

American Filtration & Separation Society

DESCRIPTION OF A DISPOSABLE ROTARY DRUM FILTER APPROPRIATE FOR USE  
WITH SMALL VOLUME HIGH VALUE PRODUCTS

John Kossik\*  
Steadfast Equipment, Inc.  
16511 4<sup>th</sup> Dr. SE  
Mill Creek WA 98012  
Phone: 206-409-7594  
Fax: 425-742-9653  
Email: [jmk@beaconengr.com](mailto:jmk@beaconengr.com)

Jeff Delys  
Steadfast Equipment, Inc.  
16511 4<sup>th</sup> Dr. SE  
Mill Creek WA 98012  
Phone: 206-409-7594  
Fax: 425-742-9653  
Email: [jeffd74793@aol.com](mailto:jeffd74793@aol.com)

## DESCRIPTION OF A DISPOSABLE ROTARY DRUM FILTER APPROPRIATE FOR USE WITH SMALL VOLUME HIGH VALUE PRODUCTS

### INTRODUCTION

In the pharmaceutical, fine chemical, hazardous materials, juice, beverage, beer, and wine industries, many of the production processes are batch in nature. This batch-wise processing is due to the limited volume of the material, the need for traceable "lots" of material, and/or the high intrinsic value of the product. Processes in these industries frequently require equipment that performs efficient, clean, and reliable solid-liquid separations. One specific separation used in these applications is traditional cake filtration. Typical industrial equipment used for this type of solid-liquid separation would include Nutsch, plate and frame, leaf, disc, horizontal plate, tube, and candle filters. Along with these filters, centrifuges are also used to conduct this type of separation.

The traditional batch filtration equipment mentioned above usually comes at a significant capital cost. Where this equipment is used in pharmaceutical or fine chemical applications, it is usually constructed of stainless steel and must be designed to accommodate repeated and thorough cleaning. This can lead to capital costs ranging from \$45,000 to \$200,000 or more. In applications where centrifuges are used, the inherent dynamic mechanical nature of this equipment requires even higher capital costs.

Although these batch filtration devices have been used successfully for years, they are not without their drawbacks. These difficulties are inherent with their batch operating nature, and usually have to be opened up to the environment before and after use for cleaning. The result is, high operating costs and a high potential of contaminating the material being processed and/or the operating personnel themselves. In addition, this "open" nature operation requires the equipment to be housed in a highly "controlled" environment, further increasing the cost of its operation.

As has been done in the development of more efficient filtration equipment for the Chemical Process Industries (CPI) over the years, the key to minimizing the difficulties faced by batch equipment is transitioning to the use of continuous processing techniques. As is traditional with batch filtration equipment, its size is comparable with the amount of material being processed. Thus larger batches, or "lots," of material require larger filtration equipment. With continuous equipment, the design parameters are not strictly tied to the size of the batch being processed. Instead, since the equipment operates "continuously," the time in which the device is operated becomes significant. In industries where material must be separated and processed in "lots," the transition from using a batch-style equipment to inherently continuous-style equipment involves essentially transitioning from thinking about how big the equipment will be to how long it will be operated. This allows equipment designed to operate continuously to be of significantly

smaller size than corresponding batch-style equipment. This smaller size can result in significant capital cost reductions.

When using continuous-style equipment in traditionally batch oriented industries it is important to remember that this equipment will be operated in a continuous fashion for a much shorter period of time than it would be in a typical CPI facility. In a CPI case, a continuous cake filter may operate for days, weeks, or even months before it is shut down and restarted. When used in a typical batch processing case, a continuous cake filter may only operate for a few hours. It is sometimes appropriate to denote this type of operation as “semi-continuous.”

In trying to apply continuous cake filtration techniques to traditionally batch processes, it is first advantageous to look at the existing types of continuous filtration equipment and determine why they are not appropriate in their present configurations. Some major continuous cake filtration equipment normally used in the CPI would include rotary or vacuum drum filters, rotating disc filters, and horizontal belt filters. Traditionally, these filters are too large to have applications in the majority of pharmaceutical processes. Rotary drum filters are one of those that can effectively be made the smallest, with some versions having drums as small as a couple of feet in diameter and a few feet long. This size is still too large for many pharmaceutical and fine chemical processes. The limitation in how small these devices can be made is due to their highly mechanical nature. The mechanical complication to facilitate the movement, rotation, and fluid redirection required for these devices, limits how small it can practically become.

In addition, concern must be taken when applying continuous devices to batch processes by determining how long it takes for the equipment to attain “steady-state” operation. Equipment designed to operate continuously may not yield satisfactory results while it is in its startup and shutdown modes. In typical CPI applications, this type of equipment operates for such a long period of time, any “off-spec” product generated during startup and shutdown is insignificant. This may not be the case for equipment is used in batch processes. With the equipment operating for a much shorter period, the time it takes to come up to steady state operation is critical. Also, because the products handled in these batch applications are usually of very high value, only very small losses during startup and shutdown are acceptable.

Converting continuous cake filtration techniques so that they are applicable in typically batch-dominated industries like pharmaceuticals and fine chemicals requires that they first clear the “barriers to entry” mentioned above. To do this, one of the most common types of cake filtration equipment from the CPI was chosen to be “scaled down.” The type of equipment chosen was a basic vacuum drum filter. Because of the highly mechanical nature of this equipment, involving a rotating drum and the need for a filter valve to control the vacuum the drum is exposed to, this equipment’s operation had to be taken back to its origins. Starting here, the device could then be “re-engineered” to eliminate the “barriers for entry.” The prime objective would be to simplify or eliminate the bearings, seals, and complicated internal piping typically present in a large-scale

device of this type. The result of this re-engineering would be a small continuously operating device that could be used to process large batches of material. Reducing the size allows the device to be made out of injection molded plastic. This precipitated a design oriented towards a single use, disposable, pre-cleaned or pre-sterilizable device. In addition to its low cost, its disposable, pre-cleaned nature reduces or eliminates the standard pre and post cleaning associated with both traditional batch and continuous cake filtration equipment.

A prototype was constructed to test this premise and the result is the simple, cheap, and robust Disposable Rotary Drum Filter.

