. The high pressure drops and flow rates indicated occurred only at the low end of the consistency range because the pump used

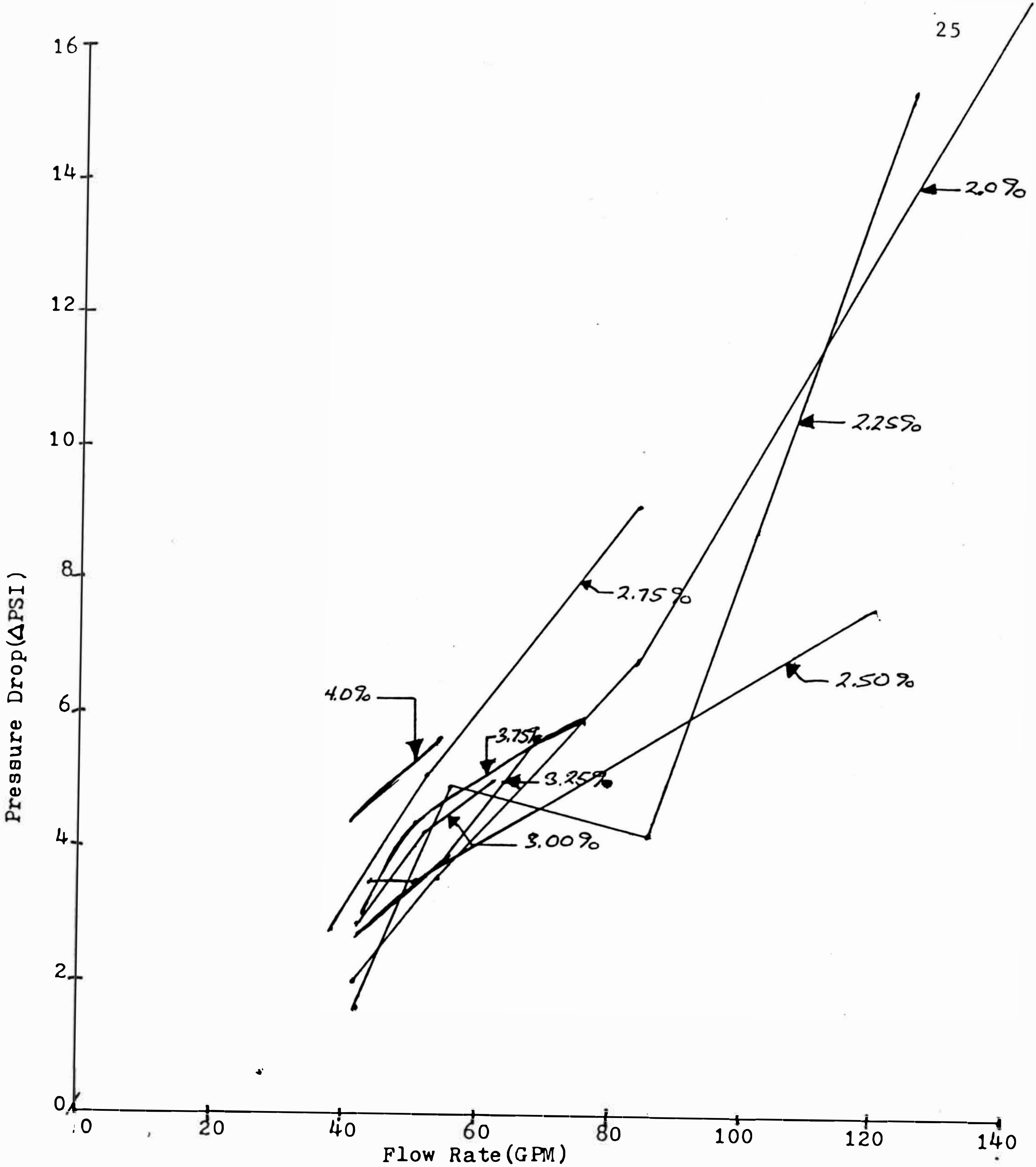



FIGURE 7

Relationship Between Pressure Drop and Flow Rate at Various Consistencies. of Unrefined Hardwood pulp.

could not pump high consistency pulps (above 2.5% for hardwood pulp) at high flow rates.

Figure 8, which shows the relationship between pressure drop and consistency at various flow rates, indicates a general decrease in pressure as flow rate goes down. This is true for the entire set of data with the exception of the high flow rate curve at 2.25% consistency where the pressure drop is 4.2 psi as opposed to a pressure drop of 4.9 psi at the same consistency but a lower flow rate. Figure 8 also shows an effect of consistency on pressure drop. However, this effect is not consistently in the same direction.

