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The Kenics Static Mixer as a Consistency Sensor

Bruce P. Marling
Western Michigan University

THE KENICS STATIC MIXER
AS
A CONSISTENCY SENSOR

by

Bruce P. Marling

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ABSTRACT

Ever since the inception of paper machines in the industry, the problem of consistency has troubled production efforts. Present sensors are sensitive to flow rate, temperature, additives and freeness as well as consistency. In spite of claims made by various manufacturers, there is still not an instrument on the market guaranteed to maintain calibration for identical uses from mill to mill. From the open type to closed type, sampling or continuous measurement type, each has its problems. A Kenics Static Mixer was evaluated in the Western Michigan University pilot plant for possible use as a consistency sensor. Research on the Mixer indicated it may measure consistency very well. Flow, of course, affects the pressure drop across the Mixer, but freeness does not seem to. More research needs to be done with different pulps at varying freenesses and flows with the use of additives and using a greater range of consistencies.

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INTRODUCTION

Consistency is one of the most important variables to control in making paper. Prior to the paper machine, consistency affects pulping, screening, washing, bleaching, beating, refining, cleaning, storage, pumping, repulping, and saveall operation. However, the final outcome, quality paper, is affected the greatest by consistency control. Consistency directly affects basis weight, which, in turn, affects tensile, tear, fold, mullen, and breaking length, wet end drainage, drying and many other characteristics in minor ways. So problems most see as basis weight control are, more than likely, consistency control problems. It is in consistency control that much money and effort has been spent by the paper industry and its suppliers(1). However, even with all the research done, there are still instances in which regulators in identical uses and positions do not perform the same(2). A brief overview of consistency regulators and their history will give better insight to the problems the paper industry faces.

HISTORY

There are two main categories of consistency transmitters; full-stream and sample. The sample devices are then divided into two types; atmospheric open-box and pressurized. The open-box type is either of the constant head or the constant velocity variety. The constant head variety measures the pressure necessary to maintain a constant flow through a viscosity tube. This is

then related to consistency. The constant velocity variety measures how much force is necessary to keep a paddlewheel turning at a constant velocity. This force is related to control the consistency. Pressurized types are used when the flow is too high for a given instrument. Any full-stream device may be used for this purpose. In all of the sampling types, the sample is usually returned upstream of the sample line. Figures 1 through 3 illustrate the three types of sample consistency transmitters(3).

Full-stream consistency transmitters are placed in the "main stream flow" so that they measure, essentially, 100% of the stream. The two types, atmospheric or open-box, pressurized or in-line, operate much like their sampling counterparts. The open type is of the constant velocity type described in the sampling category. However, lag time is greatly reduced because the consistency can be measured very close to the dilution point. Moreover, a completely closed system results, reducing piping costs, aeration of pulp and fiber bundling. Of the many devices used to measure in-line consistency, most measure shear force on a moving or stationary element. Moving element types include rotors with involute ribs, a smooth rotating disc, and a rotating threaded shaft. Stationary elements used are a pegged rod with the rod parallel to the flow, a probe perpendicular to the flow and a scimitar blade at an angle to the flow. Figures 4 through 10 illustrate how each instrument is placed in the piping and the essential parts of each(3).

The last type of consistency sensor measures head loss through a section of piping. The only added instrumentation is a differential

pressure transmitter to measure the head loss and send it to a controller. This head loss can be amplified by using a Static Mixer. Figure 11 shows the basics of such a sensor and a cut-away view of a Kenics Static Mixer(4).

All of the discussed sensors have their good and bad points. Sampling types do not take a 100% sample and may not obtain a uniform distribution of the stock tested. Personal experience has shown both in-line and sampling sensors are costly, especially with support instrumentation and maintenance problems. Head loss types may plug if not used correctly and must be used in line with a flow meter.

All in all, there is quite a bit of difference of opinion among instrument suppliers as to which is the best way to measure consistency. Foxboro's blade type, Fischer & Porter's probe type and DeZurik's involute disc are the three main ones used today. One user has stated that they may all be wrong in application of theory(5). Quite obviously, there is a problem. The five major commercial consistency sensors operate on an inferential principle, namely the measurement of shear force on either a fixed or rotating element(5). Although the head loss sensors infer consistency, too, perhaps they do it better. By experimentally testing the Kenics Static Mixer, using controlled freenesses and varying consistency, the Mixer may be proven better than the other types.

THEORY OF THE MIXER

The Kenics Static Mixer consists of sections of pipe (the

ones used were one foot long) with twists of steel welded into each section. Each twist is left or right handed and is twisted 180 degrees (Figure 11-1)(4). In each pipe section, every other twist is right handed and the remainder are left handed. Thus, a substance flowing through the Mixer encounters a twist one way, then the other. This splits the flow. After encountering just 5 twists, or elements, the substance has split its flow 32 times (Figure 11-2)(4). From section to section, the Mixer is also matched with a left to right or right to left change in element twists, so the flow continues mixing throughout the Mixer. Moreover, the substance flowing through the Mixer is rotated while the rest of the mixing is taking place (Figure 11-3)(4). Thus, because of the turbulence and mixing caused by the static obstructions in the pipe, the name Static Mixer was coined.

The theory behind the use of the Mixer as a consistency sensor comes from the shearing affect exerted by each static element on the paper fibers. This shearing affect shows up as a pressure drop or head loss across the Static Mixer. The greater the consistency, the greater the amount of fibers that are affected by the shearing force, which causes a higher pressure drop. Unfortunately, the greater the flow, the greater the shearing force affects each fiber, resulting again in a higher pressure drop. Obviously, this creates a problem. In order to adequately insure that the Kenics Mixer will work as a consistency meter, a relationship must be found between the response to consistency and the response to flow that the Mixer will make.

THEORY OF STOCK FLOW IN PIPES

In the last 25 years a great deal of research has contributed greatly to our knowledge of stock flow in pipes. At the University of Maine, relationships between flow rate, friction losses in pipe lines, consistency and pipe sizes gave the paper industry information that has since proven itself invaluable to piping and pump system designs(6)(7)(8). The second breakthrough came from Beloit Research in Wisconsin. By the use of an annular purge impact tube, stock flow, from wall edge to center line, in pipes has been studied(9).

University of Maine's work has led to friction factors for different pulps. This relates the shear force acting on the pulp from the pipe wall to consistency, flow rate, and pipe size. This wall-to-fiber shear force is responsible for head loss in pipe lines(6)(7)(8). Beloit's work brought out another type of shear force and its affect on stock flow. Fiber-to-fiber shearing is the result of fiber interaction. Moreover, this shearing breaks down at a yield stress point. Thus, the stock forms an annulus plug which decreases in diameter and flattens with decreasing consistency and increasing velocity. This type of flow is evidence that the flow of paper stock is analogous to Newtonian fluid turbulent flow characteristics. However, even though much work has been done, the data are not complete and more research is needed(9). Meanwhile, practical experience by Goulds Pump Corporation has given rise to great confidence in the work done at the University of Maine, as well as more research to back that work(10).

Thus, due to this research, there is now available to the paper industry data and formula relating consistency to flow rate, pulp type, and pipe size.

EXPERIMENTAL PROCEDURE

In the pilot plant at Western Michigan University, in the main broke chest after the beater, there is a piping system used to refine the pulp. This system may be used for recirculation or refining or both. See Figure 12 for an outline of the system. It is in this system that three Kenics Static Mixer Modules were added. The research was designed for the following:

1. Consistency at three freeness levels.
2. Flow rate the same for all measurements.
3. The consistency to be measured by two pressure gauge readings, one before and one after the Modules (Bourdon Tube Type Gauges, 0-50 psig).
4. Only 100% hardwood pulp to be used.
5. At least six consistencies to be tested.

With this in mind, additions of piping, mixers, gauges and valves were made as shown in Figure 13.

Each joint was teflon taped and each gauge piglet was filled with water prior to the day's run. The measurements took place over a four day period.

The mixer itself consisted of three 12 inch long segments screwed together. The inside diameter was 1.0 inches. Care was taken to screw the correct ends together to insure the left to right

to left continuity of the static inserts. Due to the screwed ends, overall length of the mixer was 2.7 feet long.

The procedure for each measurement was as follows:

1. Turn on agitator for five minutes and then turn off.
2. Take sample as low in the tank as possible and agitate with dipper before pulling it out.
3. Run Canadian Standard Freeness and consistency test twice and record results.
4. Turn on agitator and pump making sure valves are in re-circulation positions.
5. Close main line valve off to the mark.
6. Check flow on Mixer line at 12.25 seconds/two gallons of stock. (Stop watch and bucket technique)
7. Close or open end valve until desired flow obtained.
8. Record both gauge readings.
9. Open end valve.
10. Open main line valve. Close it and open it again to be free of plugs.
11. Turn off pump and agitator.
12. Add Dilution Water.
13. Go to Step 1.

For clean up at end of run only the following procedure was followed:

1. Sewer pulp and clean tank.
2. Flush lines entirely with pump on.
3. Remove and clean piglets with water.

RESULTS

From the Experimental Procedure, the data shown in Table I was generated. As consistency decreased, head loss decreased. This agrees with theory (See Appendix). However, as shown in Figure 14, the head loss did not correlate exactly with theory. The data curves pass through the theoretical curve but on a greater slope of approximately 2:1. Moreover, three of the data points generated did not fall on the curve.

All the data generated did not agree with theory. The 600 freeness stock did not exhibit a decrease in head loss until it was at 0.97% consistency. From 2.4 to 1.32% consistency it stayed the same, then rose. The 350 freeness stock increased from 1.07 to .71% consistency.

Figures 15 and 16 relate the inlet pressure and outlet pressure, respectively, to consistency. These show that both pressures increase as consistency decreases. There are plateaus in the graphs, but no pressure decreases corresponding to consistency decreases.