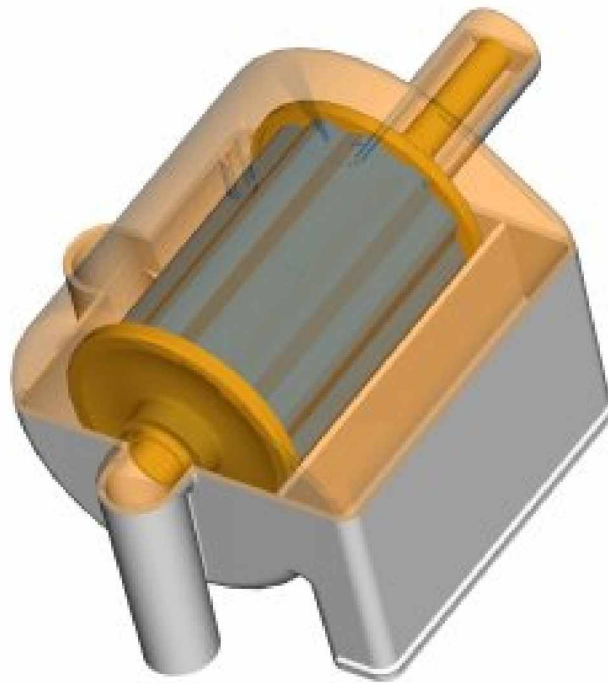


FIGURE 1, DISPOSABLE ROTARY DRUM FILTER

#### METHODS AND MATERIALS

Because of the large variety of slurries that could be processed in this device, the primary goal of the study was to determine the general qualitative feasibility of this unit. Although quantitative parameters are needed to determine the unit's general effectiveness in comparison to competing traditional batch cake filtration technology, determining which areas of the device were most prone to cause difficulties was the prime objective of this study. With that in mind the device was tested normally for one hour at a time with a final test to be conducted to determine how long the device in its current configuration could run before it failed.

Figure 2 shows the flow diagram for the processing system the Disposable Rotary Drum Filter is designed to be used in.

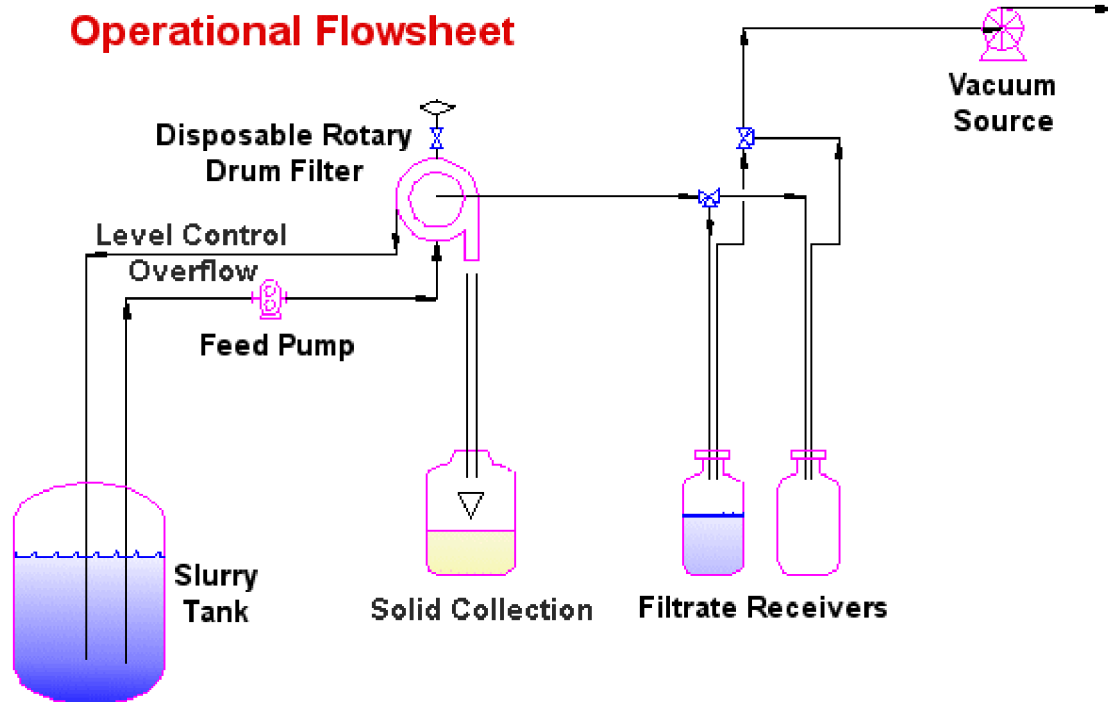


FIGURE 2

As can be seen from this diagram, the filter is operated in a semi-continuous fashion. That is, it operates continuously until the material in the Slurry Tank is emptied. Note that vacuum is applied to the filter via the filtrate receivers. Two of these receivers are alternately emptied when they are full, allowing the filter to go on operating constantly. Solids are collected into a Solids Collection container that can be periodically emptied without effecting the operation of the filter. Slurry is supplied to the filter in a controlled fashion via a peristaltic Feed Pump. The slurry level in the filter is controlled by an overflow back to the slurry tank. A cut-away drawing of the mechanical configuration of the Disposable Rotary Drum Filter is shown in Figure 3.

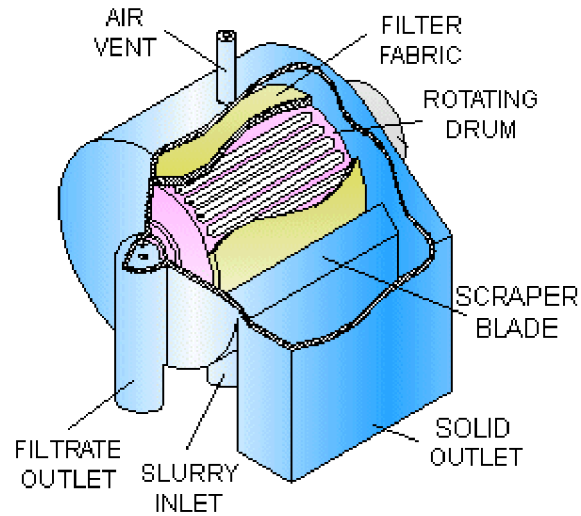


FIGURE 3, CUT-AWAY SHOWING FILTER COMPONENTS

Although the device is designed to be made of injection molded plastic, the prototype studied was milled out of nylon and polycarbonate for convenience. Figures 4 through 8 show the physical configuration of the prototype without the porous plastic filter media covering the drum.