Figures 9 and 10 are for the unrefined softwood pulp run. Figure 9 shows the pressure drop flow rate relationship for the unrefined softwood pulp. This graph shows an increase in pressure drop, with increasing flow rate, that is nearly linear. This linearity can especially be seen in the curves for consistencies in the 2.5% to 3.0% range (inclusive). The actual increase in pressure drop at a similar flow rate is not the same. The largest change in pressure drop is at 2.25% and the lowest at 2.0%. This graph also shows an increase in pressure drop as consistency increases, with the exception of the 2.25% curve.

Figure 10 shows the pressure drop/consistency relationship at various flow rates. This graph shows a definite increase in pressure drop as flow rate goes up. However, the pressure drop changes very little with increasing consis-

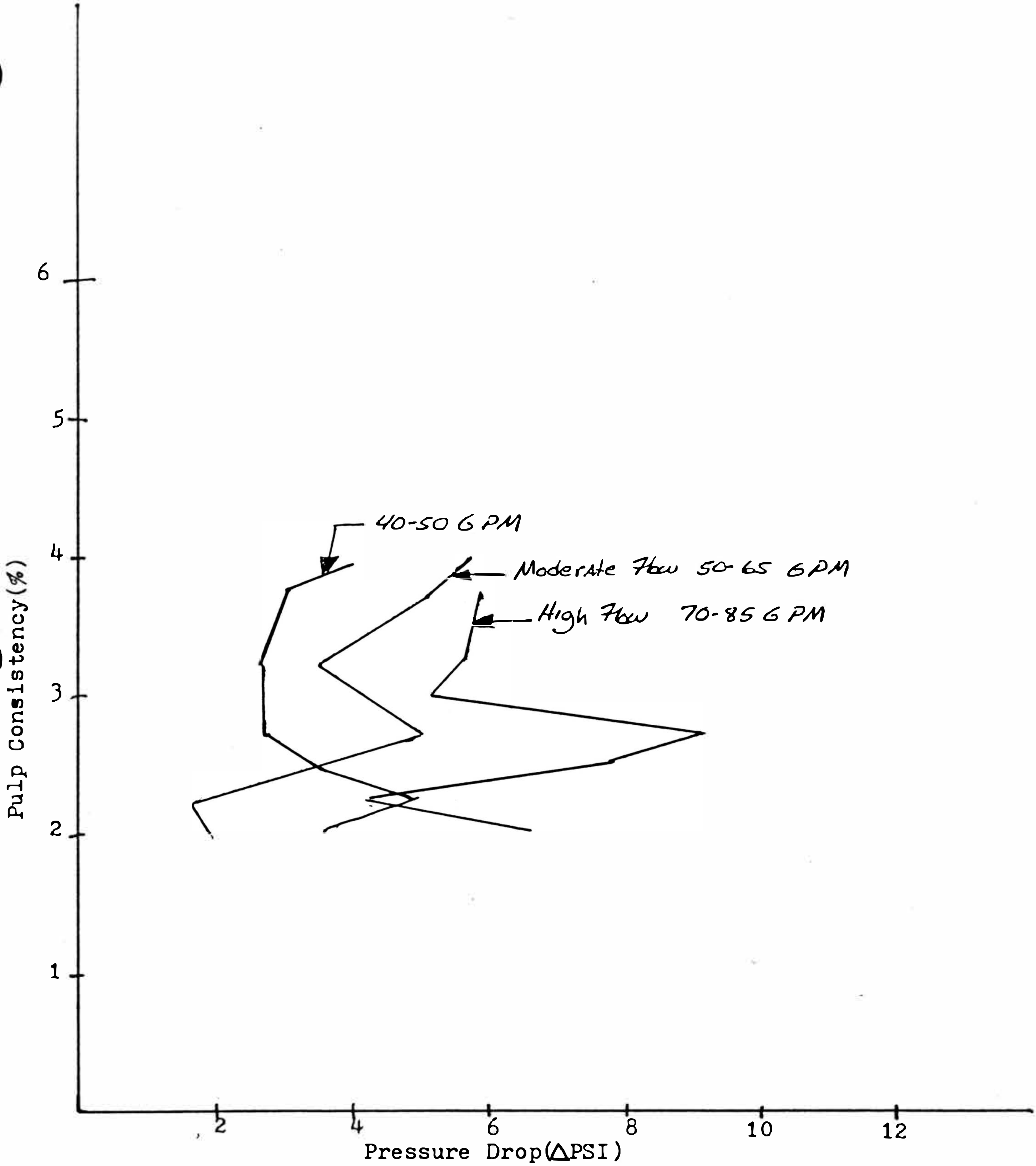



FIGURE 8
Relationship Between Pressure Drop and Consistency at Various Flow Rates of Unrefined Hardwood Pulp.

