The Effects of Air Entrainment in Centrifugal Cleaners on the Removal of “Neutral” Density Contaminants

Karrie L. Kane
Western Michigan University

THE EFFECTS OF AIR ENTRAINMENT IN CENTRIFUGAL CLEANERS ON THE REMOVAL OF "NEUTRAL" DENSITY CONTAMINANTS

BY

Karrie L. Kane

A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University
Kalamazoo, Michigan

April, 1984

ABSTRACT

In this study, two centrifugal cleaners -- the C-E Bauer Waste-Mastr and the Beloit Uniflow -- were evaluated to determine the effects of entrained air in the stock on cleaning efficiency. A "neutral" density hot melt contaminant (specific gravity = 0.99) was added to dry lap pulp to simulate a recycled furnish. Various levels of a nonionic surfactant were used to induce foam in the stock; this foam was measured as percent air by volume. The cleaners were operated at a series of air levels and pressure drops, in order to generate characteristic curves. The results of the project indicate that, among the levels examined, addition of 1.4% air by volume generally increased cleaning efficiency; beyond this level, contaminant removal was adversely affected. Recommendations for further research include exploring a wider range of pressure drops and smaller increments of air levels, and increasing consideration for the regulation of hot melt particle size.

Keywords: Hot Melt, Hydrocyclone, Air Entrainment

TABLE OF CONTENTS

INTRODUCTION

With the inflated costs of virgin pulp, the paper industry has taken an increasing interest in the cost effectiveness of secondary fiber. Unfortunately, the use of this fiber source brings with it a host of contaminants which vary in density, size and shape. The differences in the general characteristics of the contaminants necessitate diverse pulp cleaning methods. Pressurized, Jonsson, and flat screens, conventional centrifugal cleaners, and a few other methods have proven successful in the removal of "heavy" dirt (high specific gravity); this category includes lacquer inks, chipboard, metallic ink and metallic chunks. Advancements are also being made in the removal of lightweight contaminants with the use of reverse centrifugal cleaners. Examples of this "light" dirt (low specific gravity) are pressure-sensitive adhesives, plastic envelope windows, and wax from various sources. With this existing pulp cleaning technology, one problem remains -- the removal of neither light nor heavy dirt, i.e. "neutral" density contaminants.[1] These are very close in specific gravity to that of water, rangin~ from about 0.96 to 1.1. Included in this class are: cotton fiber from bond papers; burned paper; tissue; PVDC coatings; and synthetic paper. In addition to visual defects, these contaminants can cause printing problems as well as adversely affect machine runnability.[2]

Objective:

The purpose of this study was to examine the removal of neutral density contaminants by means of two different centrifugal cleaners. A modification of the conventional cleaning procedure was to aerate the stock by adding a nonionic surfactant to the mixing chest. According to the theory of floatation deinking,[3] the entrained air should have improved removal efficiency by lifting contaminants off with the reject flow.[4,5,6] Operating variables evaluated were percentage (by volume) of air in the stock, and the pressure drop across the cleaner.

THEORETICAL DISCUSSION

Basic Hydrocyclone Principle:

Centrifugal cleaners operate on the utilization of fluid pressure energy to create rotational fluid motion. This rotational motion causes relative movement of particles suspended in the fluid and effects a separation of these particles.[7] Stock enters the cleaner tangentially at the base of a conical pressure vessel; the velocity of the stock increases as it moves helically toward the apex of the cone. As the stock spins along this path, the aforementioned separation of particles occurs. The heavier

fraction is thrown radially outward to the wall of the cone and the lighter fraction displaced toward the center, which is occupied by a very stable air core. As the stock approaches the apex of the cone, some of the flow reverses direction and follows a helical path upward toward the vortex finder (overflow) end of the cleaner. The overflow is thus mainly comprised of the lightweight fraction of the stock. The heavier components are simultaneously discharged from the apex (underflow) of the cleaner.