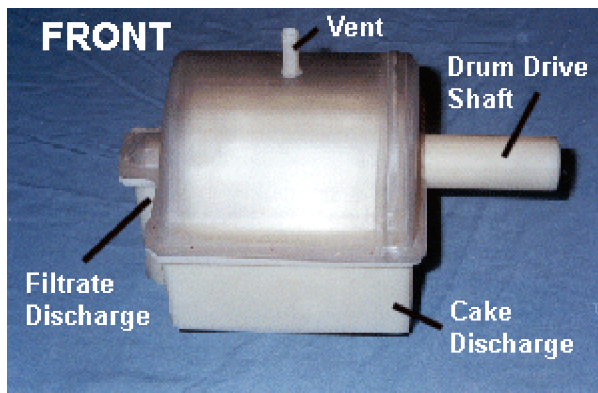


FIGURE 4

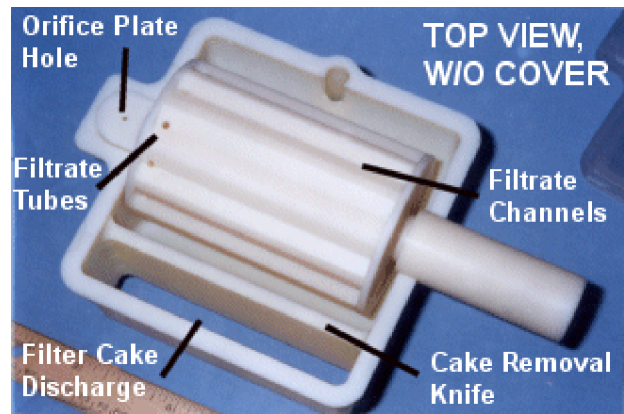


FIGURE 5



FIGURE 6



FIGURE 7

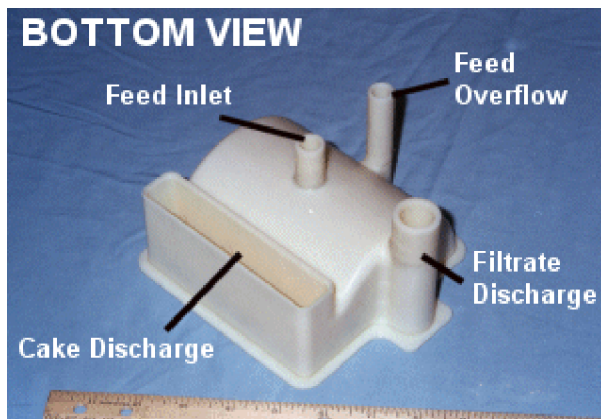


FIGURE 8

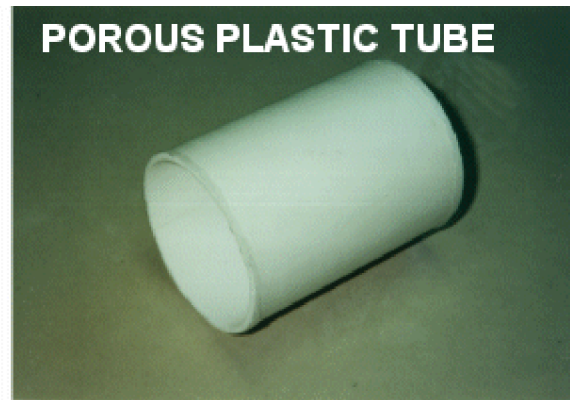


FIGURE 9

The initial prototype size was chosen to accommodate batch capacities normally seen processing applications ranging from the laboratory to the small-scale production facility. The outer housing enclosing the device measures 4.5" in diameter and about 6.5" long. The size chosen for this drum, 3" in diameter and 4.5" long, determines the filtration surface area of the device and has the most significant effect on its processing capabilities. Figure 9 shows the porous plastic tube used as the filter media. This tube slips over the drum and supplies a self-supporting filtration surface. The porous plastic for this device was 0.125" thick, hydrophilic polyethylene, 15-40 micron pore size, supplied by Porex, Fairburn, GA.

Figures 3 and 5 show the filtrate channels that run longitudinally around the circumference of the drum. These channels carry the filtrate that flows through the porous plastic filter into the filtrate tubes at the left end of the drum. These tubes carry the liquid from the channels to the filtrate discharge area of the device. The orifice plate separates the filtrate tube penetrations into those

above it and below it. The penetrations that are below the orifice plate are exposed to the surface of the drum that is submerged while those above it are exposed to the surface that is open to the air. There is a hole in the orifice plate and vacuum is pulled on the filter through the filtrate discharge on its bottom side. In this arrangement, the pressure differential between the bottom and top of the orifice plate is the airflow pressure drop through the hole. This allows a higher motive force to be present on the filtrate tubes whose ends are submerged. The pressure drop across the orifice plate is equal to the difference in pressure drops of liquid passing through the cake and air passing through the cake. As the drum is rotated, this simple configuration replaces the complicated filter valve piping required in traditional vacuum drum filters. Using this Orifice Plate configuration instead a traditional filter valve is a prime reason this device can be successfully “scaled-down” from traditional vacuum drum filters. Figure 10 shows the Orifice Plate / Filtration Tubes configuration in greater detail.