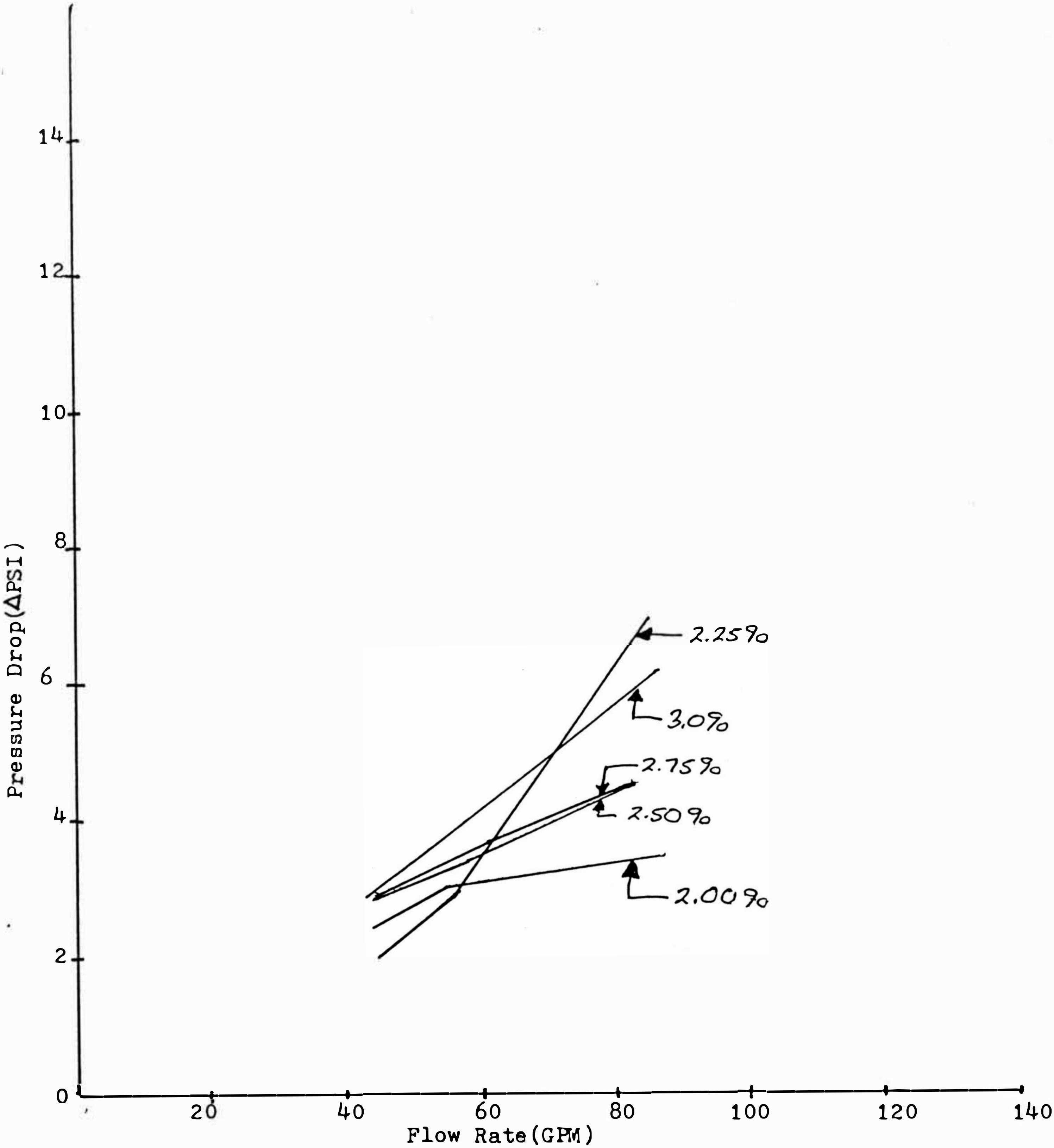



FIGURE 9

Relationship Between Pressure Drop
and Flow Rate at Various Consistencies
for Unrefined Softwood Pulp.