TABLE I

DATA FROM EXPERIMENTAL PROCEDURE

CONS	CSF	PSI	PSI	dPSI	CONS	CSF	PSI	PSI	dPSI	CONS	CSF	PSI	PSI	dPSI
%B.D.	mls	ONE	TWO		%B.D.	mls	ONE	TWO		%B.D.	mls	ONE	TWO	
					3.0	330	28½	11	17½					
2.4	615	29	14	15	2.66	342	29½	14	15¼	2.4	210	29½	14	15½
2.05	605	29½	14½	15										
1.72	590	30½	15½	15	1.73	350	30½	16	14¼	1.58	240	30½	16	14½
1.42	592	31	15½	15½	1.4	355	30¾	17	13¾					
1.32	610	31	15¼	15¾										
.97	600	31	17	14	1.07	350	31¼	18¼	13	1.09	215	31	17	14
.87	600	31½	18	13½						.93	225	31½	18¼	13¼
.75	600	31½	18	13½	.71	350	31½	18¼	13¼					
										.545	225	31½	19¼	12¼

DISCUSSION OF RESULTS

The data show that the Kenics Static Mixer is insensitive to freeness. However, they do not show how sensitive the gauge readings were to flow rate. While taking the measurements, the end valve was varied. As it was varied, flow varied. The pressure readings needed only a tenth of a second change in flow rate to vary drastically. This showed the Mixer to be very sensitive to flow rate. Since this is true, data variations could have resulted from inaccurate flow measurement. A flowmeter would have been much more accurate than the bucket and stopwatch method used. Overall, however, the data show that the Kenics Static Mixer is sensitive to consistency variation. More research needs to be done to show if it is sensitive enough, however.

There were a few problems that arose with the use of the Mixer. Some may prohibit the use of the Mixer as a feasible instrument in paper mills. The worst problem was the plugging found after the Mixer was disassembled. Some stock was in each module. It was not known if the stock plugging occurred before, during, or after data were taken. It could have affected the data. Therefore, each run should be made in one day and the system should be disassembled and cleaned at the end of each run. Because of the nature of the stock plugging, it could keep the Mixer from being feasible in a mill. Lines that plug are useless and dangerous. However, use of larger diameter static mixer modules should prevent this. Other problems included stock plugging the pigtail on one of the gauges, vibration from the pump causing the

gauges to shake, and valve plugging. The plugging was taken care of by cleaning after each run, while vibration can be eliminated by using pressure transducers instead of gauges mounted on the piping.

There is a distinct need for further research in this area, both to validate the data taken, and to test other furnishes. With additional information, the Kenics Mixer could very well turn consistency measurement into reliable instrumentation.

As related in the Appendix, the data taken did not agree with theory. There are a few explanations for this. The equations used show the density equal to 62.4 lb/ft^3 at all consistencies. This was assumed to be constant by the Gould Pump Manual. Since it was not measured, it is not known if it varied or not. In Paper Technology classes, a value of 1gm/ml was assumed for both pulp and water densities at low consistency stock. This means that specific gravity does not change. Obviously, something affected the data, and affected it quite uniformly at all three freenesses. It could be that the specific gravity did affect it.

Another affect on the data could have been the calculation of the Reynolds Number from the Darcy friction factor. Read from the Kenics Data Table, it was assumed that there was laminar flow in all cases. If this were not so, it would drastically affect the figuring of the Reynolds Number, which in turn would affect the reading of K (K directly affects the theoretical pressure drop). Because the viscosity of the pulp at different consistencies was not known, the Reynolds Number could not be figured directly

from the formula given by Kenics. Therefore, the curve is, at best, a good estimate. But it is also a wise estimate in that flow at 3.7 feet per second is usually laminar. All in all, the theoretical data agrees with the trend the actual data follows; an increase in consistency is indicated by a higher pressure drop. However, because the slope of the theoretical curve did not agree with the slope of the curves of the actual data, the validity of both needs to be verified.

CONCLUSIONS

The results of the experiment display a trend showing consistency to be related to pressure drop across the Kenics Static Mixer. Although the trend did not conform exactly with theory, it demonstrates the possibility of the use of the Static Mixer as a consistency sensor. The data are too incomplete and the research has barely skimmed the surface of the in-depth study needed for evaluation of the Mixer as a consistency sensor.

RECOMMENDATIONS

During the research, problems came up which must be looked out for if reliable data is to be obtained. Moreover, the research did not cover much of the scope of consistency problems in a mill. The following general recommendations are made:

1. Use gauges which do not need piglets and are less sensitive to vibration. Paper Machine Components makes an inline sensor which can be connected to post mounted gauges. The stock number is PMC-PT-100#-N-Ti-S matched pair at $121.00 each. The sensors require an air supply that is identical, so a "Y" or "T" splitter is required in the supply line. See Appendix, Supplementary Information Page.
2. Clean the valves, piping, and mixer after each run.
3. Do a run in one day, not in two or more. This makes sure that the piping will not plug up.
4. Run through the procedure five times before taking any data. This insures that a consistent procedure is set before data goes on paper.

Additional research is needed in these areas:

1. Different pulps (softwood, blends, groundwood, different woods, different pulpings of woods).
2. Filler affects.
3. More research in different freenesses.
4. A greater range of consistencies.

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APPENDIX

The Kenics Manual provides an instant (estimated) readout of pressure drops at certain flows and pipe sizes. However, this does not help when applied to pulp slurries. Moreover, the information given is insufficient when using the available formula, so an outside source is required. The Gould Pump Manual supplied all additional equations and, with some common equivalence constants, a theoretical curve was generated, relating consistency to head loss.

The following are equations used in generation of the data. The log-log curves used are available in the above mentioned sources (4) (10).

$$V = \frac{Q \times 0.321}{A_{ID}}$$

$$R_e' = \frac{\left(\frac{D}{12}\right)^{0.205} V \rho}{\left(C_{AD}\right)^{1.157}}$$

$$\Delta P = \frac{f V^2 L K (2.31)(12)}{D}$$

$$N_{RE} = \frac{L Q^2 (64)(1.35 \times 10^{-2})}{\Delta P D^5}$$

$$\Delta P_{KM} = K \Delta P$$

$$\Delta P_T \approx \Delta P_{KM} + \Delta P$$

A_{ID}= Cross sectional area of pipe

C_{AD}= Air dry consistency

D= Inside diameter of pipe

f= Friction factor (Goulds)

K= Pulp constant (1.20)

L= Total length of modules (2.7)

N_{RE}= Reynolds number

ΔP= Pressure drop for pipe (psi)

ΔP_{KM}= Pressure drop for modules (psi)

ΔP_T= Pressure drop for modules and pipe length between gauges

ρ = Density of stock (assumed to be 62.4 lb/ft

R_e'= Pseudo Reynolds Number

Q= Flow rate (G.P.M.)

V= Flow (ft/sec)

TABLE II

Consistency of 100% Northern Hardwood Kraft as it relates to Head Loss in a 1" Pipe Line and a 1" Kenics Static Mixer

CONSISTENCY (%)		HEAD LOSS (p in psi)		
Bone Dry	Air Dry	Empty Pipe	Kenics Mixer	Total Loss
3.0	2.7	1.764	21.43	23.19
2.66	2.4	1.424	19.19	20.61
2.4	2.16	1.190	17.71	18.90
2.05	1.84	0.871	15.47	16.34
1.73	1.56	0.638	13.82	14.46
1.62	1.46	0.563	13.27	13.81
1.58	1.42	0.542	13.15	13.69
1.42	1.28	0.457	12.52	12.98
1.4	1.26	0.446	12.45	12.90
1.32	1.12	0.351	11.67	12.02
1.09	0.981	0.276	11.09	11.32
1.07	0.963	0.266	11.00	10.87
0.97	0.873	0.223	10.60	10.82
0.93	0.837	0.208	10.48	10.69
0.87	0.783	0.185	10.27	10.45
0.75	0.675	0.140	9.75	9.87
0.71	0.639	0.128	9.67	9.80
0.545	0.4905	0.0956	8.03	8.14

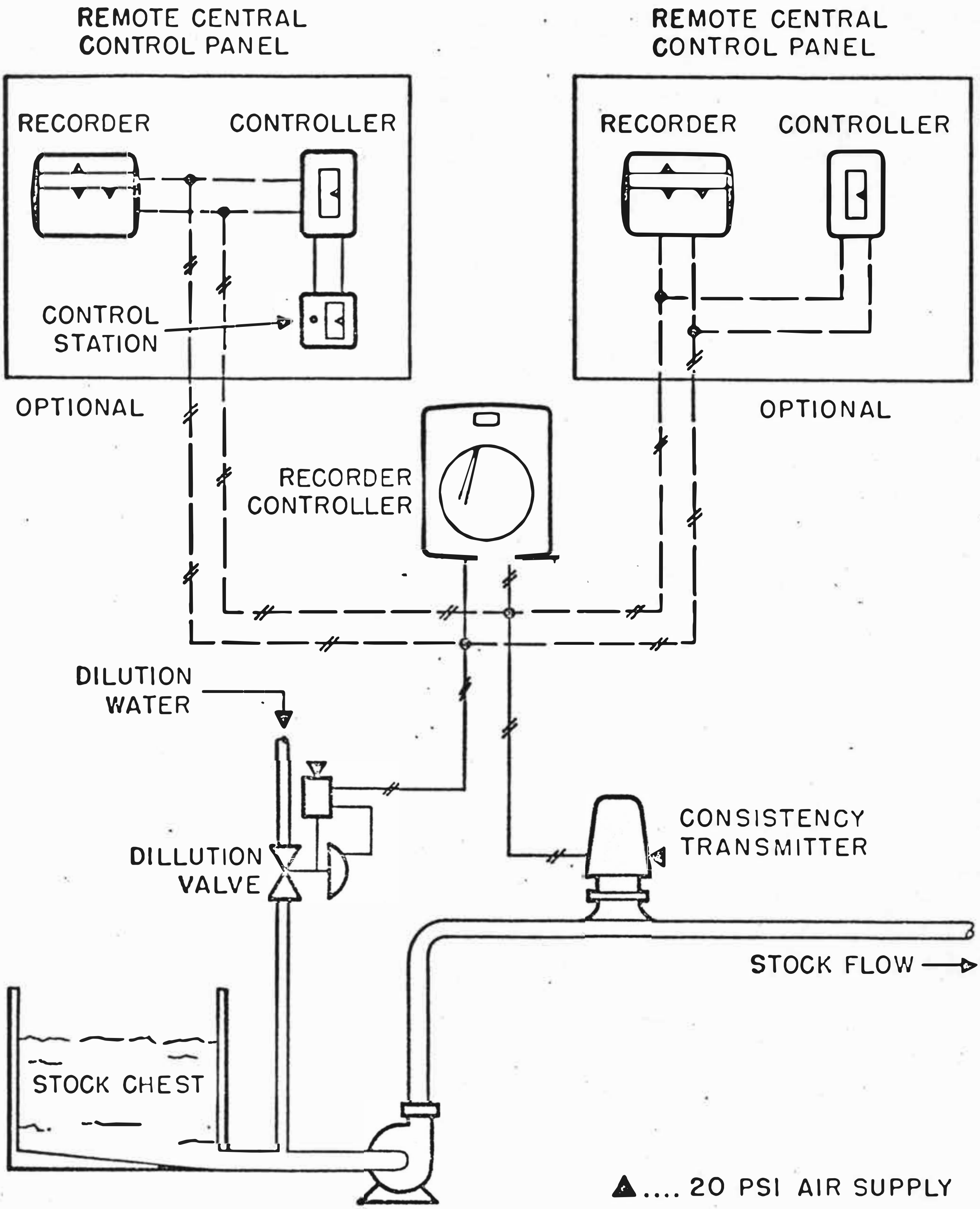
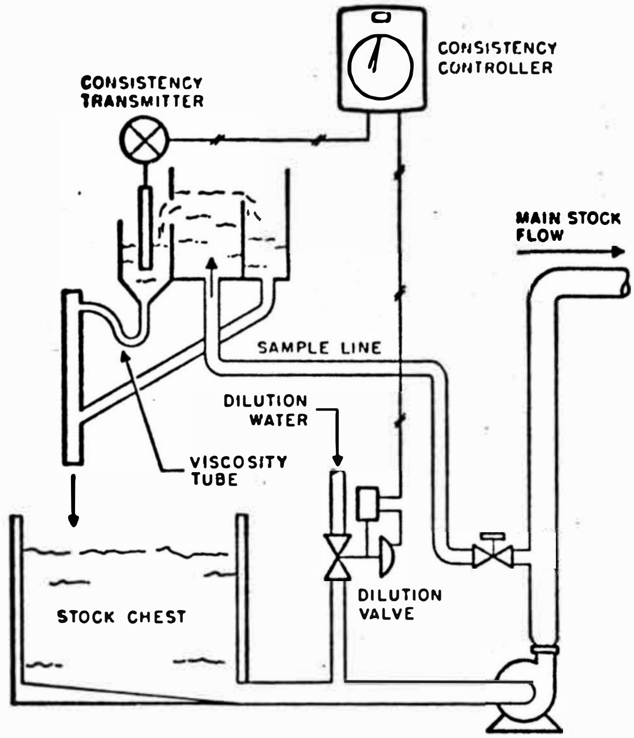