Forward vs. Reverse:

While the basic principle of operation is the same, several differences exist between forward (conventional) and reverse cleaners. The forward cleaner is generally used to remove heavy foreign materials; therefore the rejects are discharged through the underflow nozzle, while the accepts (mostly good fiber) travel up through the overflow. Reverse cleaners normally are employed after the forward stages.[8] The remaining contaminants are then, for the most part, lighter than fiber and comprise the lightweight fraction of the feed stream. As a result, the accepts (fibers) are discharged through the underflow while the rejects (lightweight and neutral density contaminants) are discharged through the top; thus the term "reverse" cleaner.[1]

Both design and operating variables differ on the two types of cleaners. The forward cleaners, as a general rule, operate at

a much lower pressure drop than their reverse counterparts; the latter can have a ΔP of close to 90 psi as opposed to below 40 psi for the former.[1] Obviously this significant power difference must be justified in the lower furnish price of secondary fiber. The orifice sizes and, subsequently, the flow splits of the cleaners are also different. Because of the accept discharge being through the underflow, the nozzle at the apex of the reverse cleaner is larger than that of the forward cleaner;[9] a much greater portion of the flow travels through this end. The table below compares rough estimates of flow and fiber splits, as well as consistency.[10]

	FORWARD	REVERSE
OVERFLOW		
FLOW	95%	60%
CONSISTENCY	0.5%	0.5%
FIBER	85%	15%
UNDERFLOW		
FLOW	5%	40%
CONSISTENCY	2%	2%
FIBER	15%	85%

Flow Patterns:

The flow pattern in a centrifugal cleaner can be expressed as a spiral within a spiral. The stock enters the cylindrical portion of the cleaner and flows along its walls. This, combined with the rotational motion to which it is constrained, creates the outer spiral. As the flow approaches the apex, the diameter is increasingly smaller; the inability for all of the flow to be

discharged through this nozzle forces some of the fluid to move toward the vortex in the center. This fraction is then carried upward and exits through the overflow nozzle. Since this stock is also rotating, an inner spiral is also created.[7,11]

The obstruction of the stock's tangential velocity by the cleaner wall induces the strong, axially-directed current that carries the flow toward the apex. Other flow patterns can also be noted within the cleaner (see Appendix A for flow pattern diagram):

> Short circuit flow -- again, due to the obstruction of the tangential velocity, this flow travels accross the roof of the cleaner and out through the overflow without ever circulating through the cleaner.[7,11]
>
> Eddy flows -- a vertical flow found between the inner and outer spirals, this pattern is caused by the inability of the overflow to handle the entire amount of flow traveling up through the vortex. This exists in the form of a recirculating eddy(ies).[7]
>
> Locus of zero vertical velocity -- Due to the fact that there exists an outward region of downward flow and an inner region of upward flow, there must be a point at which there is no vertical velocity. This locus of zero vertical velocity is the center for the eddy flows. (Also know as the mantle.)
>
> The air core -- the rotation of the stock in the cleaner creates a low pressure axial core. Since the outlet is in direct contact with the atmosphere, this core is air-filled and runs the entire length of the cleaner. It is generally of constant diameter throughout the cyclone; diameter increases with an increase in flow rate and/or overflow nozzle diameter. It is unaffected by a change in underflow diameter. The formation of this air core is an indication of vortex stability. For a given cleaner there is a minimum flow rate (thus a minimum pressure drop) to give this stability.[7]

EFFECTS OF CLEANER VARIABLES

Temperature:

The temperature of the stock has a significant effect on the amount of fiber being discharged with the rejects. Since an increase in temperature decreases water viscosity, the hydraulic drag also decreases. This essentially results in a diminishing of the force that carries the fibers toward the upward vortex and out with the accepts (in the case of forward cleaners). Obviously then, more fibers remain in proximity to the cleaner wall. Ultimately, as the temperature of the slurry increases, an increased amount of fiber is rejected.[12] However, temperature has probably the greatest effect of any one variable on efficiency -- at higher temperatures, efficiency is significantly increased. This efficiency is based on spot counting:[10]

$$\text{Removal efficiency, \%} = \left[1 - \frac{\text{spots/g of accepted pulp}}{\text{spots/g of feed pulp}}\right] \times 100$$

Consistency:

In general terms, cleaning efficiency rapidly drops off as consistency is increased.[13] The consistency of the underflow tends to be higher than that of the feed stream; this increase in consistency is known as the thickening factor:[11]

$$\text{Thickening factor} = \frac{\text{underflow consistency}}{\text{feed consistency}}$$