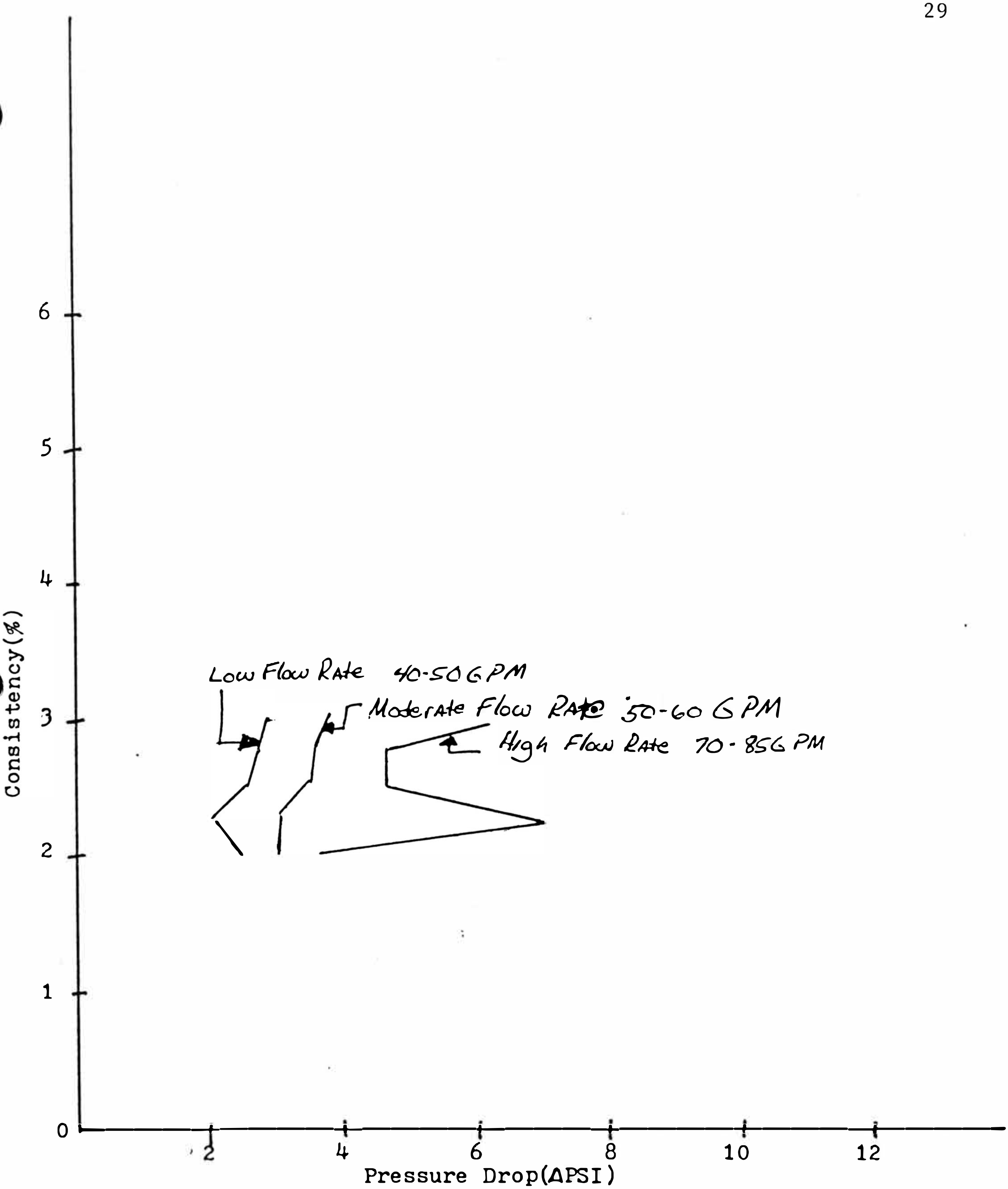



FIGURE 10

Relationship Between Pressure Drop and Consistency at Various Flow Rates for Unrefined Softwood Pulp.

tency. Low and moderate flow rate curves are nearly identical in shape. The high flow rate curve shows quite erratic changes in pressure drop with increasing consistency.

Figure 11 and 12 are for the refined softwood pulp run. Figure 11 shows the flow rate/pressure drop relationship. Once again an increase in flow rate creates an increasingly higher pressure drop. Pressure drop increases nearly linearly with increasing flow rate. Figure 11 also shows that the size of the pressure drop increases as consistency decreases. Figure 12 shows the pressure drop/consistency relationship at various flow rate ranges. Once again it can be seen that the magnitude of the pressure drop increases as flow rate goes up. This graph also shows that pressure drop increases with consistency with the exception of the high flow rate curve which shows a nearly linear drop in the magnitude of the pressure drop with increasing consistency.

