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Entrained Air in a Beloit Uniflow Cleaner and Its Effect on Removing Neutral Density Contaminants

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ENTRAINED AIR IN A BELOIT UNIFLOW CLEANER AND ITS EFFECT ON REMOVING NEUTRAL DENSITY CONTAMINANTS

BY

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ABSTRACT

In this study, the Beloit Uniflow Cleaner is evaluated to determine the effects that entrained air has on the removal of neutral density contaminants. Various levels of air are injected at the inlet header. The results of this project are that, at 0% air entrainment, the removal of efficiency is at its maximum. Introducing air causes the removal efficiency to fluctuate between 0% and 0.5%. Results, though, are inconclusive. Recommendations for further research include exploring particle size and shape, vary stock temperature and consistency, and determine the maximum particle size before cleaning efficiency is adversely affected.

Keywords: Hydrocyclone, Air Entrainment.

TABLE OF CONTENTS

INTRODUCTION

Due to the high cost of virgin pulp, the paper industry is taking a look at secondary fibers as a variable means to supplement virgin pulp. Unfortunately, with an increase in the usage of secondary fibers comes an increase in the probability of contaminants being introduced into the pulp stream. These contaminants can be removed by several methods. These methods are Pressurized, Johnson and flat screens, centricleaners, and a few other methods. Due to the differences in the general characteristics of the contaminants, one method can prove to be more effective than the next. In general, the contaminants can be divided into three categories. Category one is the heavyweight contaminants.[1] These contaminants have a specific gravity greater than that of fibers. Some examples are lacquer inks, magnetic inks, fluorescent ink, metallic ink, shives, bark, splinters, etc. This type of contaminant can be removed by any of the above-mentioned methods. Category two is the lightweight contaminants.[1] These contaminants have a specific gravity less than that of the fibers. Some examples are rubber, envelope windows, tar, pressure sensitive adhesives, and wax. This type is best removed by a modification of the conventional centricleaner called reverse cleaners. Category three is the neutral density contaminants[1] which have a specific gravity near that of fibers (0.96 to 1.1). Some examples are cotton fiber from bond papers, burned paper, tissue, PVDC coatings, and synthetic paper. No method currently available removes this type of contaminant satisfactorily. It should be mentioned here that the efficiency of any one method at removing the three general types of contaminants can not only be influenced by specific gravity, but also by particle size and particle shape. Having these contaminants in the pulp stream can lead to visual defects, printing problems, and machine runnability problems.[2]

OBJECTIVE

The purpose of this study is to examine the removal of neutral density contaminants by means of a Beloit Uniflow cleaner. A modification will be made on the cleaner by injecting air into the feed stream just prior to it entering the cleaner. According to one theory, deinking theory,[3] the air should improve efficiency by lifting the contaminants off with the reject flow.[4] Another possibility is that because of the presence of air bubbles in the feed stream, the contaminants will more easily move to the center vortex and be carried out the cleaner. Operating variables to be evaluated are percentage air by volume, bubble size, pressure drop, consistency of feed stream, and temperature.

THEORETICAL DISCUSSION

Basic Operation of Uniflow Cleaner

The Beloit Uniflow centricleaner is a two exit cyclone which removes lightweight contaminants from stock slurries. In a free vortex, the action of the device comes from momentum which has been given to the fluid by an outside power source. As stock enters the cleaner tangentially, the head section guides the flow to impart a rotating motion to the stock. This motion develops into a spiraling downward pattern. A liquid free air column develops about the axis of the cleaner. As the stock flows inward and downward, the velocity increases. This increase in velocity is accompanied by a decrease in pressure. In other words, the velocity increases from the outside of the cleaner to the core and from top to bottom. The increase in velocity results in higher centrifugal forces which drive the dense particles (fiber) outward and downward away from the reject tube and into the accepts chamber and out. The lights (rejects), due to pressure differential, flow toward the center of the cleaner and into the reject tube.

Operational Characteristics of the Uniflow Cleaner

The Beloit Uniflow cleaner was developed specifically to remove lightweight contaminants. Due to differences in design, as compared to the more conventional forward and reverse cleaners, there are operating characteristics which arise. These characteristics need to be mentioned, if only briefly.

When the pressure drops and the hydraulic reject rates are in their normal operating ranges and at equal feed consistencies, the reverse cleaner removes contaminants somewhat more efficiently than the flow through flow cleaner, particularly for very small contaminants.[3]

Through flow cleaner efficiency improves only marginally as hydraulic reject rate increases above 10%. Little or nothing is gained by operating through flow cleaners at hydraulic reject rates higher than 15%, because the efficiency only approaches that of reverse cleaners at comparable reject rates. Also, more accept pressure is required to produce higher hydraulic reject rates at a given pressure drop, and appreciably large second stages are required. This greatly reduces the two major incentives to consider through flow cleaners in the first place, namely, low energy consumption and low reject rate.[5]

Increasing the pressure drop of a flow through cleaner can improve its contaminant removal efficiency, somewhat, in the range of 10 to 15 psi; however, at higher pressure drops, more accept pressure is required to produce a given hydraulic reject rate. Consequently, considerably more inlet pressure is required to marginally improve the efficiency.[5]

The maximum reasonable operating consistency for small diameter through flow cleaner is about 1.0%. Contaminant removal efficiency falls sharply as the feed consistency increases from 1.0 to 1.5%, particularly for smaller size contaminant particles.[5]

Increasing temperature tends to improve the efficiency of through flow cleaners, although the extent of the improvement is dependent on the operating parameters, and the contaminant characteristics.[5]