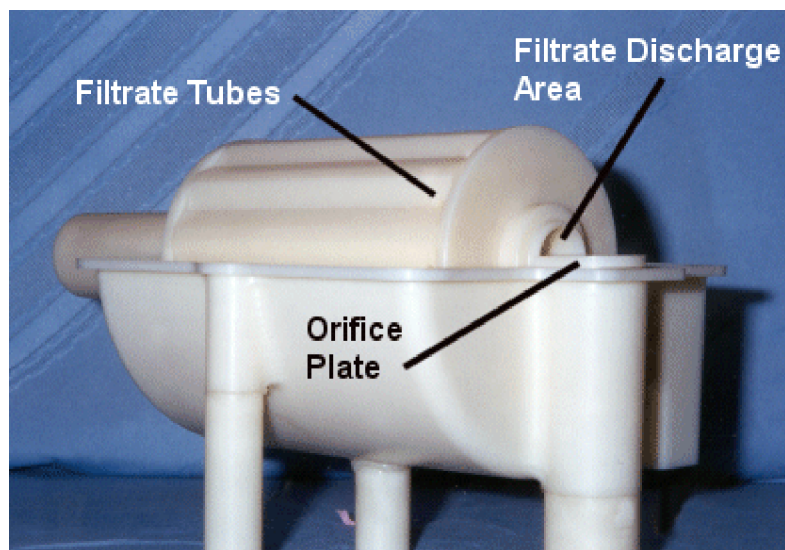


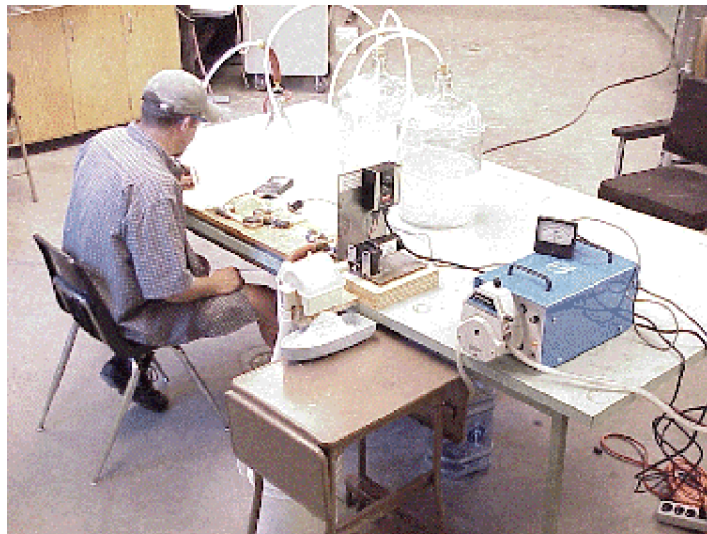
FIGURE 10

Slurry enters the outer housing via a Feed Inlet. The level is controlled via a level control overflow shown in Figure 7. As with traditional vacuum drum filters, cake accumulates on the outer surface of the drum as it rotates through the slurry. As it rotates out of the slurry and is exposed to air the cake dries. Lastly, the cake comes in contact with a Cake Removal Knife, is partially scraped off, and the dried solids fall out of the device. It should be noted that no washes or blow-backs are used in this device since their inclusion would have made its operation too complicated.

There are a number of novel simplifications designed into this device that allow it to be “scaled-down” successfully. First, there is the replacement of a complicated filter valve assembly with

the simple orifice plate. Second is the presence of only one vacuum sealing surface in the device. This surface is located where the rotating drum touches the outer housing on the Orifice Plate side of the device, and can be sealed dynamically using a simple o-ring or shaft seal. Third is that the bearing surfaces of the rotating drum are simply plastic sleeves that ride on plastic hubs in the outer housing. Because this device will be disposable and runs for only hours instead of days or weeks, this plastic-to-plastic bearing surface is more than adequate. Lastly, the small nature of this device allows a simple DC gear motor either directly or magnetically coupled to the drum to easily rotate it.

Initial tests of this filter were conducted in an apparatus configuration based on Figure 2 and shown in Figures 11 and 12.



**Apparatus testing setup**

FIGURE 11



**Dry cake discharge**

FIGURE 12

In testing the device, diatomaceous earth (DE) was used in various aqueous concentrations from 1 wt.% and 4 wt.%. Rotation speed of the drum, between 1 and 6 RPM, and source vacuum on the device, between 250 and 450 Torr, were also evaluated as to effects on the device's performance. To evaluate this performance, the slurry processing rate, or filtrate flow, was measured along with the percent moisture content of the cake produced from the device. In addition to these 30 minute to 60 minute duration experiments, two runs were conducted running the device for 6 to 8 hours to determine its the long term and overall robustness.

### RESULTS AND DISCUSSION

These experiments generated filtrate flowrates of 0.35 liters/min to 2.89 liters/min and product cake moisture measurements of 70.9 % by wt. to 33.7 % by wt. Figure 13 shows a typical cake formation while the device was in operation.

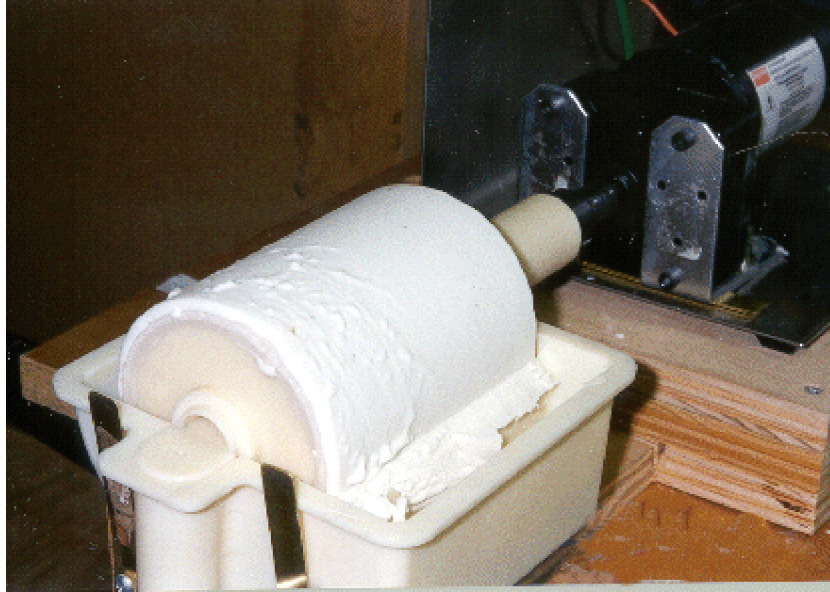


FIGURE 13, TOP REMOVED FOR CLARITY

These flowrate and moisture content values denote a large range of results whose causes should be analyzed before the actual effects of the independent variables tested are quantitatively evaluated. The range of these experimental results is primarily due to design problems with the initial prototype that directly affect the robustness of its operation. Determining these critical design factors was the primary purpose of this initial study.

There were four major critical design factors affecting the functionality of this device uncovered by this study. The first factor addressed was the sealing of the outer housing and outside of the drum from the vacuum source. This sealing surface for the initial experimental runs was plastic-to-plastic contact between the side of the outer housing and a rotating surface on the drum at the filtrate discharge end of the device. This sealing surface proved to be inadequate in the early stage experimental runs. Vacuum leakage through this seal caused it to function as a filtration location causing unacceptable solids accumulation at that end of the device. Figure 14 shows the effects of this seal failure.



FIGURE 14

Upon addition of a simple O-ring between these two sealing surfaces the leakage problem was eliminated.

The second and probably most critical functionality problem determined in the testing of the device was the accumulation of solids in the bottom of the outer housing. As with all vacuum drum filters, solids from the slurry tend to settle out and accumulate on the bottom of the filter trough, or in this case the bottom of the outer housing. In traditional vacuum drum filters some type of agitator is designed into the bottom of this trough to keep the solid suspended. Accumulation of this sort seen during testing is shown in Figure 15.