Figure 1 -- Typical Consistency Control Loops



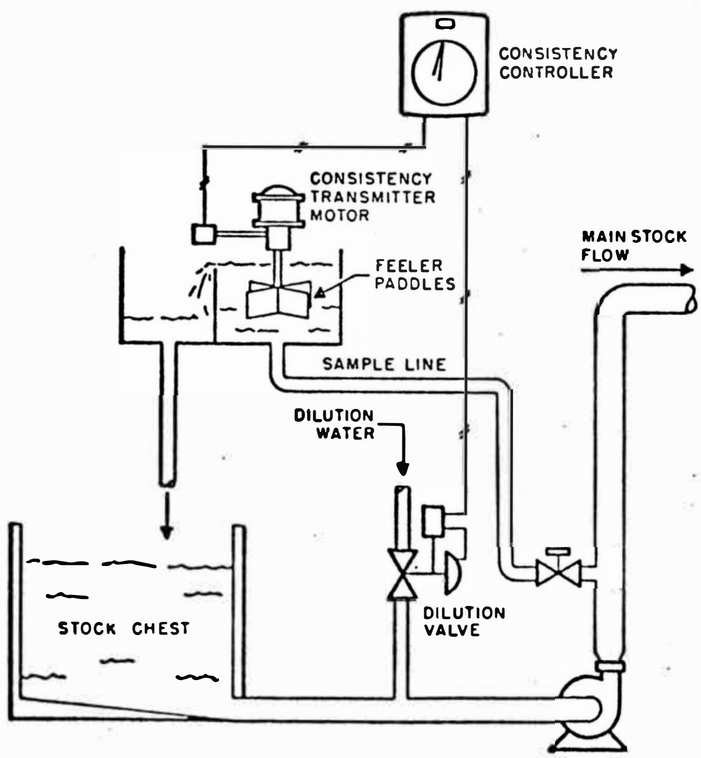


Figure 2 -- Open Box Sample Type Consistency Transmitters

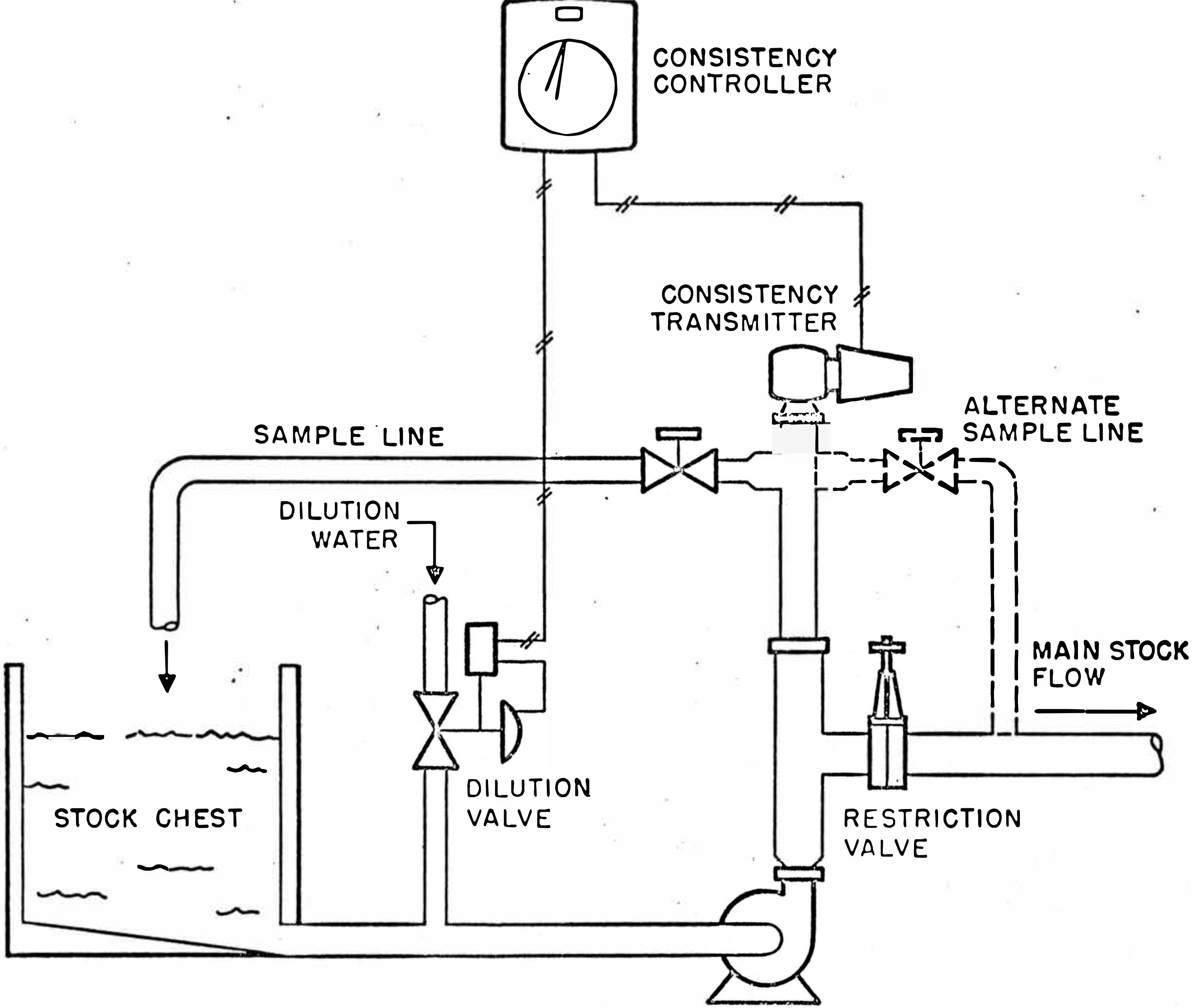


Figure 3 -- Pressurized Sample Type Consistency Transmitter

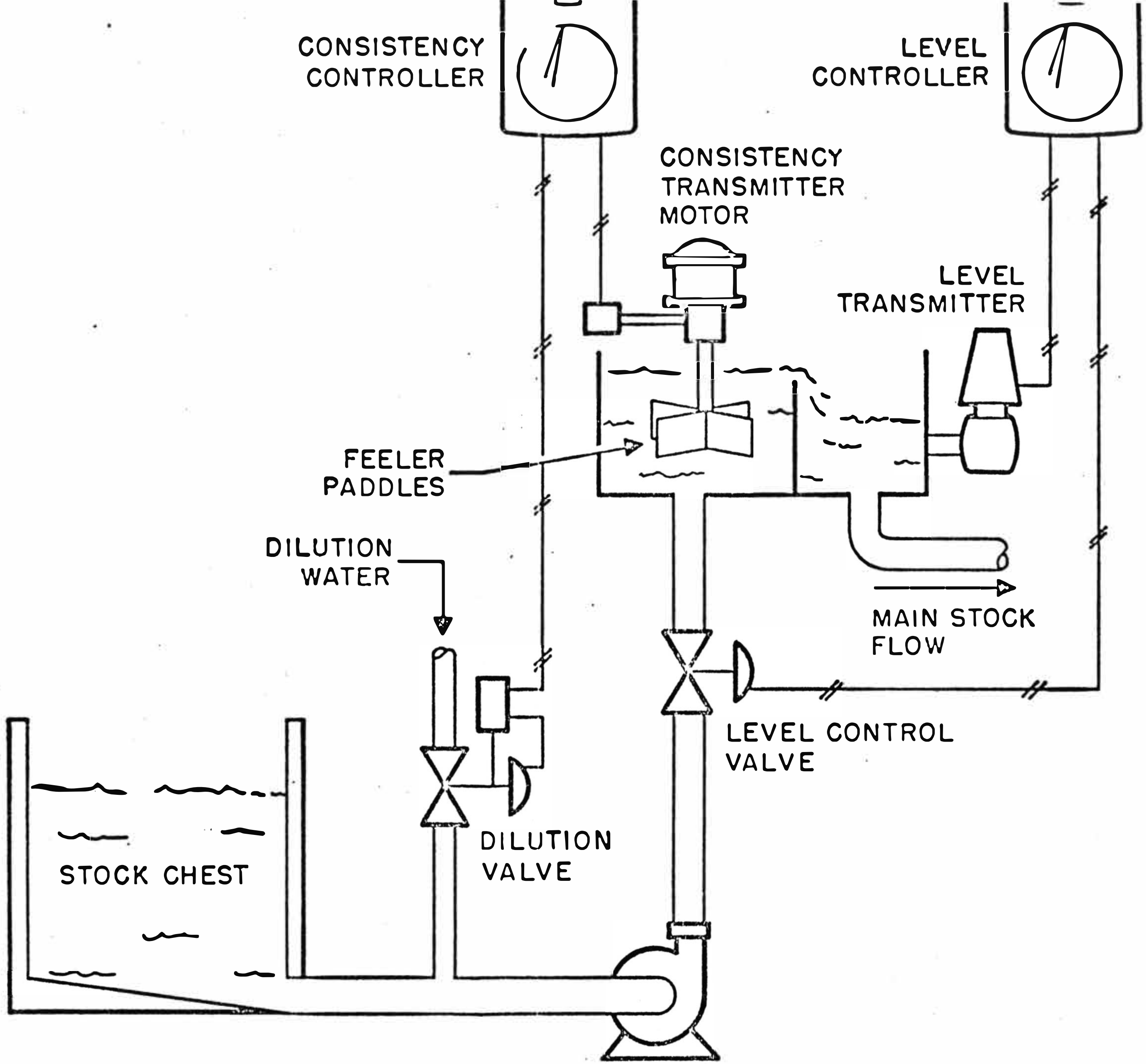