Centricleaner Variables

Centricleaner variables are many and interrelated. A single centricleaner has variables that can be broken down into two major groups.[6] These groups are:

Single Centricleaner Variables

size of cyclone	vortex finder, design, and length
inlet diameter	inlet pressure and throughput
accept diameter	thickening changes
reject diameter	loading
	blockage

Contaminant and Fiber Variables

size of contaminant	fiber length
shape of contaminant	fiber diameter
specific gravity of dirt	wetness of the stock
contaminant concentration	consistency of stock
fiber shape	

Some variables affect cleaner efficiency more than others.[7] Following is a list of those variables:

- feed pressure
- accepts pressure
- stock type
- feed consistency
- stock temperature
- concentration of contaminants
- contaminant(s) size
- contaminant(s) density
- contaminant(s) shape
- entrained air
- bubble size of entrained air

For this thesis, I will be mostly concerned with stock temperature, stock consistency, entrained air, pressure drop, and the bubble size.

EFFECTS OF CLEANER VARIABLES

Temperature

The temperature of the inlet feed stream has a significant effect on cleaning efficiency. Increasing the temperature decreases the viscosity which reduces the force (hydraulic drag) necessary for the lightweight contaminant to move to the center of the cleaner and thus be carried out the reject stream.[8] Also increasing the temperature can ultimatly result in increasing the amount of fiber rejected.[9]

Consistency

Consistency of the inlet feed stream also can have an effect on cleaning efficiency. Increasing consistency gradually decreases efficiency. At a consistency of about 0.9%, the efficiency drops off sharply.[8]

Throughput (Pressure Drop)

There are two principle forces in a centrifugal cleaner to induce separation: the hydraulic drag, which forces the lightweight fraction (lightweight contaminant) toward the center; and the centrifugal force that throws the heavy fraction (fibers) out toward the cleaner wall. Changing the pressure drop across the cleaner by changing the throughput rate alters the magnitude of these forces.[10] In general, increasing the pressure drop increases cleaner efficiency.[8]

Air Entrainment

Air, and other gas, is always present in a non-deareated slurries in various quantities. These quantities typically range from 0.25% to 8.0% by volume. Generally, air in excess of 0.5% by volume is defined as free air.[11,12,13] The air at 0.5% and less is defined as residual air.[11,12,13] Dissolved air exists in proportion to its solubility at a given temperature and pressure.[13] Literature states that at a level of 2% volumetric air extrainment lightweight contaminant removal efficiency is at a maximum.[4]

There is no clear cut reason as to why entraining air will improve the efficiency of a cleaner at removing the neutral density contaminants. One theory states that these contaminants affix themselves to the air bubbles and are carried out the reject stream.[4] Another possibility is that because of the entrained air, present in the form of bubbles, the force (hydraulic drag) necessary to move the neutral density contaminants to the center vortex is reduced, thus increasing the efficiency.

Unfortunately, there are disadvantages to entraining air in a pulp stream[11] and are as follows:

(1) Surface foam that is formed and the problems that are associated with it.
(2) Air in stock increases the beating time needed to obtain the desired degree of fiber hydration.
(3) Air in stock increases the tendency towards fiber flocculation in the headbox and also the flocs are more difficult to disperse because the bubbles tend to serve as bridges holding the fibers together.
(4) A sheet formed with a higher air content stock is more porous, has a lower density, and is not as smooth as that formed with deareated stock.
(5) Gas bubbles in the formation zone tend to block pores of the fiber matt and thus retard drainage.

(6) Web wet strength and tensile strength of a finished paper can be reduced.

Bubble Size

Bubble size may or may not be significant in improving cleaner efficiency. It is known that if bubble size becomes too large, the bubbles coelesce causing plug flow.[14] It is also known that a homogeneous mixture will be more effective at improving cleaner efficiency. Because of these two knowns, a method of determining the maximum bubble diameter is desirable. To calculate the maximum bubble diameter,[14] see Appendix A. It is beyond the scope of this thesis to evaluate bubble size.

EXPERIMENTAL PROCEDURE

PREPARATION

Furnish

Furnish use will be critical. Two choices are possible: using a secondary fiber from a supplier or using virgin dry lap and introducing a contaminant. The problem with the former is the difficulties with the contaminant analysis, both quantitative and qualitative. The advantage with the latter is the ability to control both furnish and the type and quantity of contaminant. For the above reasons, a virgin dry lap was chosen containing 50% softwood and 50% hardwood.

Contaminant

The contaminant use of of four basic types. The first type had a specific gravity between .8920 and .9432, was dyed red, and had a spherical shape. The second type of contaminant present had a specific gravity of .9432, was dyed yellow, and had a spherical shape. The third type had a specific gravity of 0.99, was not dyed, and was spherical in shape. The fourth type was rodlike in shape, was opaque, and was composed of titanium dioxide.

EQUIPMENT

A Beloit Uniflow Centricleaner was used for the experiments described herein. It was chosen for its effectiveness at removing neutral density contaminants. The principle of operation of this cleaner can be found under Basic Operation of Uniflow Cleaner -- page 2.

EXPERIMENTAL DESIGN

The variable under consideration for this experiment is entrained air for the reason of observing and explaining its effect on removing neutral density contaminants. The variables to be held constant are pressure drop, temperature of the stock, and the consistency of the stock. The Uniflow Cleaner will be run as near to the manufacturer's design recommendations as practical. These conditions should allow for a reasonable comparison of the cleaner's removal efficiency at the different air entrainment levels. The levels of entrained air to be examined were 0.5%, 1.5%, 2.5%, and 3.5% air based on the volumetric flow rate of the feed stream.