FIGURE 15, TOP AND DRUM REMOVED

Because of the small size of this device installation of an agitator as used in large vacuum drum filters is not feasible. Instead, other methods for re-suspending these accumulated solids were tried. The first modification was to add a slurry distributor over the feed inlet. This distributor can be seen in the center of Figure 15. Its function is to increase the velocity of the slurry entering the device with the intention of increasing the velocity of the incoming liquid and thus providing greater agitation of any accumulated solids. The distributor aided in the cleaning of solids from around the area of the inlet itself, but there still existed accumulations on both ends of the device. Another, untried, solution would be the periodic drainage of the slurry out of the outer housing either via the Feed Inlet itself, or via drain outlets oriented probably at the ends of the device were the largest amounts of solids accumulated.

It was also noted that the solids accumulating at the bottom of the device were of a larger than average particle size. Because there was a large particle size distribution in the DE used in these experiments, the accumulation of solids on the bottom of the outer housing essentially functioned as a separator. Periodic draining of the device to remove these larger particles should prove to be effective, but further study on this aspect is required.

Two other, more minor, operability design considerations were uncovered by these preliminary tests. The first of these was the surface tension effects on the level of liquid in the outer housing. The initial fabricated level of the Cake Removal Knife and size and level of the Feed Overflow were found to be inadequate. Initial design calculations determining these sizes and levels did not account for the significant effects of water surface tension in a device this small. Essentially, this caused the operating level of the prototype to be too high and require operator attention to

prevent improper functioning of the device. Although troublesome for operation of this prototype, these problems are easily solved by small changes in these components. Modifications of this type should insure very little operator intervention in future designs.

The final minor effect on these test results was due to eventual plugging of the filtration media itself. An example of this plugging is seen in Figure 16.



FIGURE 16

Once a filter experienced this plugging problem, the device was disassembled and the porous plastic filter media tube was removed and replaced with a new one.

There are two plausible explanations for this plugging phenomenon. First is microbiological growth in the porous plastic between experimental runs, and second is plugging of the 15-40 micron pores with DE that is of a smaller size. Although both of these could have contributed to this phenomenon, microbiological growth is seen to be the primary contributor. This assumption is based on the fact that the last two runs for this study were done with new filter media and successfully operated continuously for a period of 6.5 hours and 8 hours. These long-term runs were initially designed to determine how long this device could operate continuously. During these runs no significant change in processing rate, and no indications of plugging were observed.

The majority of the runs to determine the effects of different independent parameters on this device were conducted for a period of 30 to 70 minutes. Only a few of these runs were conducted per day after which the filter was cleaned and the all the cake removed. It could not

be determined if all the moisture was removed from the filter media in this cleaning operation. It is assumed that microbiological growth could have occurred as the device was idle between times of operation. This is further confirmed by the existence of a faint gray color to the filter after it was removed due to plugging. After the filter media showed signs of plugging, it was replaced with new filter media. The flowrates drastically increased when a new filter media was installed. This produced some discrepancies in the data collected, and clouded the actual effects of the independent parameters being evaluated.

This plugging phenomenon, although significant in the initial testing of the device, is not of prime importance for its industrial applications since the commercial device will be a single use, disposable unit.

The primary purpose of this prototype testing was to validate the design's general applicability, and to look for design areas that could limit the functionality. The general operating observations noted above serve this purpose. In addition to the qualitative information gained from these experiments, specific quantitative information about the effects of certain independent variables were evaluated. It should be remembered in looking at the data, some of it is clouded by the plugging problems that initially occurred.

The specific relationships evaluated were:

1. Effect of DE Concentration on Flowrate
2. Effect of Vacuum on Flowrate
3. Effect of Drum Rotation Rate on Flowrate and Cake Moisture Content
4. Effect of Vacuum on Cake Moisture Content
5. Effect of DE Concentration on Cake Moisture Content