This factor may range from 1.0 to 3.5 or higher. This increase in the underflow sometimes causes problems in conventional cleaners, with the small diameter nozzle plugging easily. In reverse cleaners, the larger diameter underflow nozzle can better handle this thickening and, while efficiency is still reduced, the effect is not so extreme. Beyond approximately 0.9% consistency, the efficiency drops sharply.[12]

Percent Air by Volume:

Air, and other gas, is always present in a non-deaerated slurry in various quantities. These quantites typically range from 0.25 to 8.0% by volume. Generally, air in excess of 0.5% by volume is termed free air. The air at 0.5% and less is residual air. A third form of air, which exists in proportion to its solubility at a given temperature and pressure, is know as dissolved air.[14] For this study, the major concern will be the free, or entrained, air injected into the feed stream. The theory that these bubbles will lift off the neutral density contaminants is based on the same principle as flotation deinking.[4,5,6] There seemed to be little or no information specifically regarding how bubbles affix themselves to the contaminants in such high shear areas, as in a cleaner; however, one reference states that this air entrainment does improve efficiency when the cleaner operates at low velocities (laminar flow region) and very low (0 - 5 psi) pressure drops.[6] Another reference reports success using air from a non-ionic surfactant.[5]

Pressure Drop (Throughput Rate):

There are two principle forces in a centrifugal cleaner to induce separation: The hydraulic drag, which forces the lightweight fraction toward the inner vortex; and the centrifugal force that throws the heavy fraction out toward the cleaner wall. Changing the pressure drop across the cleaner by changing the throughput rate alters the magnitudes of these forces. If the P is increased, the efficiency increases;[15] for a given cleaner (as mentioned previously) there is a minimum flow rate and consequently a minimum pressure drop required to maintain vortex stability.[4] The manufacturer provides maximum, minimum and design pressure drops to ensure peak cleaning efficiency.[16]

PREPARATION

Furnish:

In determining what type of furnish to use, an actual recycled pulp was considered; this idea was rejected due to the difficulties in contaminant analysis, both quantitative and qualitative. For these reasons, a virgin dry lap furnish (70% hardwood, 30% softwood) was contaminated with the hot melt at a 1% level, based on the oven-dry (O.D.) fiber weight. This level of loading was chosen not only because it closely simulated a typical recycled furnish, but also because it provided an

adequate spot count for evaluation purposes. With this method of stock preparation, both type and amount of contaminant could be controlled.

Hot Melt:

The hot melt used in this study was a synthetic resin-based, fast-setting adhesive for case and carton sealing. Since its specific gravity is 0.99, it qualifies as a "neutral" density contaminant. The adhesive was melted at 350° F; a stirring rod was dipped into the beaker and thin strips of the glue were drawn down on tared dry lap. (See Appendix B for sample strip.) The sheets were then reweighed, and the amount of hot melt calculated. Following this, the dry lap sheets were cut into small pieces, making the hot melt particles as uniform as possible. The resultant particles were a rod-like shape; their attachment to the fiber further approximated a recycled pulp.

Surfactant:

As previously mentioned, a nonionic surfactant was used to create entrained air in the system. Triton X-100 (alkyl aryl polyether alcohol) was chosen because, among the nonionics, it is midscale in water solubility; nonionic was selected over anionic because of the greater foam stability obtained. The surfactant was diluted to a 10% solution prior to its addition to the stock.

The main concern in the addition procedure was the resultant air level, rather than the amount of surfactant added. Thus, the final values were:

0.8% Air	No Surfactant
1.4% Air	40 ppm Triton X-100 solution*
2.6% Air	66 ppm Triton X-100 solution*

*"ppm" based on total stock volume

EQUIPMENT

For the laboratory work, two cleaners were evaluated: the C-E Bauer Waste-Mastr, and the Beloit Uniflow cleaner. While used in similar applications, their operating characteristics differ significantly. A tabular comparison of the design conditions of the cleaners is located in Appendix C.

C-E Bauer Waste-Mastr:

The Waste-Mastr is designed specifically for separation of lightweight contaminants from wastepaper and similar recycled grades. It functions as a regular reverse cleaner; this operating concept was discussed in the previous section, "Forward vs. Reverse".