Figure 4 -- Open Box Full-stream Type Consistency Transmitter

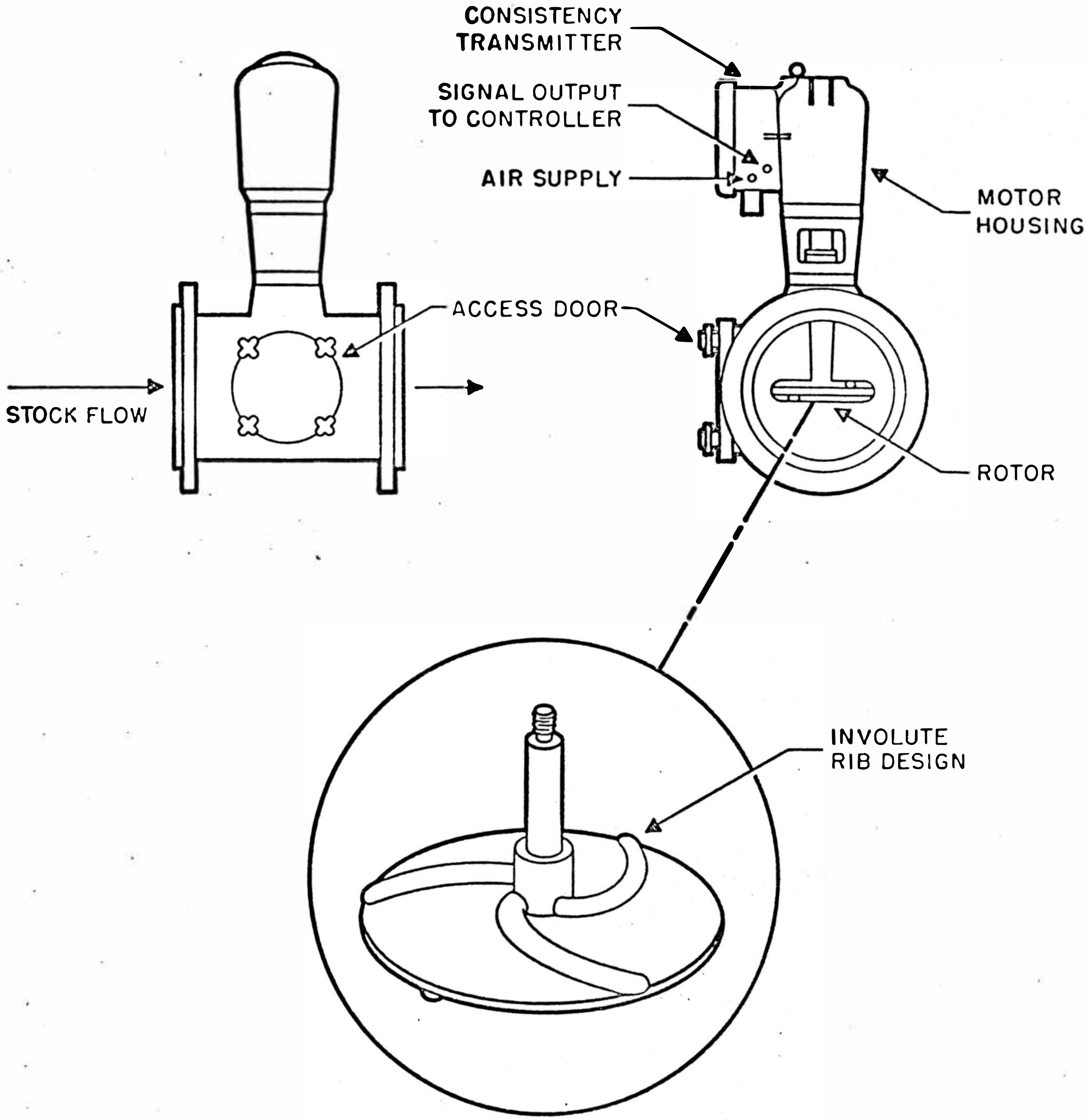


Figure 5 -- Pressurized In-line Rotating Sensing Element Type Consistency Transmitter

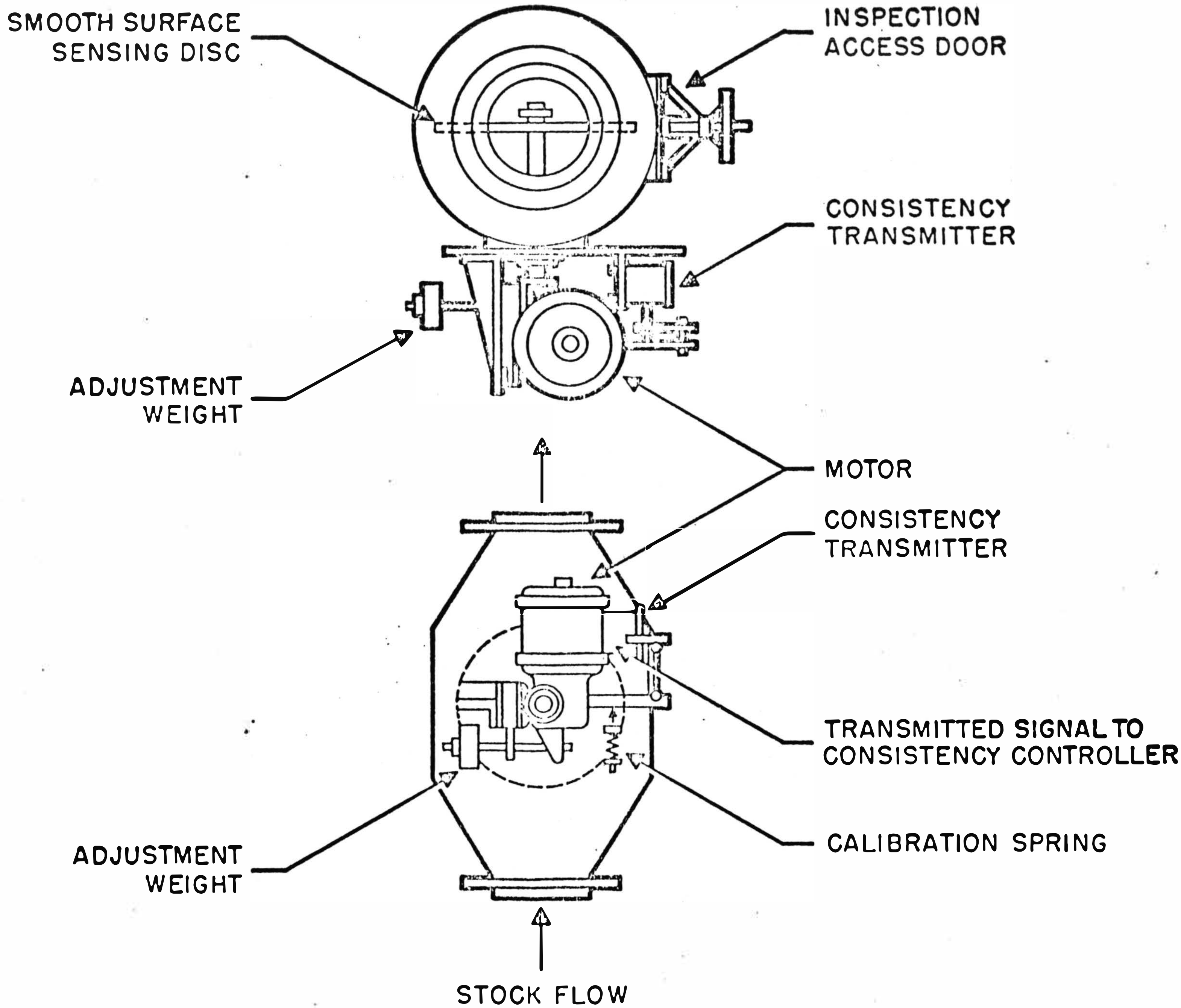


Figure 6 -- Pressurized In-line Rotating Sensing Element Type Consistency Transmitter with Smooth Surface Sensing Disc