Figure 17 shows the observed relationship between DE Concentration and Flowrate

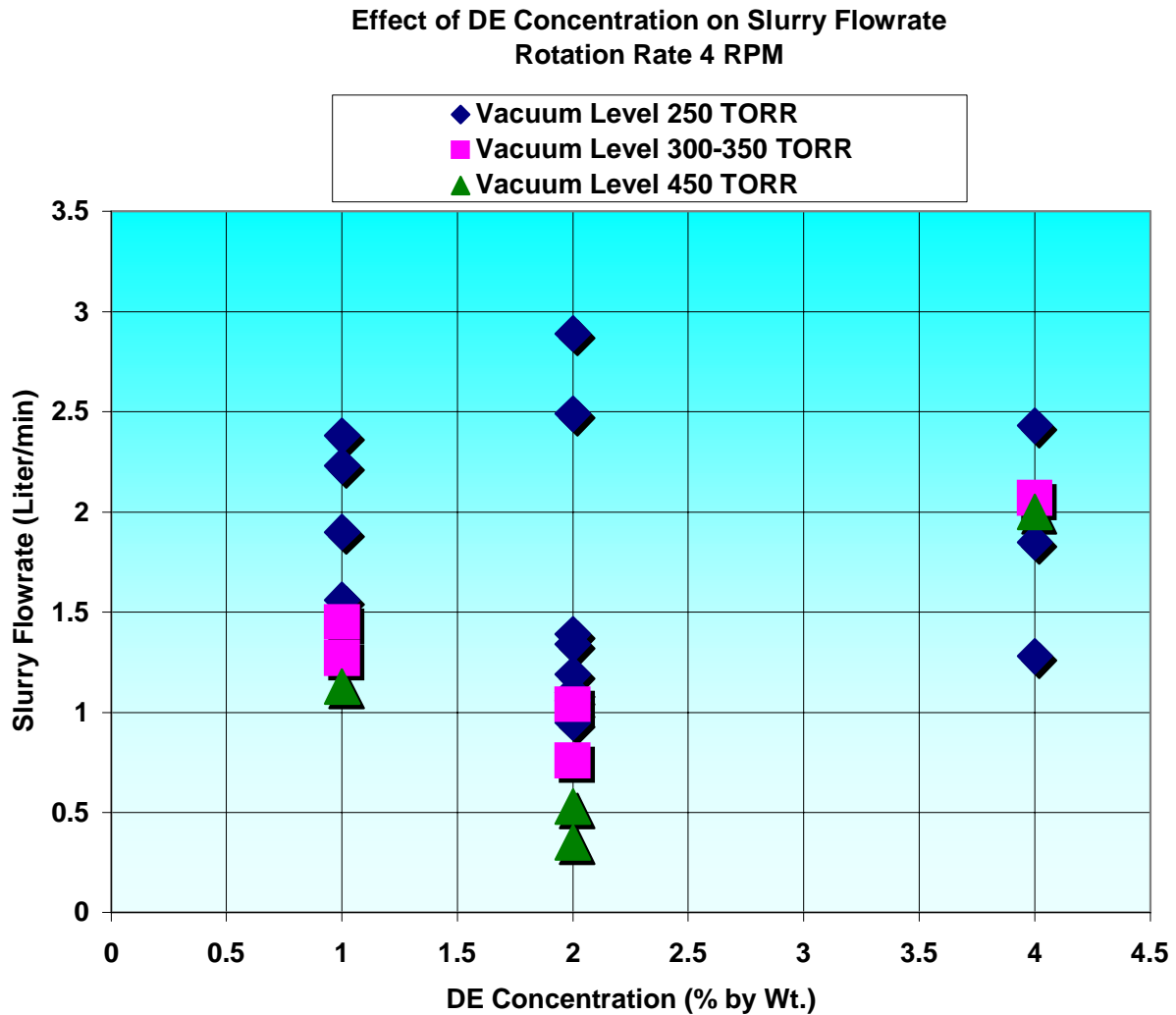


FIGURE 17

It can be seen here that flowrates for this device varied between less than 1 liter/min. to almost 3 liter/min. The lower numbers on this data are primarily due to filter pluggage not that of DE concentration. Although intuitively it may be thought that flowrate should decrease with higher DE concentration this appears not to be the case. The combination of limiting the DE upper limit concentration to 4% and plugging problems contributed to the lack of any appreciable trend to this data.

Figure 18 shows the effect of vacuum, or absolute pressure, at the filtrate outlet on flowrate.

**Effect of Vacuum on Slurry Flowrate  
Rotation Rate 4 RPM**

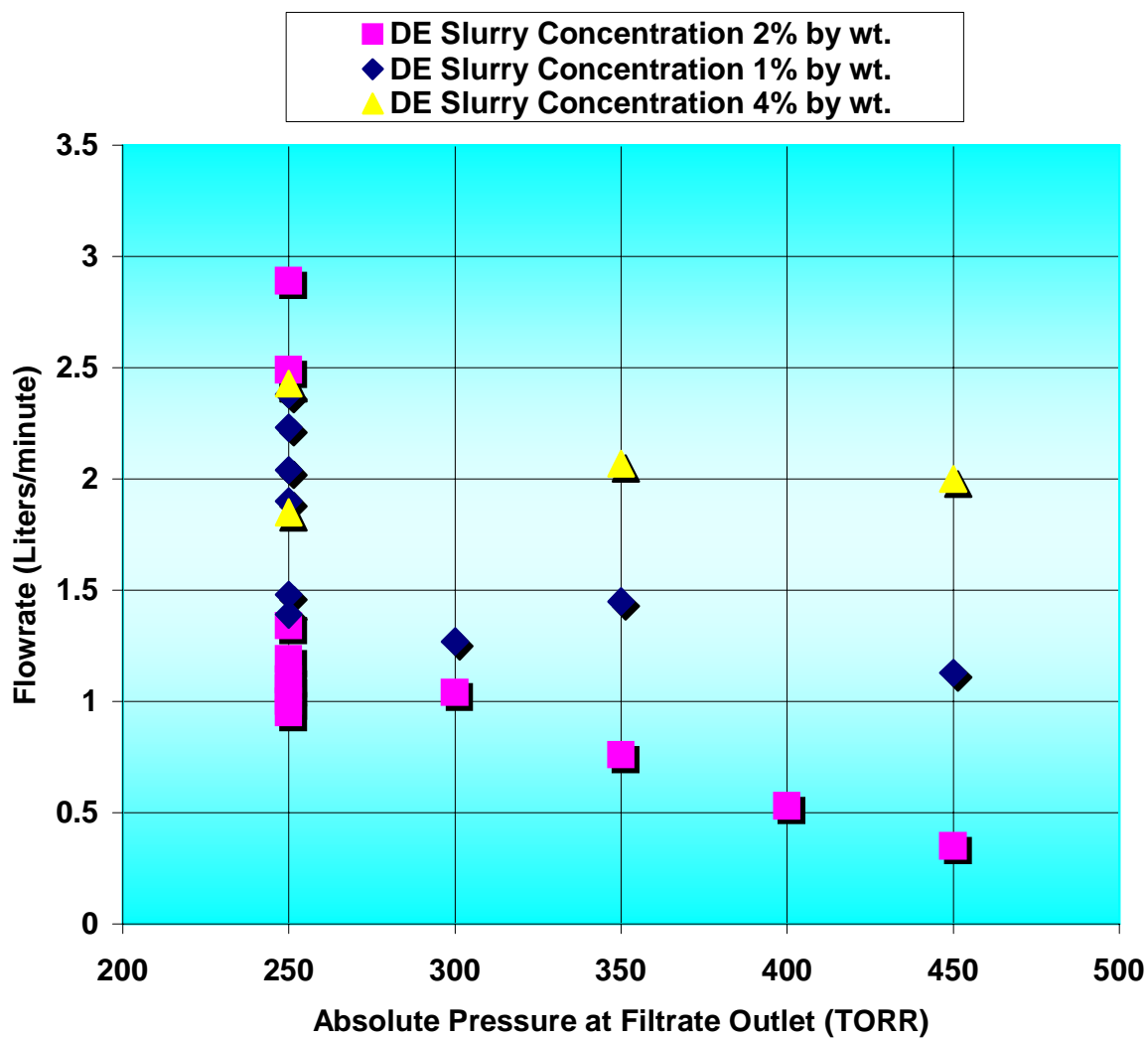


FIGURE 18

Again this data is tainted especially at the low end by plugging problems, but a slight downward trend of flowrate with increasing absolute pressure maybe present. This could be due to the decreased pressure differential driving force across the cake, but again this trend is suspect.

Figure 19 shows the effect of rotation rate on both cake moisture content and flowrate.