INSTRUMENTATION AND PROCEDURE

The cleaner evaluations were performed in the recycling area of WMU's pilot plant facility. The 50% hardwood - 50% softwood stock was slurried in the Black Clawson Hydropulper at 3% consistency. During this process, it was discovered that the dump valve had been left open causing an unknown amount of the stock slurry to be blown out to the sewer. This stock was then pumped to the #4 mixing chest where it was diluted in stages, with a consistency run at the end of each dilution stage, to 0.6%

consistency. See Appendix C for a detailed flow diagram of the system employed for this experiment.

The first trial consisted of operating the Beloit Uniflow Cleaner at its designed conditions with no air added. For this run, and all runs following, the cleaner was operated as close to the conditions listed in Appendix A as practical. For this run, and all runs following, flow rates were determined for the accept and reject streams. Both of these streams are continuously recirculated into #4 mixing chest. For this run, and all following runs, samples from the accepts and rejects were run through a Valley Vibrating screen to determine the number of contaminants in a known quantity of stock. For this run, and all runs following, percent air by volume was determined for the accept and the reject streams using the Voith-Morden Inc. "percent volume container" according to instructions in Appendix E, Part B.

For the second trial, the above procedure was repeated for 0.5% entrained air based on the feed streams volumetric flow rate. For this run, and all runs following, the air flow rate was controlled by a rotameter manufactured by Linde, which is a division of Union Carbide.

For the third trial, the above procedure was repeated for all entrained air level of 1.5% by volume.

For the fourth trial, the above procedures were repeated for an entrained air level of 2.5% by volume.

For the fifth trial, the above procedures were repeated for an entrained air level of 3.5% by volume.

For a detailed, step-by-step procedure of the experiment, see Appendix D.

EVALUATION

Percent Air by Volume

The percent air by volume was regulated by setting a rotameter to a predetermined level to correlate to a given percent air by volume. (See Appendix E, Part A.) An attempt was made using the Voith-Morden Inc. "percent volume" container, designed for use with their Boi-Z cleaner to determine the percent air by volume of the accept stream and the reject stream. With this method, the container was submerged in a bucket of accept stock and reject stock, capped, and inverted; the percentage of entrained air could then be easily read from a scale off the side of the container. (See Appendix E, Part B.) No correlation could be observed between the rotameter and the Voith-Morden device.

Efficiency

As noted earlier, for each trial, a known amount of accepts and a known amount of rejects were collected. Each sample was then run through a Valley Vibrating Screen. The number of contaminants in each stream were then counted. All evaluations were then based on one minute's production, thus the number of contaminants per minute of each stream was determined, given its flow rate. The removal efficiency was calculated from the following formula:

$$\text{Removal Efficiency, } \% = 1 - \frac{(\#\text{ contaminants/min.})\text{ accepts} \times 100}{(\#\text{ contaminants/min.})\text{ rejects}}$$

It should be noted that the number of contaminants in the feed stream were evaluated by first determining the feed flow rate by means of a mass balance and then determining the number of contaminants in the feed stream in a similar manner. To do this, two assumptions were made: first, that the mixture was homogeneous; and second, the flows were at steady state conditions. It should also be noted that it was stated earlier that there were four different types of contaminants added to the system to see what effect shape and density, at various air entrainment levels, had on cleaning efficiency. The samples obtained from the accept and reject streams were allowed to set overnight before evaluation. In so doing, the individual contaminants lost their color code. As a result, the efficiency calculations were based on "total" contaminant added.

DISCUSSION OF RESULTS

The results of the five trials are summarized in Table 1. Included are the conditions that the trial was run, the percent air entrainment as determined by the rotameter and the Voith-Morden instrument, the hydraulic reject rate, the removal efficiencies, and the percentage of fiber rejected. The relationships between air entrainment and removal efficiency, air entrainment and percent fiber rejected, air entrainment and hydraulic reject rate, and hydraulic reject rate and removal efficiency are illustrated graphically in Figures 1 - 4 respectively.

It can be observed that, with no addition of air, the cleaner efficiency was 4.3%. (See Figure 1, page 13.) This result was totally unexpected. A very much higher efficiency would have been expected. As the air entrainment level increased, removal efficiency fluctuated between 0% and 0.5%. It was expected, from previous theses and from the literature, that removal efficiency would increase until about 1.5% air and then decrease thereafter.

The factors which affect removal efficiency most significantly are temperature, pressure drop, hydraulic reject rate, feed consistency, percent air entrainment, and contaminant species. Temperature, pressure

Summary of Results

	Run 1	Run 2	Run 3	Run 4	Run 5
Stock temp. (F^o)	82^o	82^o	82^o	82^o	82^o
Feed-header pressure (psig)	30	30	30	28	32
Accept-header pressure (psig)	10	10	8	8	10
Pressure drop: header-to-header	20	20	22	20	22
Feed Flow Rate (lbs./min.)	352.3	402.0	358.032	338.92	288.38
Reject Flow Rate (lbs./min.)	11.25	6.55	6.18	7.28	5.75
Accept Flow Rate (lbs./min.)	341.05	395.45	351.852	331.67	282.67
Feed Consistency (%)	.57	.68	.66	.67	.688
Reject Consistency (%)	.094	.10	.11	.14	.082
Accept Consistency (%)	.59	.69	.67	.68	.70
Air level @ Feed (% by vol.)	0.0	0.5	1.5	2.5	3.5
Hydraulic Reject Rate (%)	3.30	1.63	1.76	2.19	2.03
Cleaning Efficiency	4.3	0.4	0.0	0.5	0.0
Air @ accepts (% by vol.)	0.4	0.4	0.5	0.4	0.7
Air @ rejects (% by vol.)	0.4	0.6	0.5	0.2	1.0
Percent fiber rejected	0.5	0.3	0.3	0.4	0.3