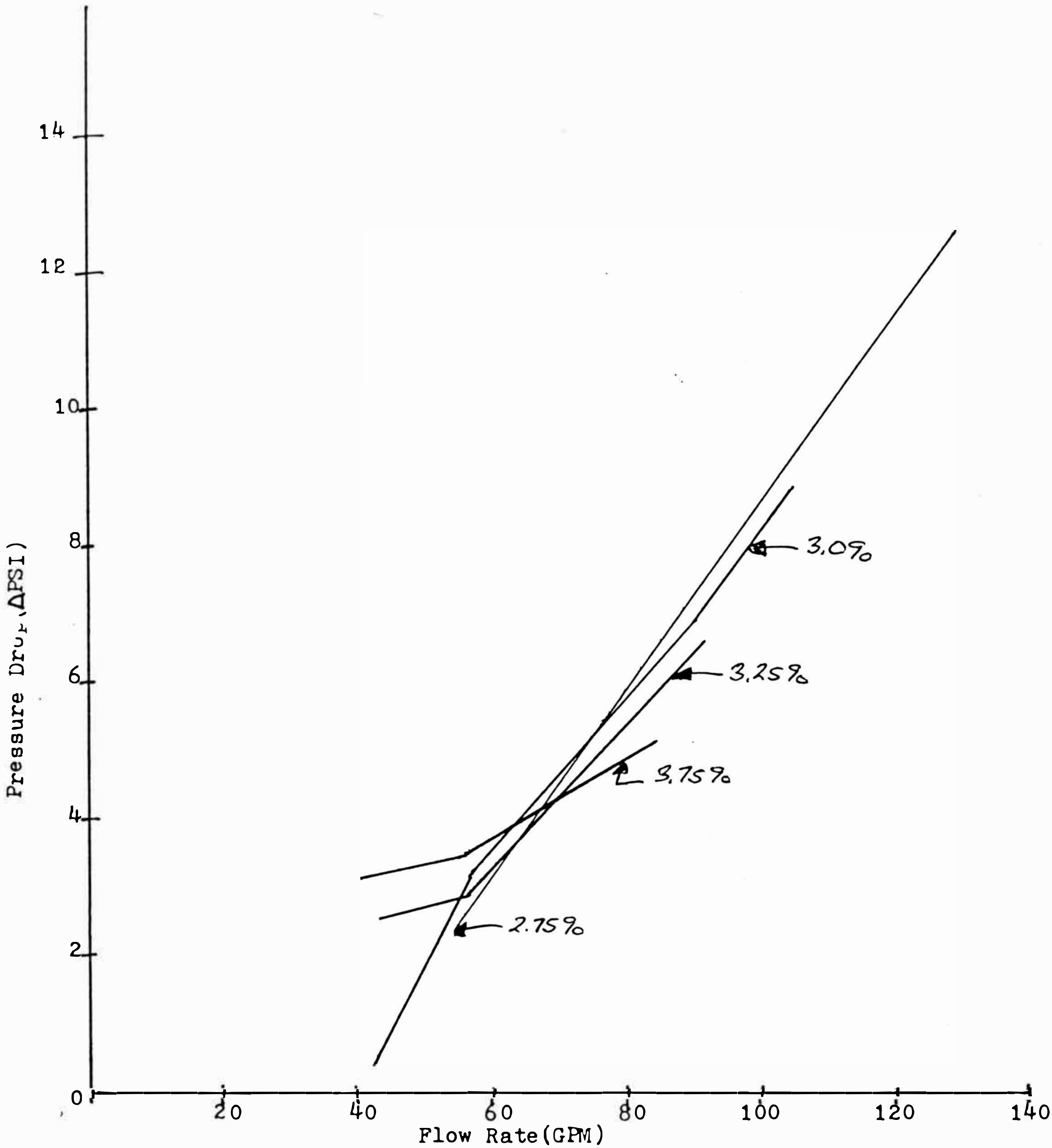



FIGURE 11
Relationship Between Pressure Drop and Flow Rate at Various Consistencies for a Refined Softwood Pulp.