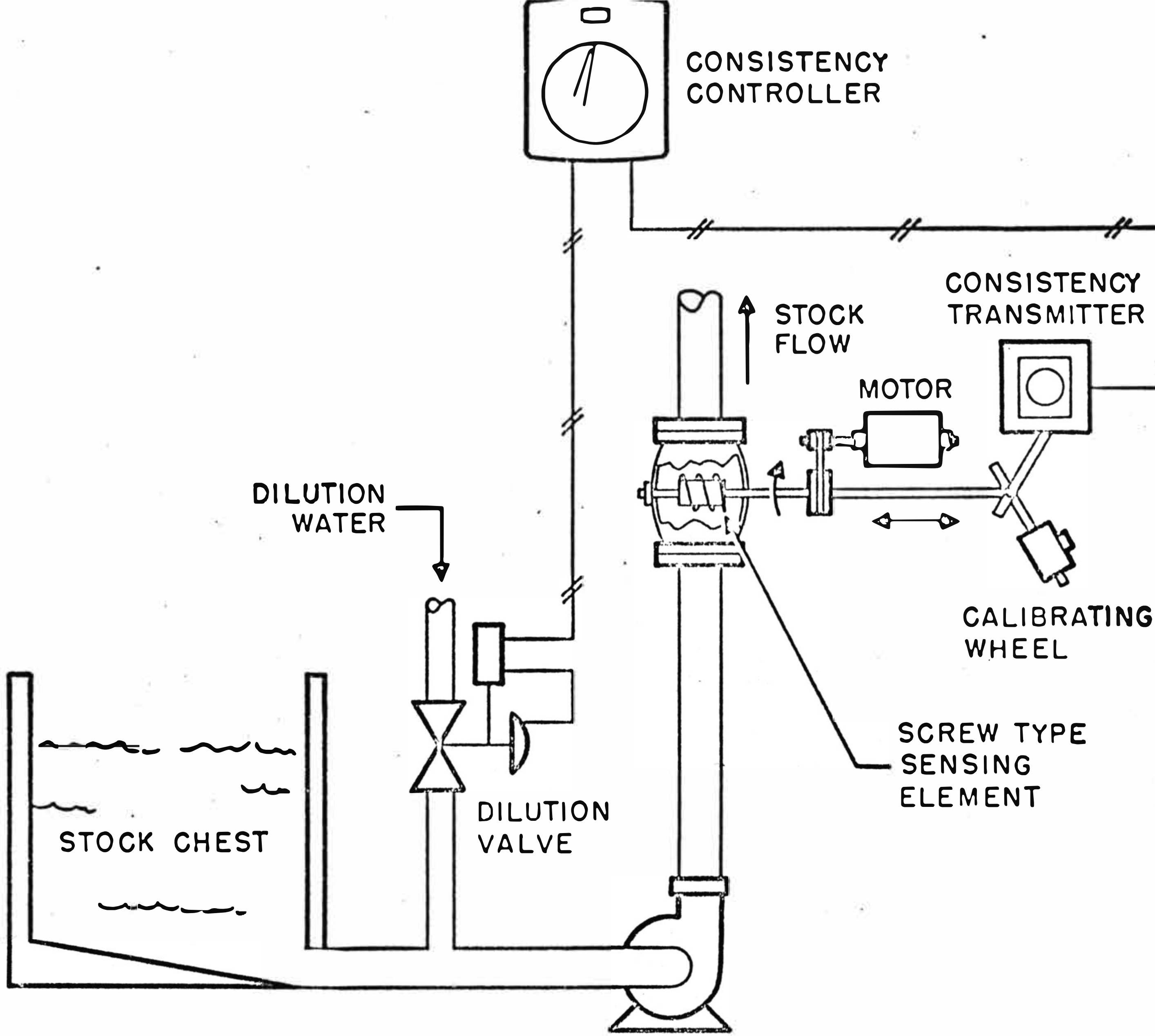


Figure 7 -- Pressurized In-line Rotating **Sensing Element Type** Consistency Transmitter with **Screw Type Sensor**

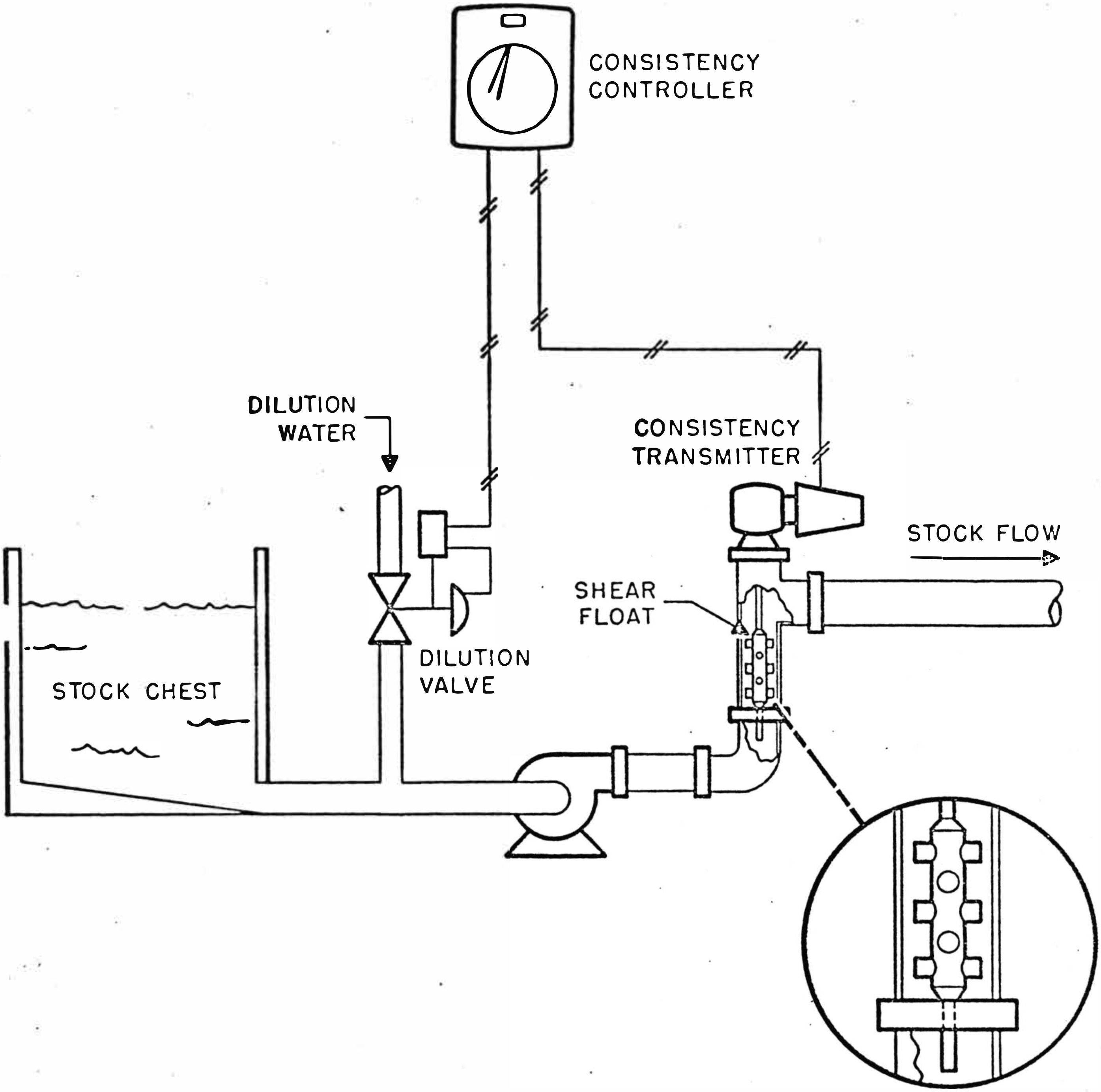


Figure 8 -- Pressurized In-line Stationary Sensing Element Type Consistency Transmitter -- Pneumatic Transmission

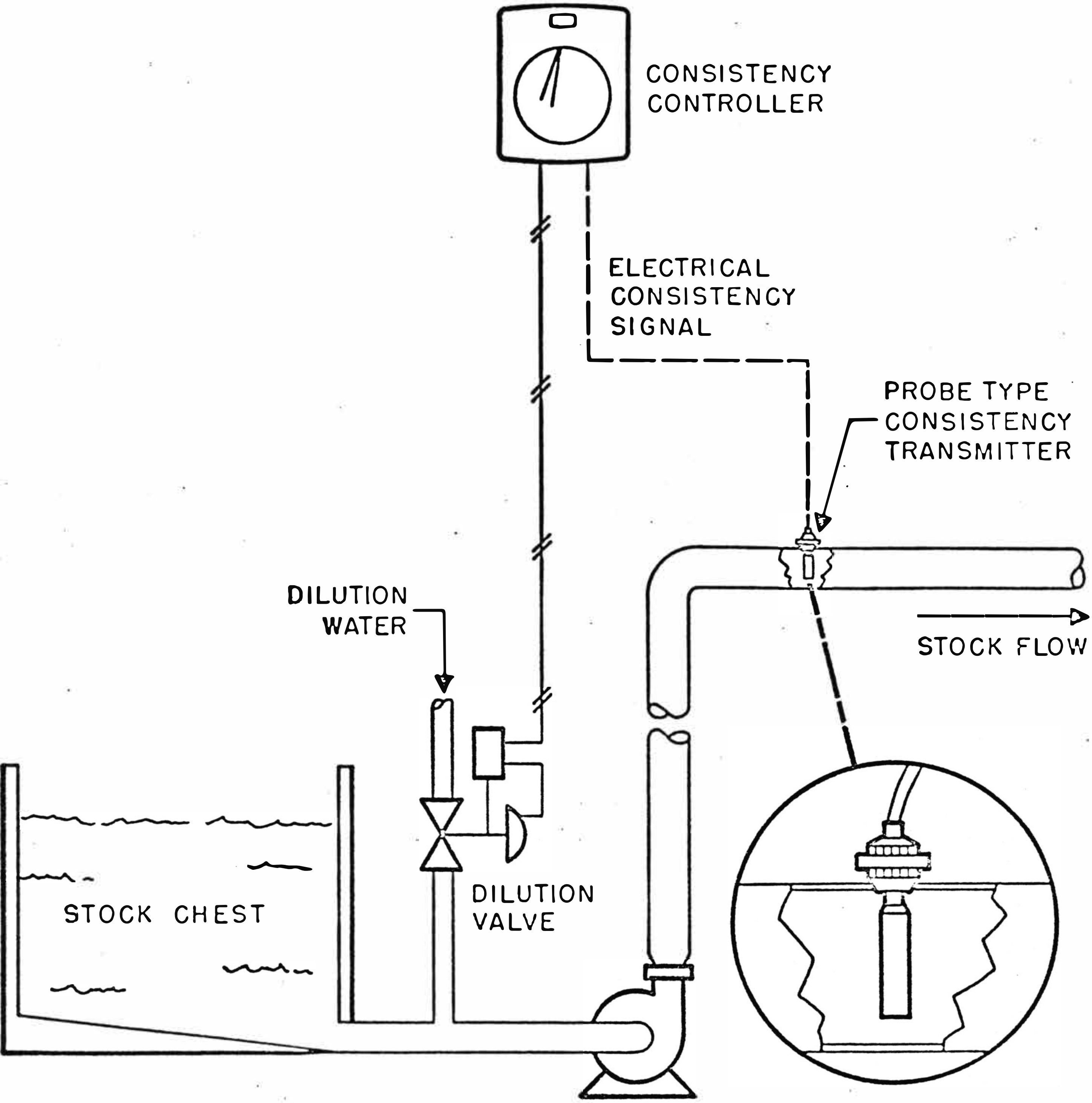


Figure 9 -- Pressurized In-line Stationary Sensing Element Type Consistency Transmitter -- Electrical Transmission