TABLE 1

Air Entrainment vs. Removal Efficiency

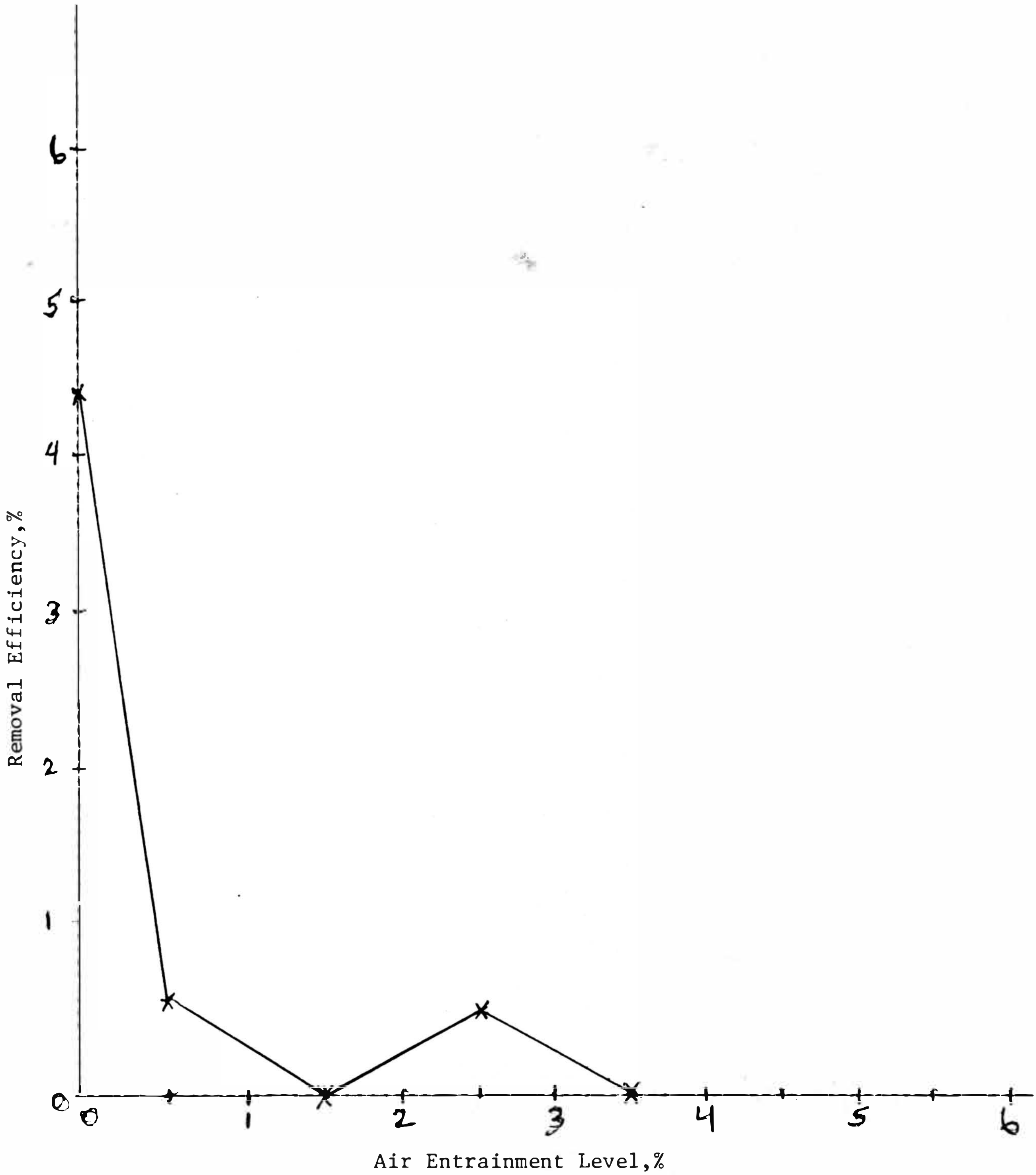

FIGURE 1.