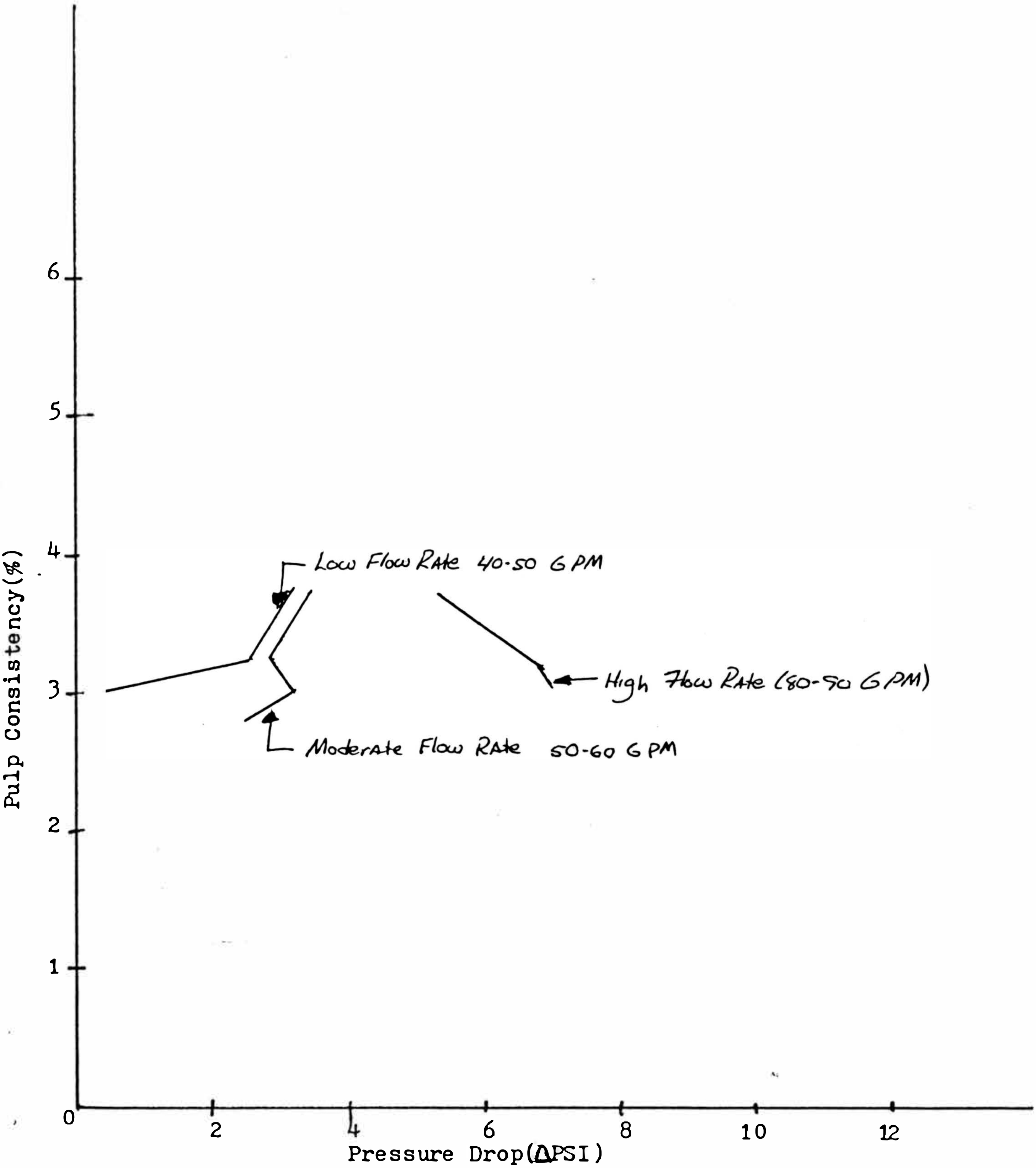



FIGURE 12
Relationship Between Pressure Drop
and Flow Rate for Refined Softwood Pulp.

## DISCUSSION OF RESULTS

The most obvious thing that can be seen from the data obtained from this project is that the magnitude of the pressure drop across the Imco Mixer increases as flow rate increases. This effect can be seen in Figures 7, 9, and 11. The only point where this is not true is in Figure 9 where at a flow rate of 85 gpm the pressure drop is 0.75 psi less than it was at the next lowest flow rate. For example, at a flow rate of 80 gpm the pressure drop is, in all but the above noted exception, always higher than the pressure drop at a lower flow rate of 50 gpm. This result of increasing pressure drop with increasing flow rate can be explained with Bernoulli's Equation. The effect of flow velocity on pressure drop is the main problem involved with development of a consistency sensor based on pressure drop measurement.

Figures 8, 10, and 12 shows the pressure drop/consistency relationships at the various ranges of flow. Figure 8, which contains the most complete set of data, shows quite clearly the pressure drop is affected by pulp consistency. For example, in Figure 8, at a moderate flow rate, each 0.25% change in consistency causes a considerable change in pressure drop. The change, however, is not always in the same direction and the direction of change seems to depend on flow rate to some extent. The unusual behavior

may be due to the fact that pulp slurries are non-Newtonian and their flow properties are effected by their consistency and by shear stresses induced during flow which are dependent on flow rate. Figure 10 and 12 also show that pressure drop is effected by consistency, but to a lesser extent. This indicates that pulp species is a factor in this type of consistency measurement. The difference in pressure drop between the hardwood and softwood pulps may be due to the fiber length differences or to the type of pulping process used.