**Effect of Rotation Rate on Flowrate and Moisture Content**  
**Absolute Pressure 250 Torr**

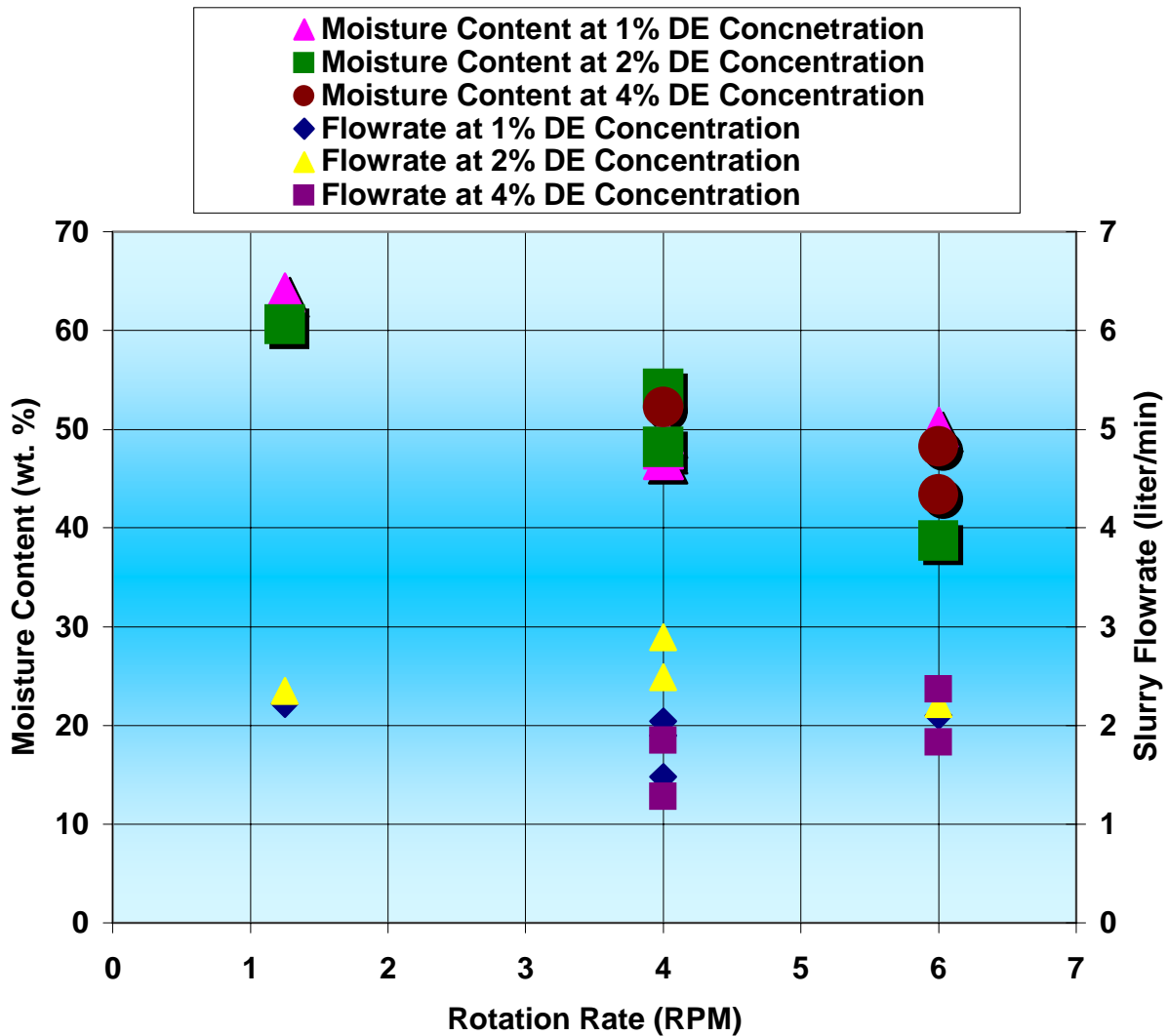


FIGURE 19

According to this data, rotation rate seems to have little effect on the processing flowrate capable in this device.

As for the rotation rate's influence on cake moisture content the effects seems to be very pronounced. In fact, it seems to be the most pronounced trend resulting from these experiments. Perhaps this is due to the plugging problems having little effect in influencing the moisture

content. Initially, it would seem that a slower rotation rate would produce a dryer cake, primarily due to the fact that the slower rotation rate would allow more time for the cake to be exposed to the air drying portion of the rotation cycle. Although this is true, the slower rotation rate also allows more cake thickness to accumulate on the drum. As a result, then the cake reaches the Removal Knife a thicker cake is discharged. Although the outer layers of this cake may be dryer, the inner layers are not. At faster rotation rates there is less time for drying, but there is also less time to accumulate cake on the drum. The thinner cake means that less cake is removed at the Knife. Since only the extreme outer layer of the drum cake is removed, it is dryer, producing a lower cake moisture in the product. Thus the effect of removing only the extreme outer layer of the cake is more important than how long the cake is in the drying portion of the rotation cycle.

Figure 20 shows the effects of vacuum on the cake moisture content.