Air Entrainment vs. Hydraulic Reject Rate

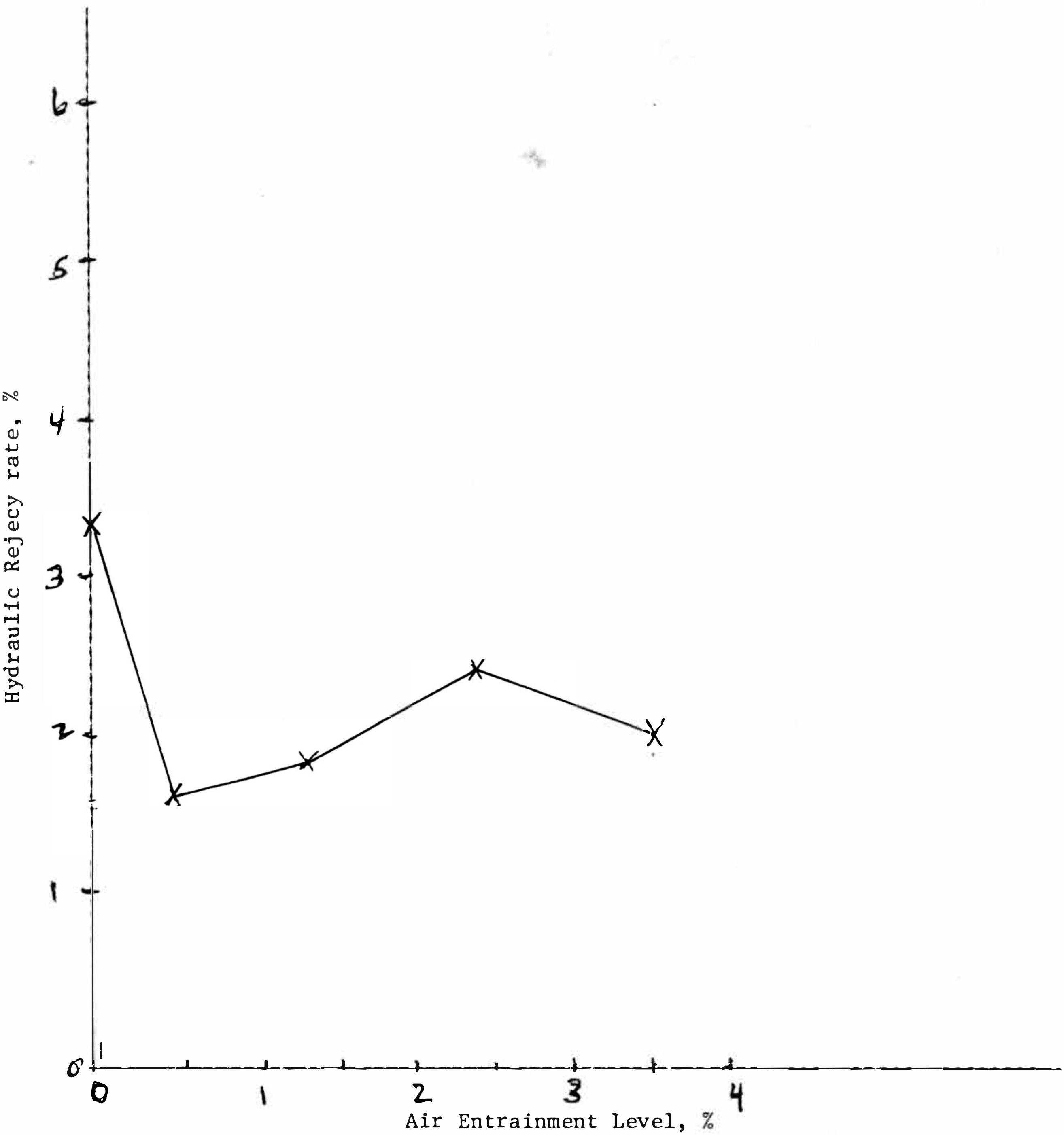

FIGURE 2.