The effect of refining is seen by comparison of Figures 10 and 12. The data seems to show that refined pulp generally experiences a lower pressure drop at low and moderate flow rates. The higher pressure drop in the unrefined, low and moderate flow runs may be due to network formation in the pulp slurry that was difficult to break up at the lower flow rates. The higher pressure drop in the refined softwood high flow rate run, as compared to the unrefined softwood run at a similar flow rate, may be due to a change in rheological properties caused by refining. At the higher flow rate, the networds are easily broken in both pulps which allows the rheological effect to show up.

# CONCLUSIONS

This experiment indicates that use of a static mixer unit as a means to imply consistency by measuring pressure drop across the mixer placed in the pulp line is not very practical. The main problem with the device was that flow rate greatly affected the pressure drop at a given consistency and that the effect of flow rate seems not to follow any pattern. This would make the calculation of a correction factor quite difficult. The pressure drop is also effected by the pulp species, a fact that would make the static mixer a poor choice for consistency measurement, especially in applications where pulp types are changed frequently or where pulps are mixed. Also, due to the fact that only three runs were made with no repeat runs, the data reported herein are not very conclusive.

## RECOMMENDATIONS

Future work in this area of consistency measurement should be done as the paper industry can always use a better and more reliable method of consistency measurement. To help insure better results, equipment designed to handle higher consistencies should be used. The equipment used in this experiment was designed to handle low (less than 2%) consistency slurries. A better method of mixing dilution water in the stock chest is also recommended. With the quantities of pulp available for this experiment, stock levels in the chest were too low for the stock agitator to do much good. This resulted in poor mixing of the dilution water in the chest. More pulp should be used to raise the level in the chest or a smaller chest should be used. Manometers were tried in this experiment, but no suitable means of keeping pulp out of the manometer tubes was available. Further work in this area should also include at least two trials for each pulp type in order to evaluate the degree of repeatability.

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# APPENDIX 1

## Pressure Drop Correction Calculations

1. Flow rate(gal/sec)x(60 sec/min)x(.13368$ft^3$/gal)=$ft^3$/min
2. Flow velocity in the 3 inch pipe=
   $ft^3$/sec x 1/cross sectional area of 3 in. pipe=$ft^3$/sec/.051$ft^2$= ft/sec.
3. Flow velocity in the 2 inch mixer unit=$V_{2in.}$=
   $V_{3in.}$(inside dia. of 3 in. pipe$)^2$/(diameter of 2 in. pipe$)^2$=
   $V_{3in.}(3.068)^2/2.067)^2=V_{3in.}(2.203)$ft/sec.
4. Conversion of pounds per square inch to kilonewtons per meter$^2$
   Psi x 6.89473 Kn/$m^2$/1psi=kilonewtons per meter squared.
   Pressure in 2 inch pipe=pressure$_{3in.}$- $\rho_{H_2O}(V^2_{2in}-V^2_{3in.})/(1000x2)Kn/m^2$
   $\rho_{H_2O}=62.43\ lb/ft^3=1000Kn/m^2$
   $\Delta P_{2in.}=P_{3in.}-((V^2_{2in}-V^2_{3in.})/2)Kn/m^2$
   and pounds per square inch in 2 inch pipe=pressure$_{2in.}$x.14498 $\frac{psi}{km/m^2}$
   In calculating the pressure correction for the reduction in pipe size, fluid friction is assumed negligible and dropped from the calculations.[5]

# APPENDIX 2

## DATA TABLE 1

### Unrefined Hardwood

| Consistency | Flow Rate (gpm) | PSI into mixer* | PSI out of mixer | Δ PSI across mixer |
|---|---|---|---|---|
| 4.00% nominal | 54.5 | 12.8 | 7.2 | 5.6 |
| 3.95% actual | 41.6 | 11.4 | 7.2 | 4.2 |
| 3.75% nominal | | | | |
| 3.70% actual | 76.8 | 12.7 | 6.8 | 5.9 |
| | 51.7 | 10.2 | 6.6 | 4.2 |
| | 41.1 | 9.4 | 6.4 | 3.0 |
| 3.50% data not available | | | | |
| 3.25% nominal | | | | |
| 3.28% actual | 69.6 | 12.0 | 6.4 | 5.6 |
| | 56.0 | 10.3 | 6.6 | 3.7 |
| | 42.2 | 9.4 | 6.7 | 2.7 |
| 3.00% nominal | | | | |
| 3.01% actual | 61.2 | 11.3 | 6.2 | 5.1 |
| | 53.6 | 10.4 | 6.2 | 4.2 |
| | 41.6 | 8.7 | 6.0 | 2.7 |
| 2.75% nominal | | | | |
| 2.77% actual | 83.4 | 15.6 | 6.4 | 9.2 |
| | 52.6 | 10.9 | 5.8 | 5.1 |
| | 39.5 | 8.2 | 5.5 | 2.7 |
| 2.50% nominal | | | | |
| 2.37% actual | 120 | 14.3 | 6.6 | 7.7 |
| | 50.8 | 8.9 | 5.4 | 3.5 |
| | 41.6 | 8.9 | 5.4 | 3.5 |
| 2.25% nominal | | | | |
| 2.20% actual | 125 | 22.4 | 7.0 | 15.4 |
| | 85.8 | 9.6 | 5.4 | 4.2 |
| | 56.6 | 10.3 | 5.4 | 4.9 |
| | 41.6 | 6.6 | 5.0 | 1.6 |
| 2.00% nominal | | | | |
| 2.02% actual | 143 | 24.5 | 7.0 | 17.5 |
| | 83.4 | 12.2 | 5.5 | 6.7 |
| | 54.5 | 8.7 | 5.1 | 3.6 |
| | 41.6 | 6.9 | 4.9 | 2.0 |