Beloit Uniflow:

The Uniflow cleaner is also designed for the removal of lightweight contaminants; however, it is neither forward nor reverse. Operating concept: Stock enters the top of the unit tangentially, imparting the characteristic centrifugal spiraling motion. As the throughput spins downward, it flows through an area of maximum centrifugal force near the apex of the cone to ensure separation of "slower migrating" light particles. The contaminant particles migrate inward and exit through the single, central rejects outlet at the base of the unit; accepted stock discharges through its own tangential outlet at the base. Since both accepts and rejects leave from the conical apex, flow reversal is eliminated. This design feature contributes to high efficiencies and low power consumption.

EXPERIMENTAL DESIGN

Due to the one-semester limitation of this project, the experimental variables were restricted to pressure drop and percent air; the temperature and consistency of the stock were held constant. Each cleaner was run at its minimum, design, and maximum pressure drops, according to the manufacturer's recommendations. These conditions allowed a valid comparison of the two units over their respective optimum ranges. The three levels of entrained air -- 0.8%, 1.4%, and 2.6% -- were evaluated at each of the three pressure drops.

INSTRUMENTATION AND PROCEDURE

All cleaner evaluations were performed in the recycling area of WMU's pilot plant facility. The stock was slurried in the Black Clawson Hydropulper at 3% consistency and 120° F; it was then pumped to #5 mixing chest, where it was further diluted to 0.6% consistency. The flow control system employed a magnetic flowmeter sensor to measure the stock fed to the cleaners. Initially, the pressure to the inlet manifold of the Uniflow cleaner was too high; consequently, a bypass valve was installed to provide control over the inlet pressure. (See Appendix D for flow diagram.)

The first trial consisted of operating both cleaners at their three designated pressure drops, with no surfactant added to the stock. For this run, and all successive runs, flow rates of accepts and rejects were determined; both of these streams were continuously recirculated into the mixing chest.

For the second trial, the procedure was repeated with 40 ppm of Triton X-100 added to the mixing chest. The constant agitation assisted in inducing foam in the stock; this air level was determined to be 1.4% by volume.

The third trial required 66 ppm of surfactant to raise the air level to 2.6%. Again, each cleaner was run at its three predetermined differential pressures.

EVALUATION

Percent Air by Volume:

This determination of percent air by volume was made using the Voith-Morden Inc. "percent volume" container, designed for use with their Boi-Z cleaner. With this method, the container was submerged in a bucket of feed stock, capped, and inverted; the percentage of entrained air could then be easily read from a scale on the side of the container. (See Appendix E, part A, for description and procedure.)

Efficiency:

For each trial, Noble and Wood handsheets were made from the feed, accept, and reject flows; these were dried on a hot plate to allow the contaminants to melt into the sheet. All evaluations were based on one minute's production; thus, the number of spots/minute of each stream was determined, given its flow rate. The removal efficiency was calculated from the following formula:

$$\text{Removal efficiency, \%} = \frac{(\#\text{spots/minute})\ \text{rejects}}{(\#\text{spots/minute})\ \text{inlet}} \times 100$$

The low contaminant level in the accept stream dictated that the removal efficiency be based on the reject stream.

RESULTS

The results of the various trials are summarized in Table 1, page 15; included are the removal efficiencies, changes in efficiency, and the percentages of fiber rejected. The relationships between pressure drop, percent air by volume, and removal efficiency are illustrated graphically in Figure 1, page 16.

It can be observed that with the initial addition of surfactant, the removal efficiencies improved in several instances; at four of the six pressure drops evaluated, the 1.4% air level corresponded to the peak cleaning efficiency. Increasing the entrained air to 2.6% drastically reduced the cleaning efficiency at all pressure drops.

As was expected, the design pressure drop (10 psi) on the Uniflow cleaner provided the greatest success at all air levels. With the Waste-Mastr, however the peak cleaning efficiency was obtained with the lowest ΔP (30 psi); with this cleaner the highest pressure drop also provided the least amount of contaminant removal. This can most likely be attributed to the extremely high shear forces present in a reverse cleaner operating at such a large ΔP; the magnitude of these forces tended to negate the effects of the entrained air. This theory is further supported by the observation that the 30 psi Δ P had the highest efficiency at all air levels.