Hydraulic Reject Rate vs. Removal Efficiency

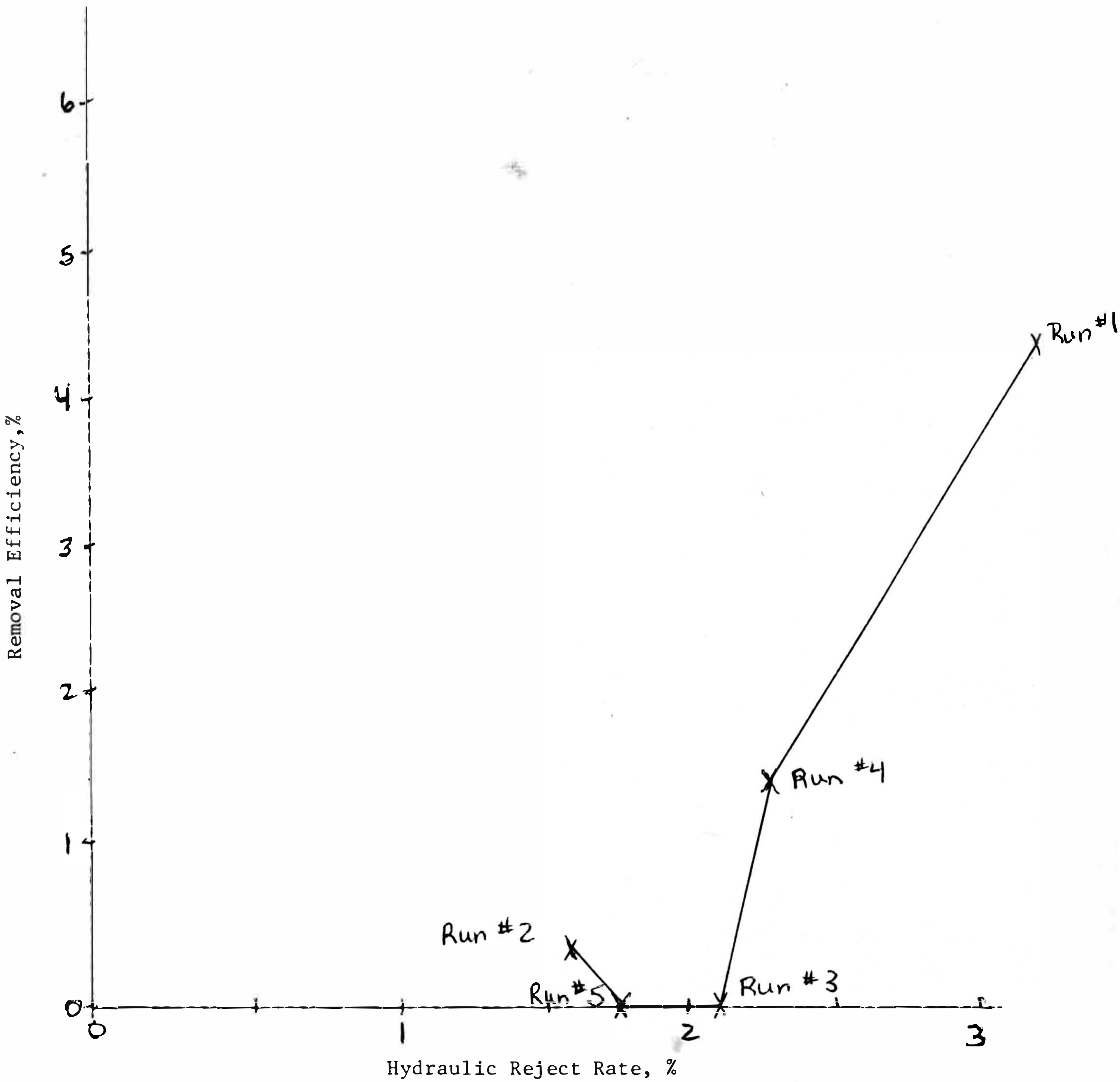

FIGURE 3.

drop, feed consistency, and contaminant species were all held constant. As a result, only hydraulic reject rate and/or percent air by volume could account for the low removal efficiencies. Again, literature and experience dictate otherwise.

One must now look at the variables held constant to try and explain the low efficiency phenomenon. Three possibilities arise as a result. The first possibility is that the hydraulic reject rate is lower than the optimum range of 5% - 10%. (See Figures 3 and 4.) Although this is a possibility, it does not appear very likely. The second possibility is that the stock temperature was held at 82 degrees fahrenheit. It is known that temperature effects removal efficiency quite drastically, the higher the temperature, the higher the efficiency. It could be that for all this cleaner, 82 degrees fahrenheit results in a very low cleaning efficiency. The third possibility is that the particle size is too large. That is because of the size of the particle the centrifugal force, which is the force that throws the heavy fraction toward the cleaner wall, overcomes the hydraulic drag, which is the force that moves the lightweight contaminant toward the center of the cleaner, and forces the overly large contaminant to the wall of the cleaner and thus, out with the accepts. Or it could be due to two or more of these possibilities acting in combination with one another.

CONCLUSIONS

To recapitulate, at 0% air entrainment, removal efficiency is 4.3%. As the air entrainment level is increased to 3.5%, the removal efficiency fluctuates between 0% and 0.5%. The reasons for these low efficiencies could be (1) hydraulic reject rates are low; (2) temperature is too low;

or (3) the contaminant particle size is too large.

Based on the above results, it could be concluded that any air entrainment will reduce the removal of neutral density contaminants through flow versus reverse. This is in direct contradiction of what was expected and what has been the case in other studies.[5,15] As a result, I would say that this experiment has been inconclusive.

RECOMMENDATIONS

Suggestions for further research include exploring different particle sizes and shapes, variations in temperature and consistency, and a study to determine the maximum particle size before the cleaner efficiency is adversely affected at removing neutral density contaminants for different cleaners.

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APPENDIX A : Derivation of Maximum Bubble Diameter Formula

To calculate the maximum bubble size the following equation may be used:

$$(1)\quad D_{MAX} = C\left(\frac{\sigma}{\rho_L}\right)^{3/5} \varepsilon^{-2/5}$$

where: C = 1.14 where gas density (ρ_G) << liquid density (ρ_L)
σ = interfacial tension
ε = energy dissipation per unit mass and time, cm/s

Energy dissipation can be shown as:

$$(2)\quad \varepsilon = \frac{dP}{dZ}\frac{U_m}{\rho_M}$$

where: U_M = superficial velocity of the mixture, cm/s
ρ_M = density of mixture, g/cm^3

and further defined by:

$$(3)\quad \frac{dP}{dZ} = \frac{2f}{D}\rho_M U_m^2$$

where: D = equivalent diameter of conduit, sm

The friction factor, , can be expressed by the Blasius equation, if the gas-liquid suspension is reasonably momogeneous.

$$(4)\quad f = a\left(\frac{U_m D}{\mu_L}\right)^{-n}$$

where: a = 0.046 , n = 0.2

APPENDIX A : Derivation of Maximum Bubble Diameter Formula - continued -

Because the mixture has high flow rate, the slip velocity (the relative motion of bubbles to the liquid phase) can be neglected, and thus the gas void fraction can be expressed as:

$$(5) \quad \alpha = \frac{Q_G}{Q_G + Q_L}$$

where: Q = volumetric flow rate, cm^3/s

Therefore:

$$(6) \quad \rho_M = \alpha \rho_G + (1-\alpha)\rho_L$$

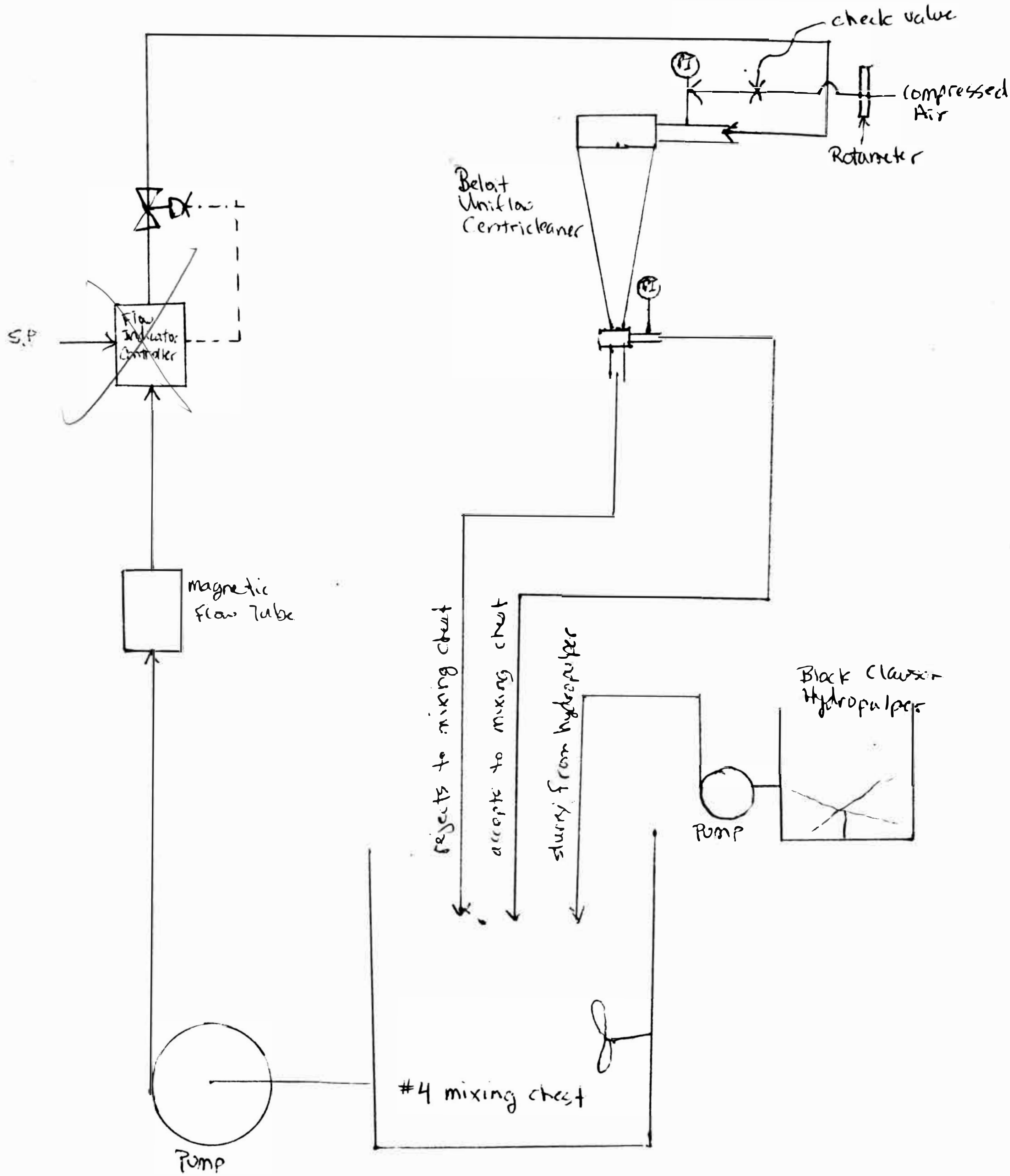
Combining equations (1) - (6) , D_{max} becomes:

$$(7) \quad D_{MAX} = 2.96 \left(\frac{D^{0.48}}{U_M^{1.12}} \right) \left(\frac{\alpha^3}{\rho_L^{2.6} \mu_L^{0.4}} \right)^{1/5}$$

APPENDIX B : Recommended Operating Ranges for Beloit Uniflow Cleaner

Feed Consistency	Up to 1.2%
Inlet header pressure (psi)	30
Accept header pressure (psi)	10
Pressure drop (psi)	20
Reject pressure	Atmospheric
Feed Flow (gpm)	34
Accept Flow (gpm)	30.5 - 32.0
Reject Flow (gpm)	2.0 - 3.5
Temperature (^{o}F)	Up to 180^{o}
T/D (Feed)	1.02 - 1.6
Fiber Rejected	0.5% - 3.5%
Rejects (Volume)	4% - 9%

APPENDIX C: Flow Diagram for Cleaner System



APPENDIX D: Procedure Used at Recycling Facility

1) Determine moisture of pulp to be used.
2) Weigh out 100 lbs. of O.D. Fiber.
3) Place 188 gal. H_2O in hydropulper.
4) Load, start, and heat hydropulper to 115°f.
5) Place 1212 gal. H_2O in #4 mixing chest. Heat to 115°f. Determine freeness of stock in hydropulper.
6) Pump 6% consistency stock from hydropulper to #4 mixing chest. Flush hydropulper with 50 gal. water.
7) Contaminant level requirement is 1% based on total O.D.F., therefore, level of contaminant is 1 lb.
8) Add the 1 lb. of contaminant to the mixing chest. Allow an appropriate time for the solution to become homogeneous.
9) Take a sample in an appropriate container. Take an air level immediately upon retrieval of the sample by using a percent volume container. Cover the sample.
10) See Appendix E for procedure on determining percent air content using the percent volume container.
11) Turn on the clearer system. (See Figure 1.)
12) Allow the system to come to steady state conditions.
13) All variables should then be adjusted in the following values:
    a) feed consistency: 0.6%
    b) inlet header pressure: 27.30 psi
    c) accept header pressure: 8.10 psi
    d) pressure drop (header-to-header): 19-20 psi
    e) temp. of stock: 110°f
    f) feed flow: 34 gpm