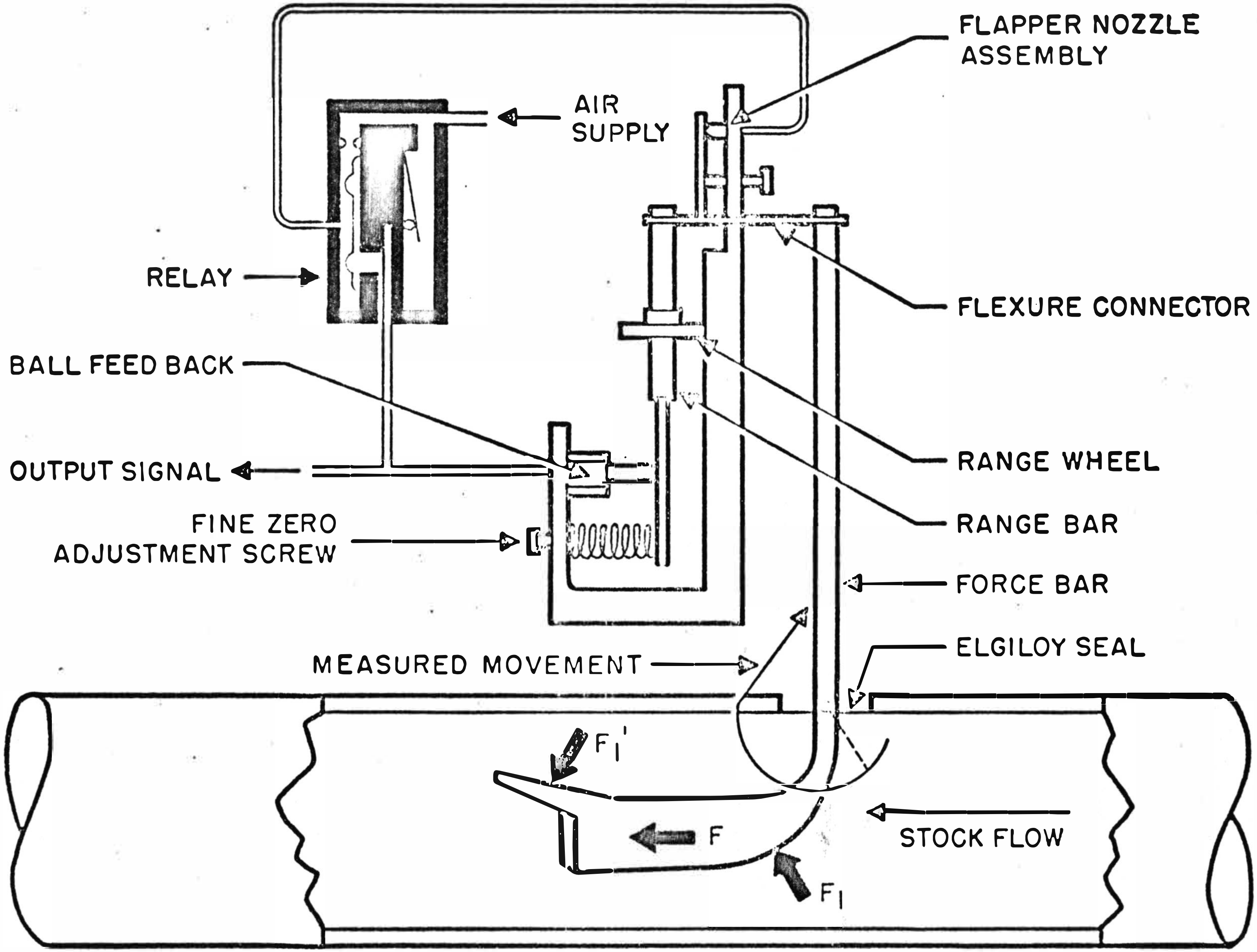


Figure 10 -- Model 19C In-line Consistency Transmitter Operation

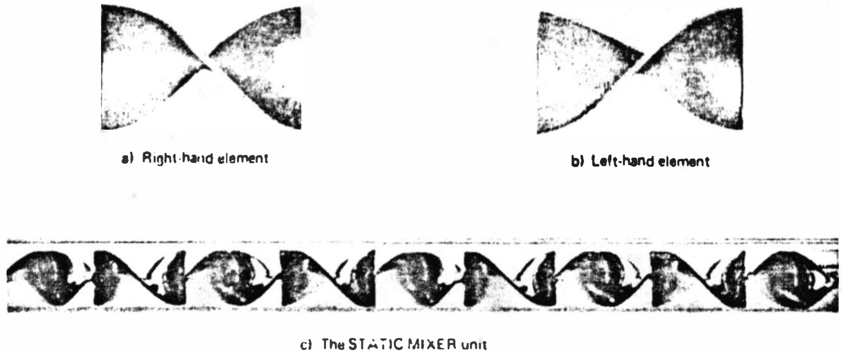


Fig.11–1. Mixer elements and the STATIC MIXER unit.

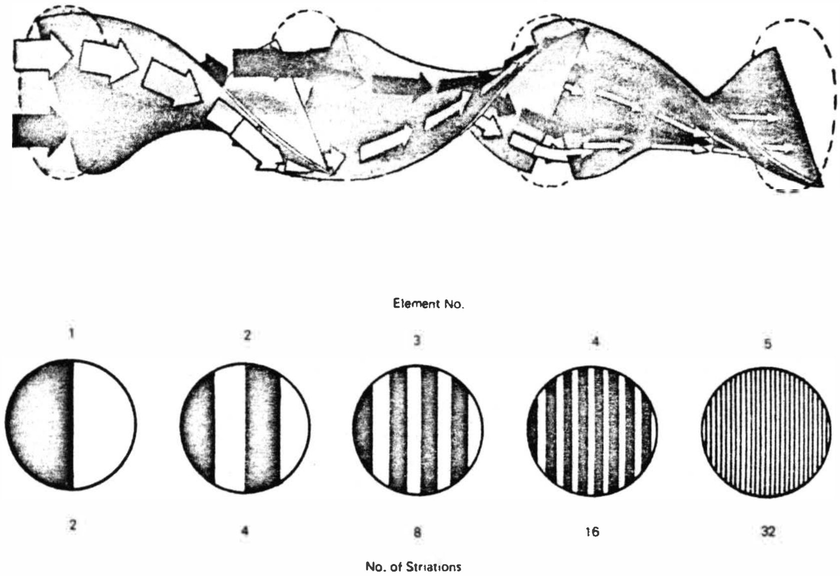


Fig.11–2. Flow division in the STATIC MIXER unit.