		UNIFLOW			WASTE-MASTR		
Percent Air by Volume	Pressure Drop, psi	6	10	17	30	50	90
0.8%	Removal Efficiency, %	68.0	71.6	67.0	62.8	50.7	31.3
	Fiber Loss, %	2.1	2.1	2.1	11.2	8.1	4.4
1.4%	Removal Efficiency, %	54.5	87.6	70.4	84.6	52.1	23.6
	Δ Efficiency, %	-19.9	+22.3	+5.1	+34.7	+2.8	-24.6
	Fiber Loss, %	2.5	2.5	2.3	10.0	7.4	5.0
2.6%	Removal Efficiency, %	44.2	46.4	41.1	39.5	23.1	16.2
	Δ Efficiency, %	-35.0	-35.2	-38.7	-37.1	-54.4	-48.2
	Fiber Loss, %	2.5	2.3	2.1	8.3	6.9	5.6

Table 1: Summary of Results

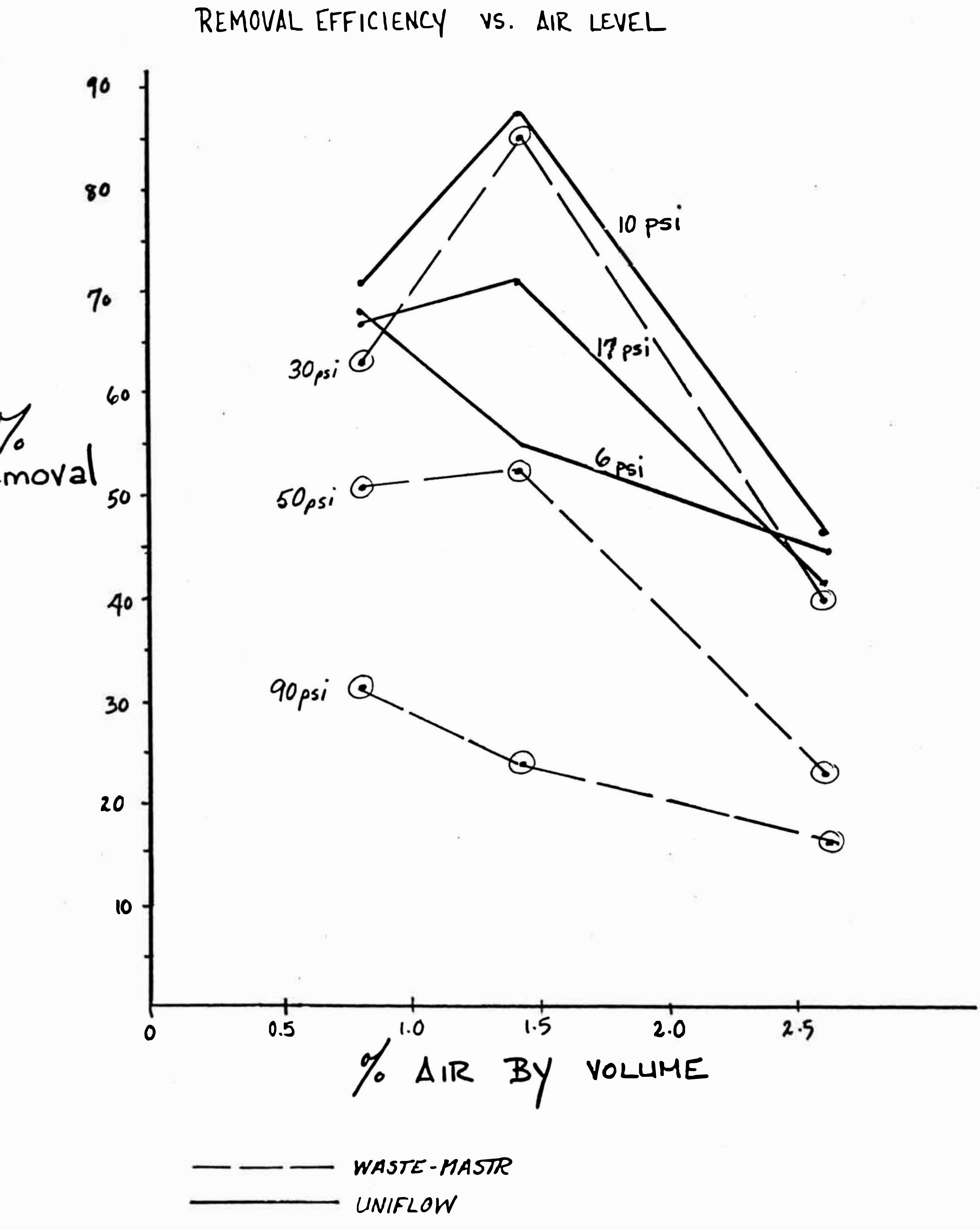

REMOVAL EFFICIENCY VS. AIR LEVEL
90
80
70
60
50
40
30
20
10
% Removal
10 psi
17 psi
30psi
6 psi
50psi
90psi
0
0.5
1.0
1.5
2.0
2.5
% AIR BY VOLUME
WASTE-MASTR
UNIFLOW

Figure 1.

There were no observable relationships between the amount of fiber rejected, the pressure drops, and the percentage of air in the stock; the only general trend was that the Uniflow consistently rejected less fiber in all trials.

CONCLUSIONS

Based on these results, it can be concluded that, up to a certain level, entrained air in centrifugal cleaners improves the removal efficiency of neutral density contaminants. In this study, 1.4% entrained air by volume was found to be the optimum of the three levels evaluated; increasing the air to 2.6% was discovered to adversely affect removal efficiency.