*These values have been corrected from the values measured on the three inch dia. pipe on the inlet side of the mixer to the two inch diameter of the mixer. Calculations used are in appendix 1.

## APPENDIX 3

### DATA TABLE 2

### Refined Softwood

| Consistency | Flow Rate (gpm) | PSI into mixer* | PSI out of mixer | Δ PSI across mixer |
|---|---|---|---|---|
| 3.75% nominal | | | | |
| 3.80% actual | 83.4 | 13.2 | 8.0 | 5.2 |
| | 53.5 | 10.8 | 7.4 | 3.4 |
| | 39.5 | 10.4 | 7.2 | 3.2 |
| 3.25% nominal | | | | |
| 3.18% actual | 91.2 | 14.1 | 7.4 | 6.7 |
| | 55.6 | 9.8 | 6.9 | 2.9 |
| | 42.2 | 9.4 | 6.8 | 2.6 |
| 3.00% nominal | | | | |
| 3.10% actual | 103.2 | 16.2 | 7.4 | 8.8 |
| | 88.2 | 14.1 | 7.1 | 7.0 |
| | 56.6 | 9.8 | 6.6 | 3.2 |
| | 41.1 | 6.9 | 6.5 | 0.4 |
| 2.75% nominal | | | | |
| 2.69% actual | 142.8 | 20.5 | 8.0 | 12.5 |
| | 54.5 | 8.6 | 6.2 | 2.4 |

Consistencies of 4.0%, 3.5%, 2.5%, 2.25% and 2.0% were not tested because of severe problems with mixing of the dilution water in stock chest.

*These values have been corrected from the values measured on the three inch dia. pipe on the inlet side of the mixer to the two inch diameter of the inlet of the mixer. Calculations used are in appendix 1.

# APPENDIX 4

## DATA TABLE 3

## Unrefined softwood

| Consistency | Flow Rate(gpm) | PSI into mixer* | PSI out of mixer | ΔPSI across mixer |
|---|---|---|---|---|
| 3.00% nominal<br>3.10% actual | 85.8 | 13.6 | 7.4 | 6.2 |
| | 53.6 | 10.5 | 6.8 | 3.7 |
| | 42.2 | 9.4 | 6.6 | 2.8 |
| 2.75% nominal<br>2.71% actual | 83.4 | 11.6 | 7.0 | 4.6 |
| | 55.6 | 9.8 | 6.3 | 3.5 |
| | 42.2 | 8.9 | 6.2 | 2.7 |
| 2.50% nominal<br>2.48% actual | 83.4 | 11.2 | 6.6 | 4.6 |
| | 55.6 | 9.4 | 6.0 | 3.4 |
| | 42.2 | 8.4 | 5.8 | 2.6 |
| 2.25% nominal<br>2.21% actual | 143.0 | 20.5 | 7.4 | 13.1 |
| | 83.4 | 13.1 | 6.2 | 6.9 |
| | 56.6 | 8.8 | 5.8 | 3.0 |
| | 42.8 | 7.4 | 5.4 | 2.0 |
| 2.00% nominal<br>1.97% actual | 150.0 | 20.1 | 8.0 | 12.1 |
| | 85.8 | 9.1 | 5.6 | 3.5 |
| | 54.5 | 8.3 | 5.4 | 2.9 |
| | 42.8 | 7.7 | 5.3 | 2.4 |

Consistencies above 3.0% were not pumpable in the piping system used.

*These values have been corrected from the values measured on the three inch dia. pipe on the inlet side of the mixer to the two inch diameter of the inlet of the mixer. Calculations used are in Appendix 1.