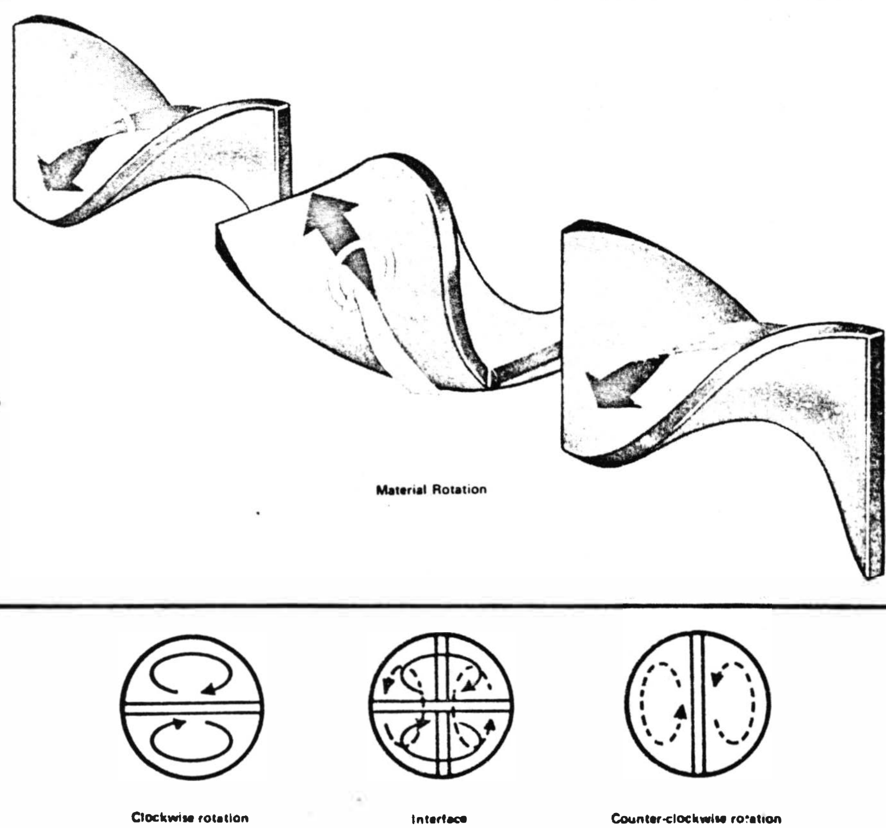
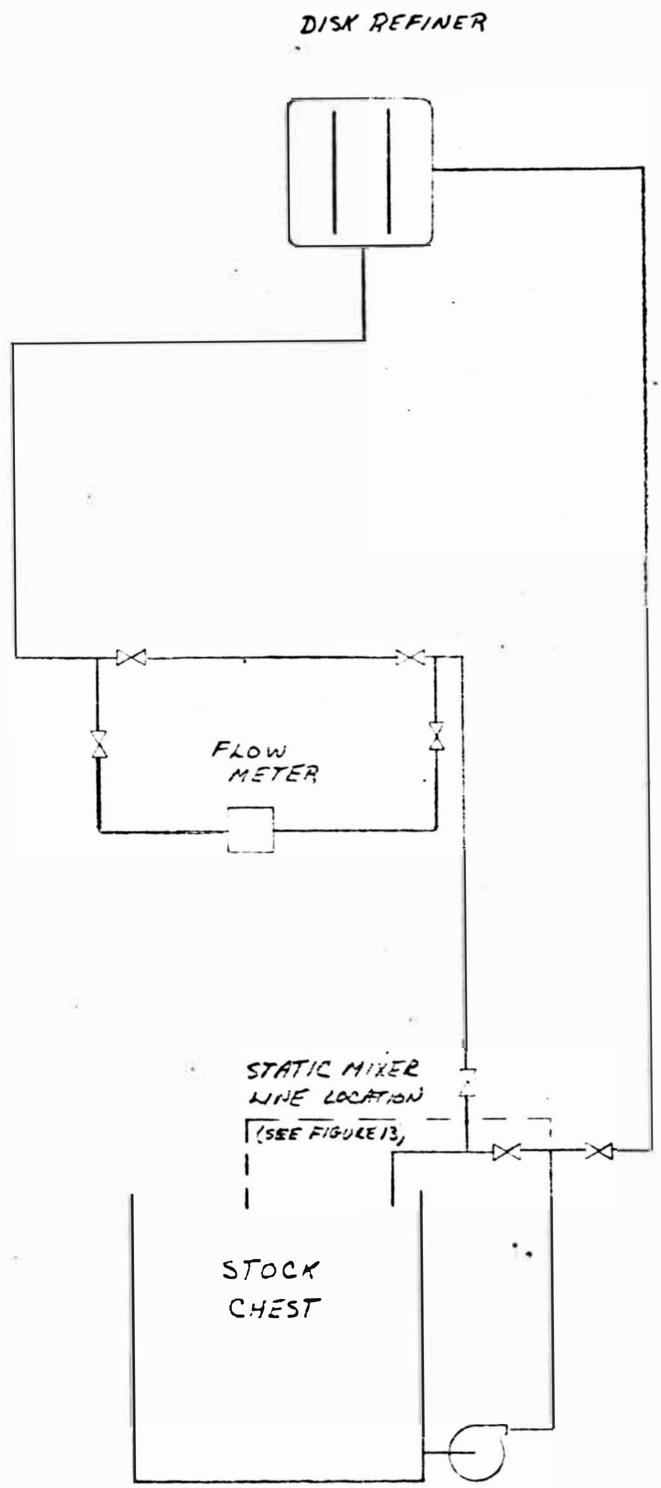
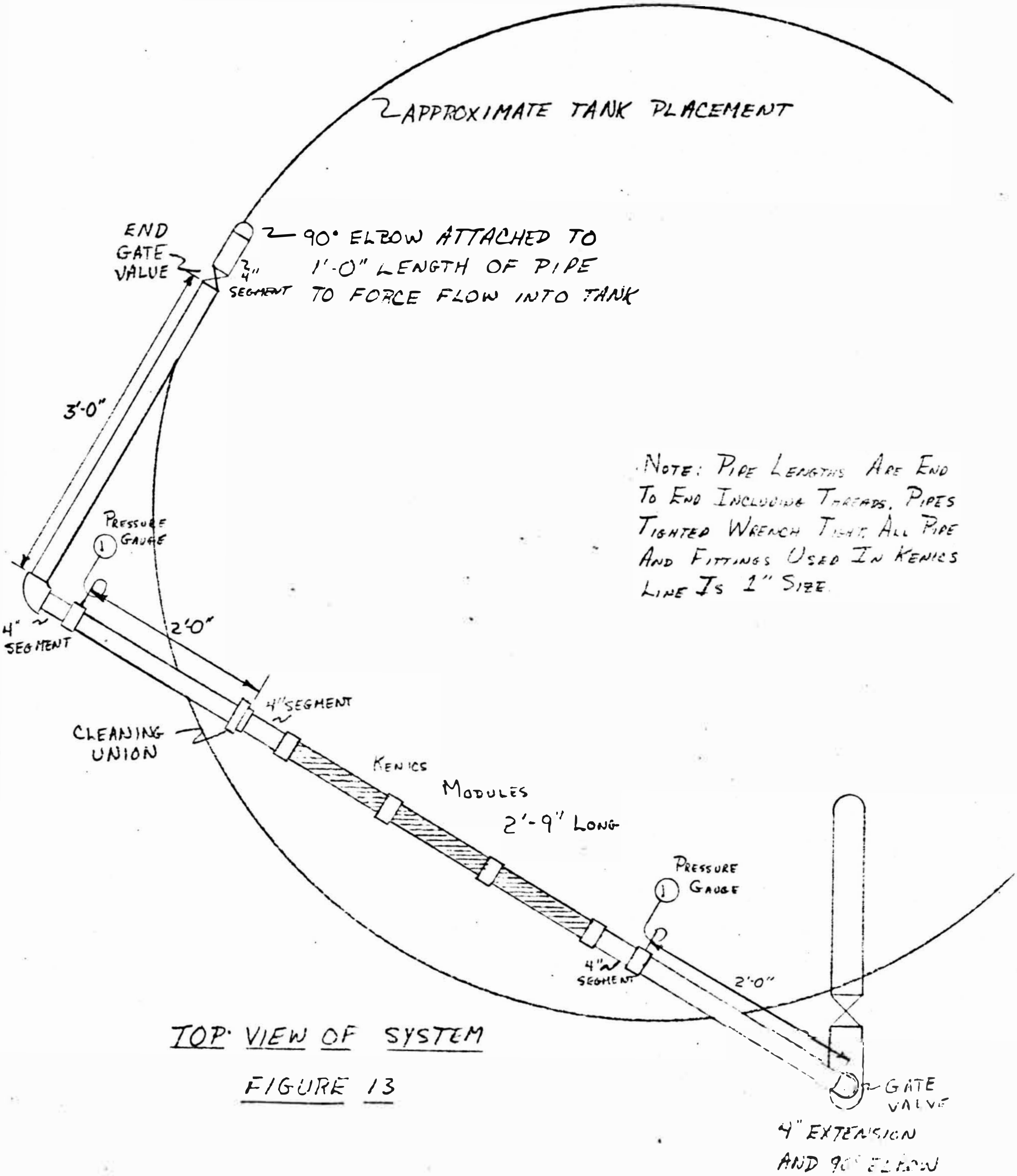


Fig.11–3. Radial mixing in the STATIC MIXER unit.



GENERAL SYSTEM OVERVIEW

FIGURE 12



TOP VIEW OF SYSTEM

FIGURE 13

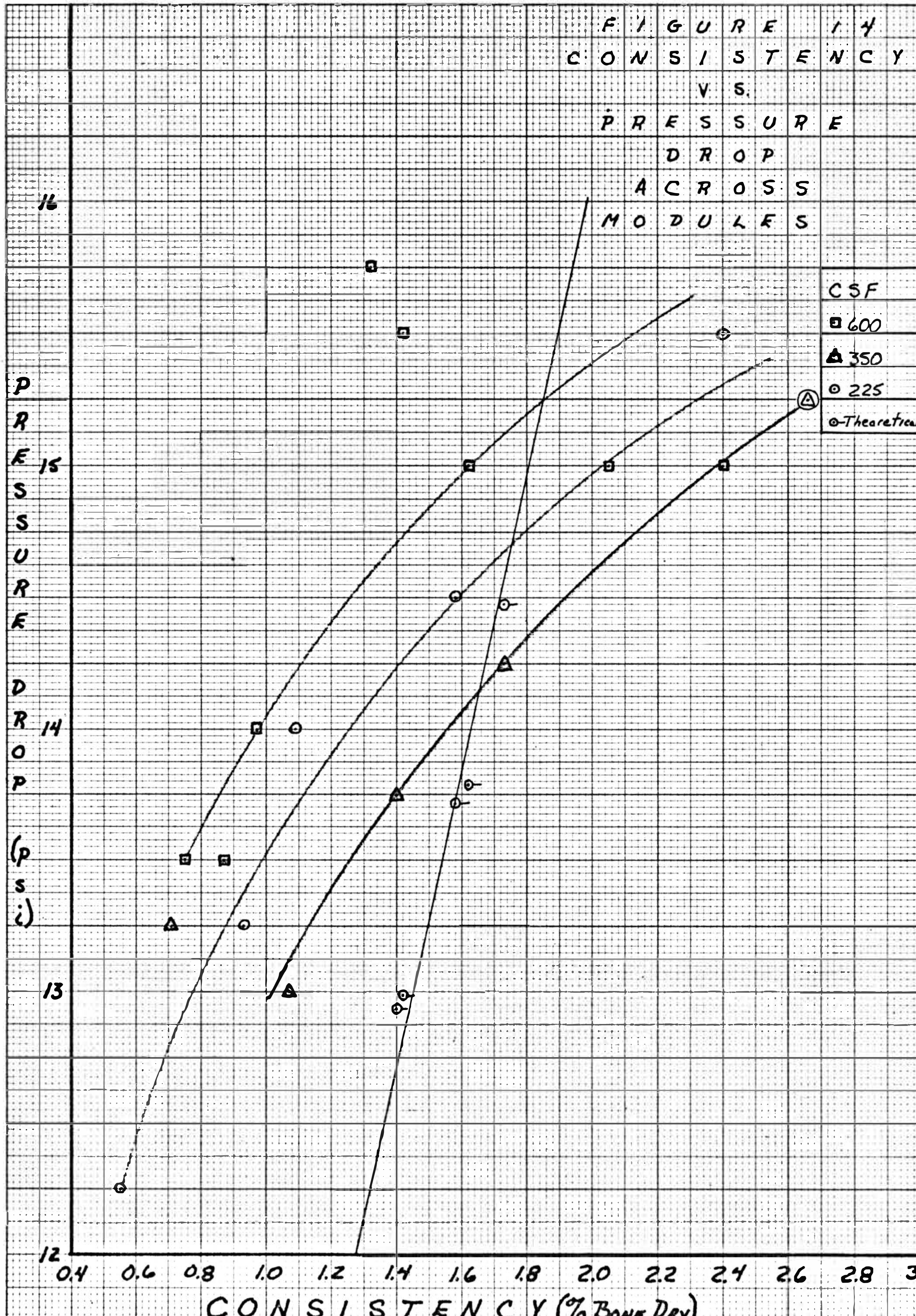


FIGURE 14
CONSISTENCY
VS.
PRESSURE
DROP
ACROSS
MODULES
CSF
600
350
225
Theoretical
PRESSURE DROP (psi)
12
13
14
15
16
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
CONSISTENCY (% BONE DRY)