Overall, it can be stated that the highest removal efficiencies obtainable with the two cleaners occurred at this 1.4% air level. For the Uniflow operating at 10 psi ΔP, efficiency was increased 22.3%; for the Waste-Mastr at 30 psi P, efficiency was increased 34.7%.

RECOMMENDATIONS

Suggestions for further research include exploring a wider range of pressure drops and smaller increments of air levels; variations of temperature and consistency should also prove to be interesting. In attempting to continue work along these lines, consideration should be given to increasing the regulation of hot melt particle size.

Literature Cited

[1]Morse, R., and Braun, H.J., 1972 TAPPI Papermaking Conference Proceedings.

[2]Bliss, T., and Crow, D., TAPPI 64(10):75(1981).

[3]Silveri, Luigi, 1983 TAPPI Pulping Conference Proceedings, pp. 401-8.

[4]Ekstrom, R., Pulp and Paper, July 1982, pp. 125-30.

[5]Hamilton, Frank, Chas. T. Main, Inc., Personal Communication.

[6]Voith-Morden, Inc., Boi-Z Cleaner Product Information.

[7]Bradley, D., "The Hydrocyclone," Pergamon Press, New York, 1965.

[8]Coan, Bill, Pulp and Paper, June 1983, pp. 94-104.

[9]Clay, James, 1982 TAPPI Stock Preparation Seminar Notes, pp. 15-18.

[10]Bliss, T., TAPPI 63(6):87(1980).

[11]Bouchillon, C.W., and Franko, A., 1983 TAPPI Annual Conference Proceedings.

[12]Woodruff, M.D., Pulp and Paper, March 25, 1968.

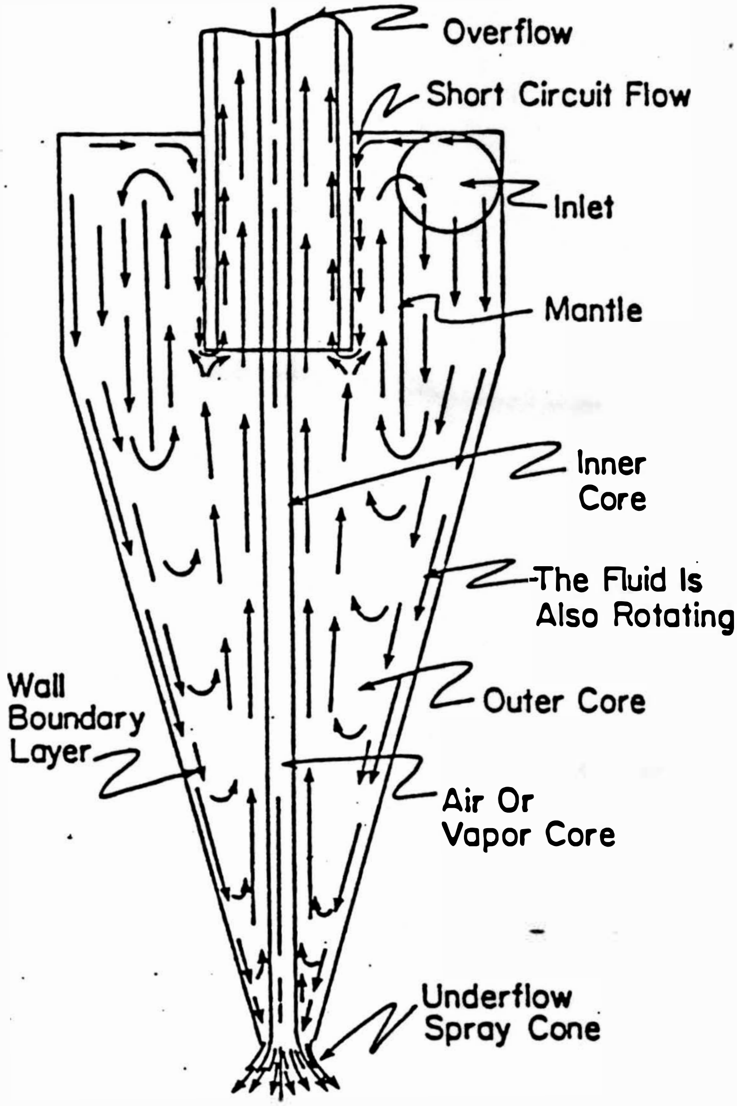
[13]Robinson, William, Richard Berg AB, Personal Communication.