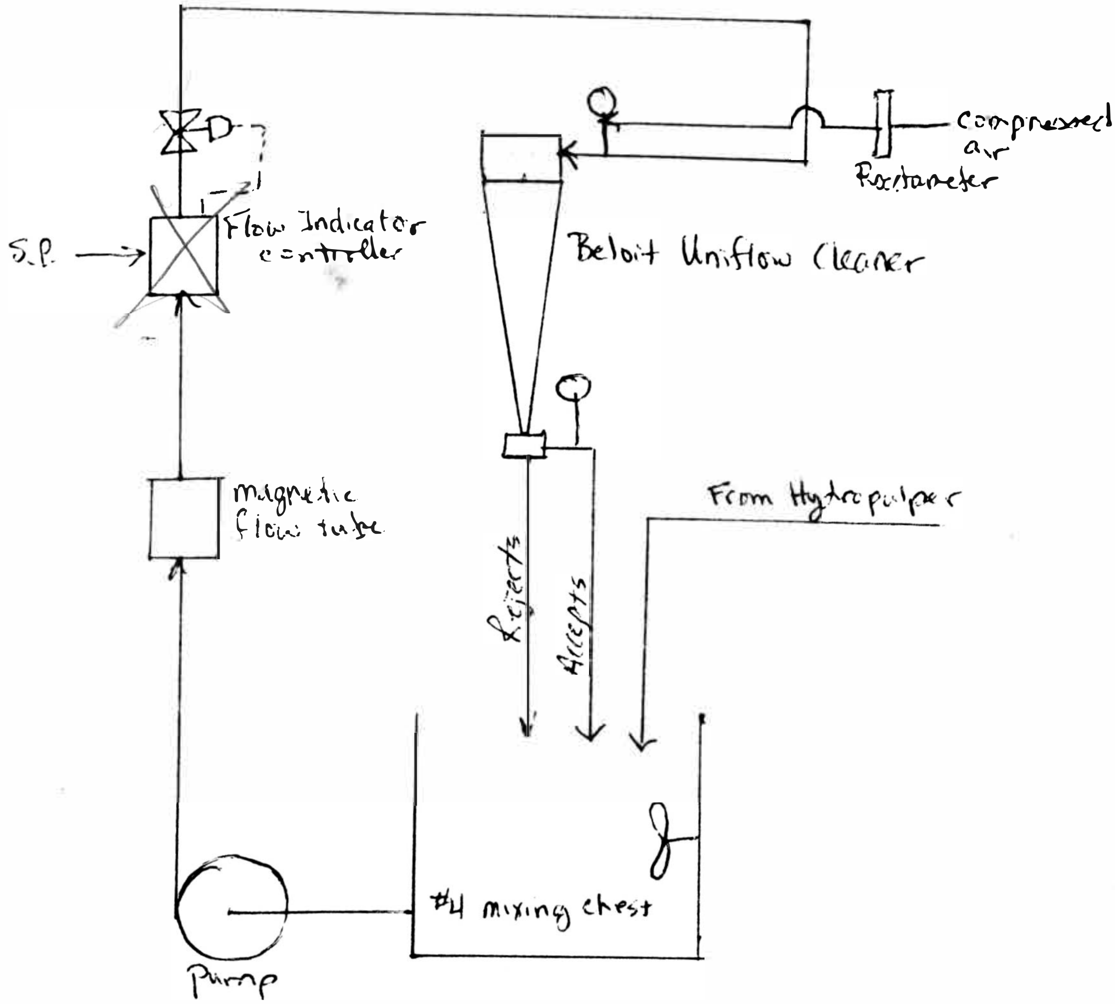


FIGURE 1. Cleaner System

g) accept flow: 30.2 - 32 gpm

h) reject flow: 2.0 - 3.5 gpm

14) This first trial will consist of 5 runs depending upon whether the device which measures the percent air content can detect ½% change in air flow rate.

15) The above variables must be held as constant as possible.

16)

Run No.	Point of Air Injection	Air Level (%)	SCfm
1	-----	0	0
2	At inlet header	0.5	0.02
3	At inlet header	1.5	0.07
4	At inlet header	2.5	0.11
5	At inlet header	3.5	0.16

17) For all of the above, the following procedure should be used:

a) Collect a sample of inlet stream in an appropriate container. Immediately upon taking sample, determine air content by using air content measuring tube.

b) Take sample to Valley Vibrating Screen and run through. Count number of contaminants as well as type. Record.

c) Save enough of sample so that a consistency can be run.

d) Also, save enough of sample so that a fiber classification can be run using clark classifier.

e) Repeat Steps (a) - (d) for the accepts.

f) Repeat Steps (a) - (d) for the rejects.

18) For each run, #17 will be followed.

Note: (1) Depending upon time considerations, temperature as well as consistency will be varied.

(2) Air level increments may be increased or decreased depending upon efficiency calculators.

Appendix E:

Part A: Correlation Between Rotameter Setting and Percent Air by Volume

Percent Air	Bead Type	Rotameter Setting	CM^3/min	SCfm
0	-----	0	0	0
0.5	sapphire	23	579	.02
1.5	sapphire	85	1,991	.07
2.5	stainless steel	88	3,123	.11
3.5	stainless steel	145	4,548	.16

Part B: Voith Morden Inc. "Special" Percent Volume Container Instructions

1) Fill a bucket with stock to be tested. (This sample should have sufficient depth to allow the container to be completely submerged in a vertical position.)
2) Submerge and fill the container.
3) Air content should be 2% to 4%. (Tapping the container will aid migrating and produce a stable level in approximately 1 minute.)