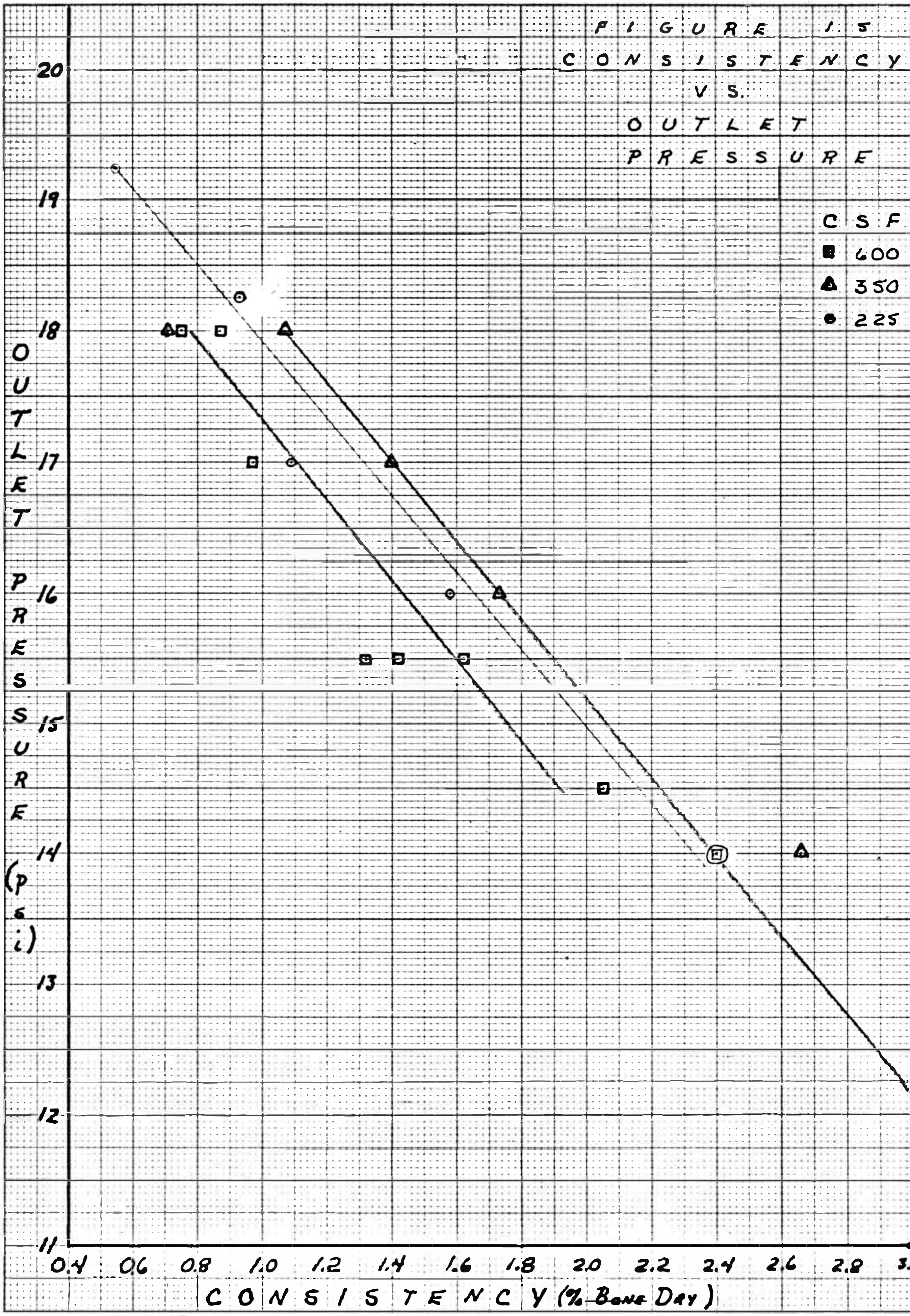


FIGURE 15
CONSISTENCY
VS.
OUTLET
PRESSURE
CSF
600
350
225
OUTLET PRESSURE (psi)
20
19
18
17
16
15
14
13
12
11
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
CONSISTENCY (% BONE DRY)

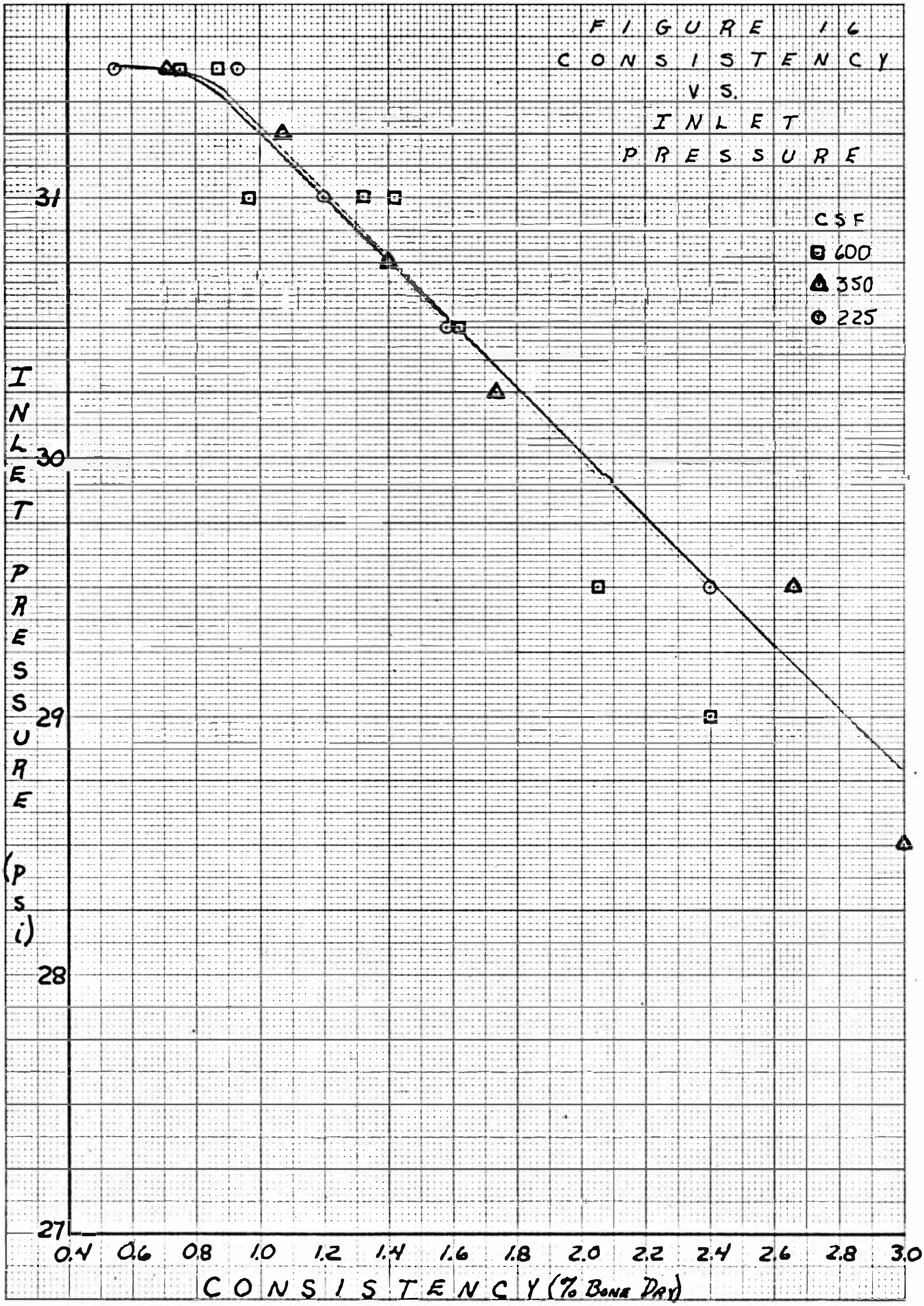


FIGURE 16
CONSISTENCY
VS.
INLET
PRESSURE
CSF
600
350
225
INLET PRESSURE (psi)
31
30
29
28
27
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
CONSISTENCY (% BONE DRY)

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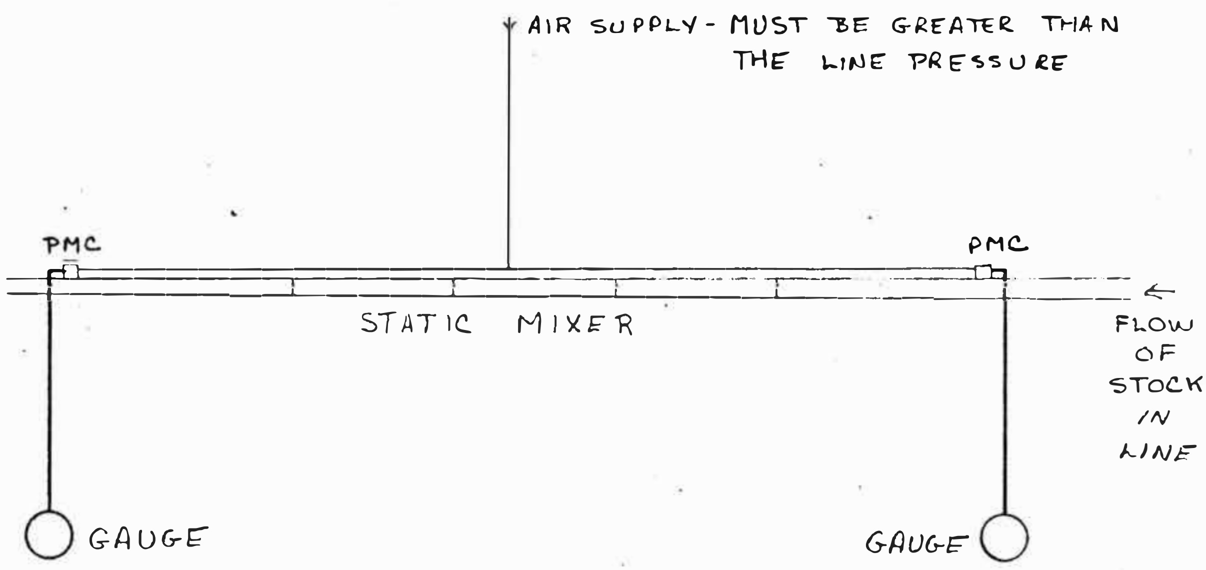
Supplementary Information

Paper Machine Component Sensors

Typical Layout



Paper Machine Components
15 Miry Brook Road
Dansbury, Conn. 06810

Phone: 203-743-9729