[14]Kurtz, K.D., "Deaeration: Some Practical Applications and Benefits for Pulp and Paper Mills," reprinted from 1978 TAPPI Conference.

[15]Woodruff, M.D., TAPPI 54(7):1148(1971).

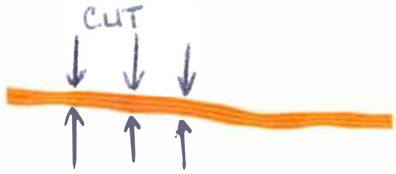
[16]Kerr, J.C., C-E Bauer, Personal Communication.

[17]TAPPI Useful Method 653, TAPPI, Atlanta, GA.



Descriptive Flow Patterns Based On Vertical And Radial Components Of Velocity In A Hydocyclone

APPENDIX A.



The hot melt was cut up as indicated above.

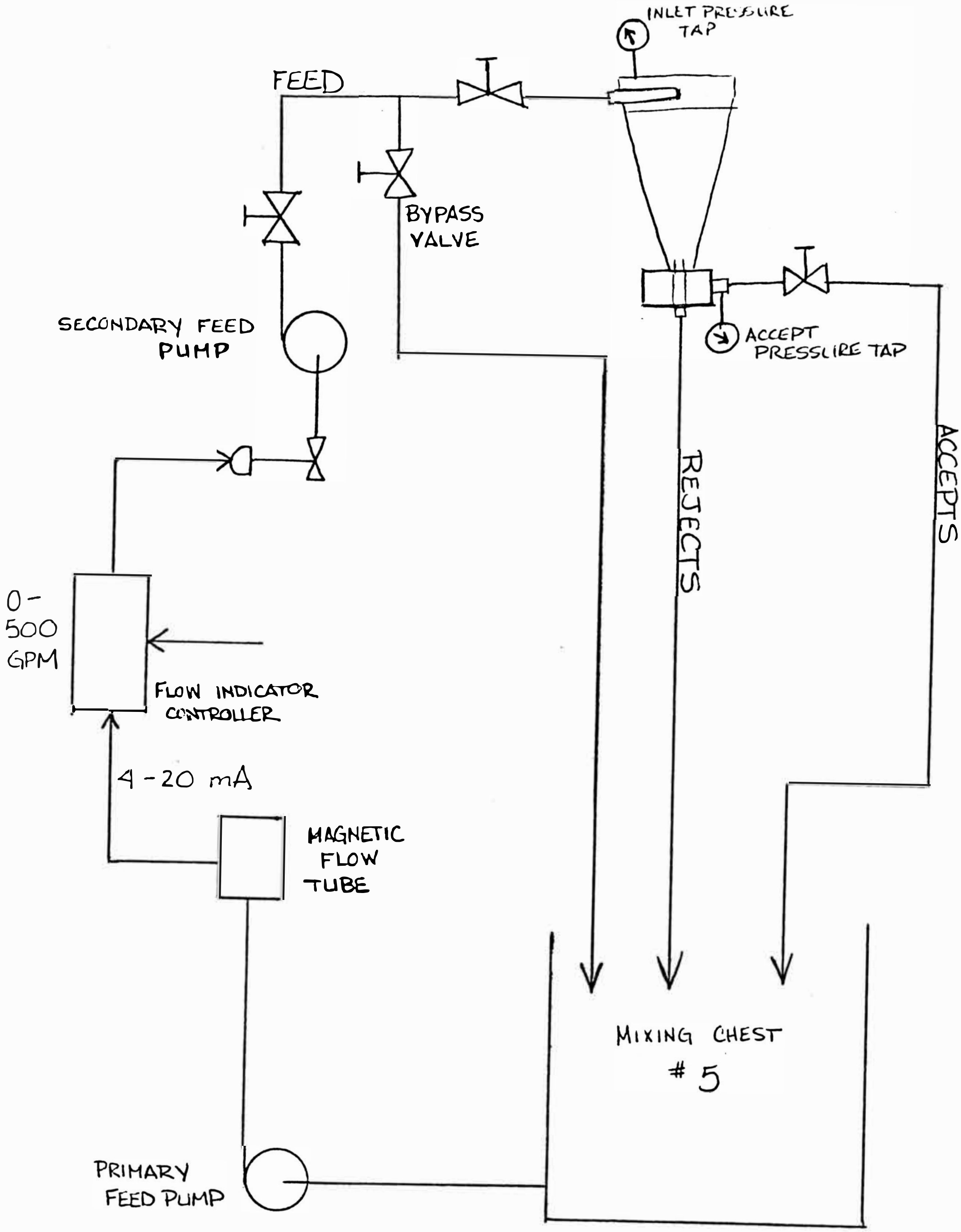
APPENDIX B: Hot Melt Sample Strip.

Appendix C: Comparison of Cleaners

	UNIFLOW	WASTE-MASTR
Diameter (inches)	4	3
Feed Rate (gpm)*	33	32
Inlet Pressure (psi)*	20	90
Accept Pressure (psi)*	10	0**
P (psi)*	10	90
Consistency (%)*	0.5	0.69

*Manufacturer's Recommended Values

**The Waste-Mastr discharges at atmospheric pressure

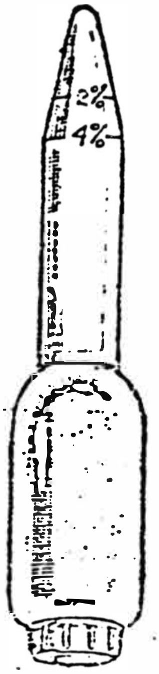


APPENDIX D: FLOW DIAGRAM

Voith - Morden Inc.

BOI-Z CLEANER
MEASUREMENT OF THE AIR CONTENT OF STOCK

A. Visual Inspection Technique: (Requires special percent volume container.)



1. Fill a bucket with the 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. Secure the cap and invert the container.

4. Air content should be 2% to 4%. (Tapping the container will aid migration and produce a stable level in approximately one minute.)

This method will yield an on the spot check and requires no additional equipment.

This container can be used to give accurate results when the air content is between .2% and 4%. If the air content is above 4%, many fibers will be supported by a foam and the accuracy will decrease.

This device works well on .5% A.D. stock; however, as the consistency increases the entrained air becomes difficult to float out of the stock.

B. Weighed Sample Technique: (Requires any suitable container and weight measuring device.)

1. Use a container of at least 300 ml which has a marked volume or sealable.

2. Weigh a volume of water at stock temperature.

3. Weigh the same initial volume of stock.

4. $$\% \text{ Air by Volume} = \frac{(\text{Water Wt.} - \text{Stock Wt.})}{\text{Water Wt.}} \times 100$$

C. Volume Reduction Technique: (Requires two 1000 ml graduated cylinders & chemical defoamer)

1. Fill first graduate with any volume of stock, and record the volume.

2. Pour stock from first graduate into second graduate, add only a couple drops of defoamer and stir. Record volume of stock without air.

$$\% \text{ Air by Volume} = \frac{(\text{Volume of Stock w/Air} - \text{Volume of Stock w/o Air})}{\text{Volume of Stock w/Air}} \times 100$$

Note: Second graduate prevents defoamer contamination of first graduate.