Effect of Vacuum Level on Cake Moisture  
Rotation Rate 4 RPM

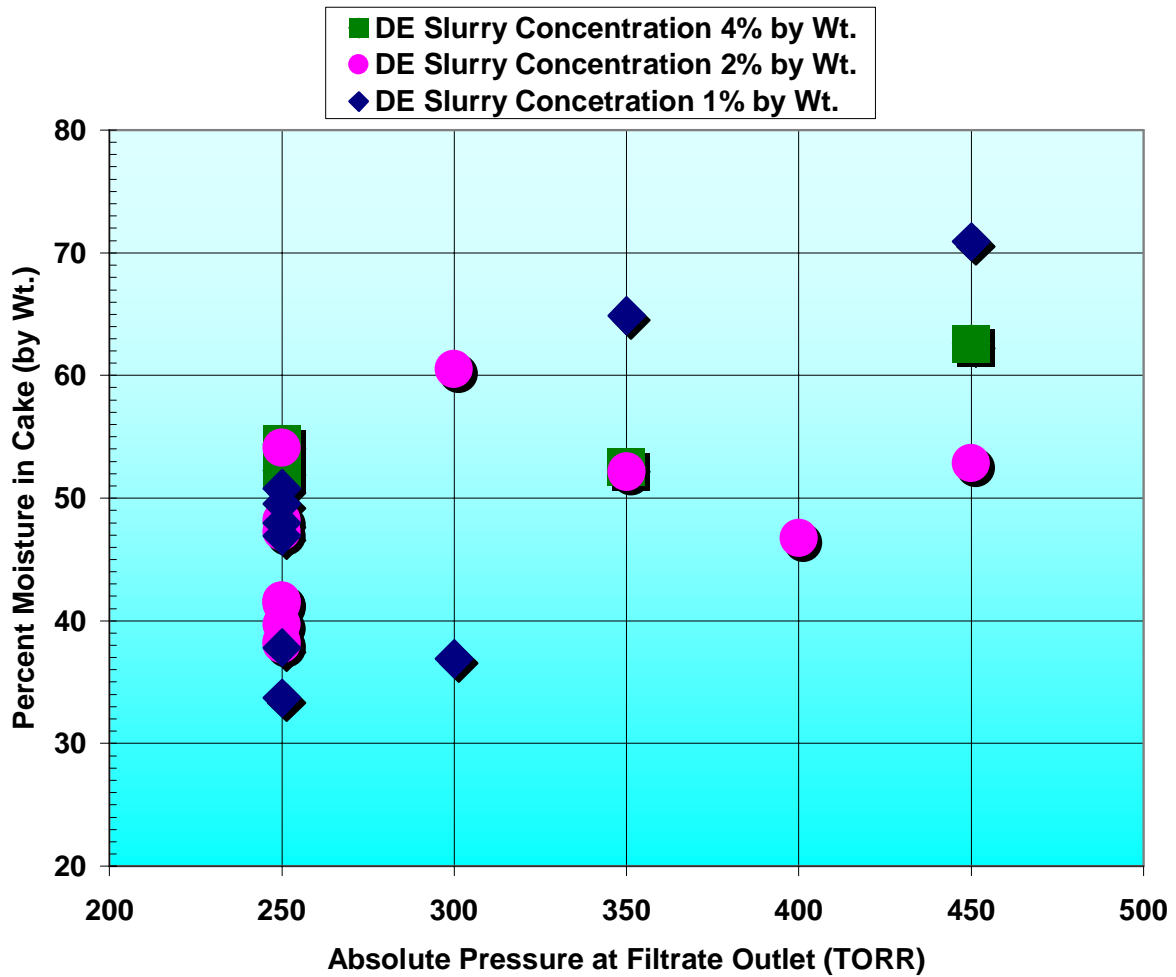


FIGURE 20

Cake moisture in this case seems to increase slightly as the absolute pressure increases. This seems intuitive since the increase in pressure decreases the air flowing through the cake to dry it.

Figure 21 illustrates the effect of DE concentration on cake moisture.

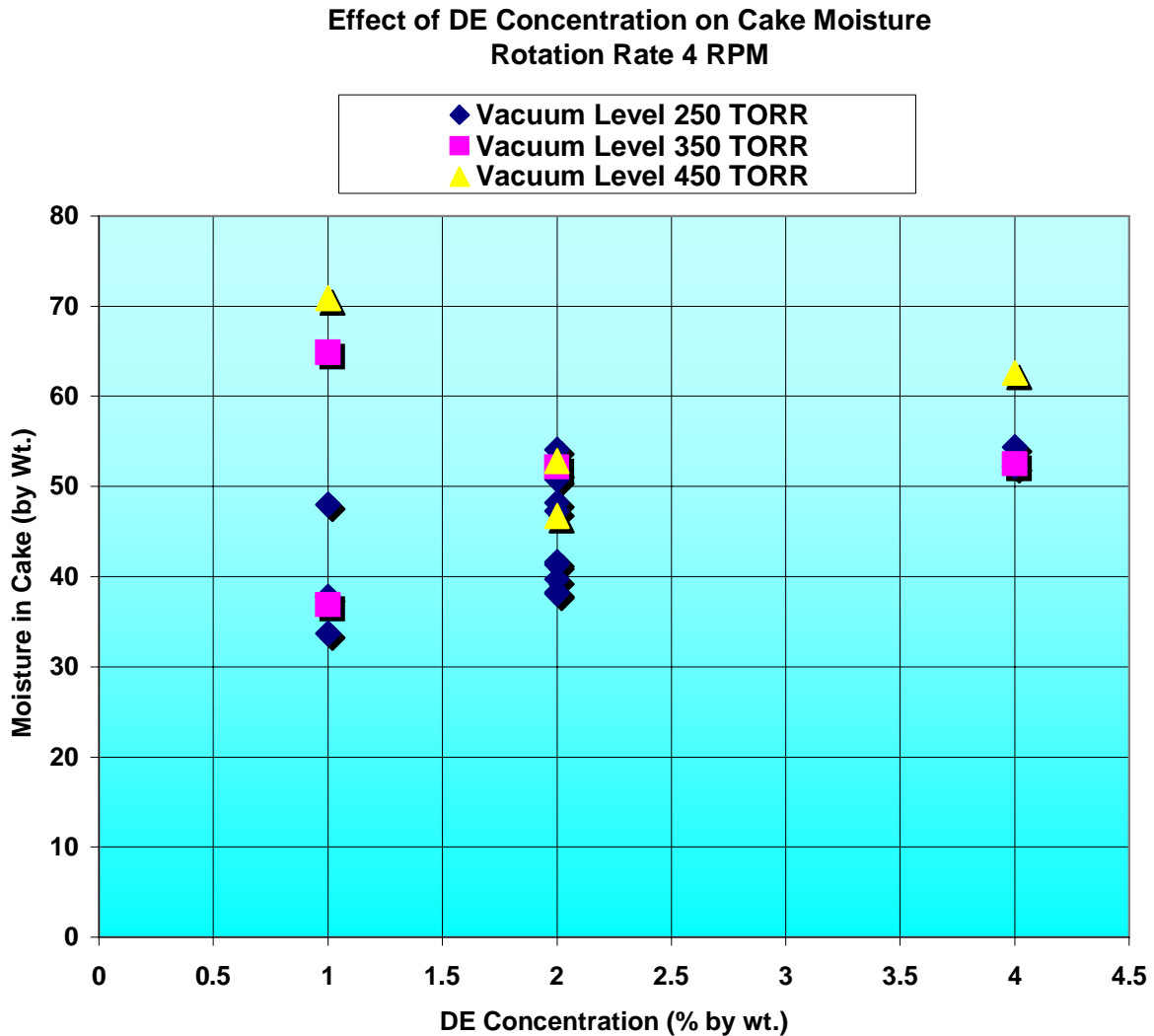


FIGURE 21

Although it may be assumed that cake moisture would increase with higher DE concentration in the feed slurry, due to thicker cakes being accumulated, the test data does not justify this assumption. No consistent trend can be deduced initially from this data.

**CONCLUSIONS**

To evaluate the true potential of this device when used in traditionally “batch” applications, a meaningful way to compare capacities must be found. A batch device’s capacity is usually determined by its total filtration surface area available. In the case of the Disposable Rotary Drum Filter, the actual surface area of the drum is very small, but since the unit operates

continuously, the functioning surface area must be evaluated over its total operation time. Using this method of analysis, Figure 22 shows the filtration surface area of the prototype as a function of time.

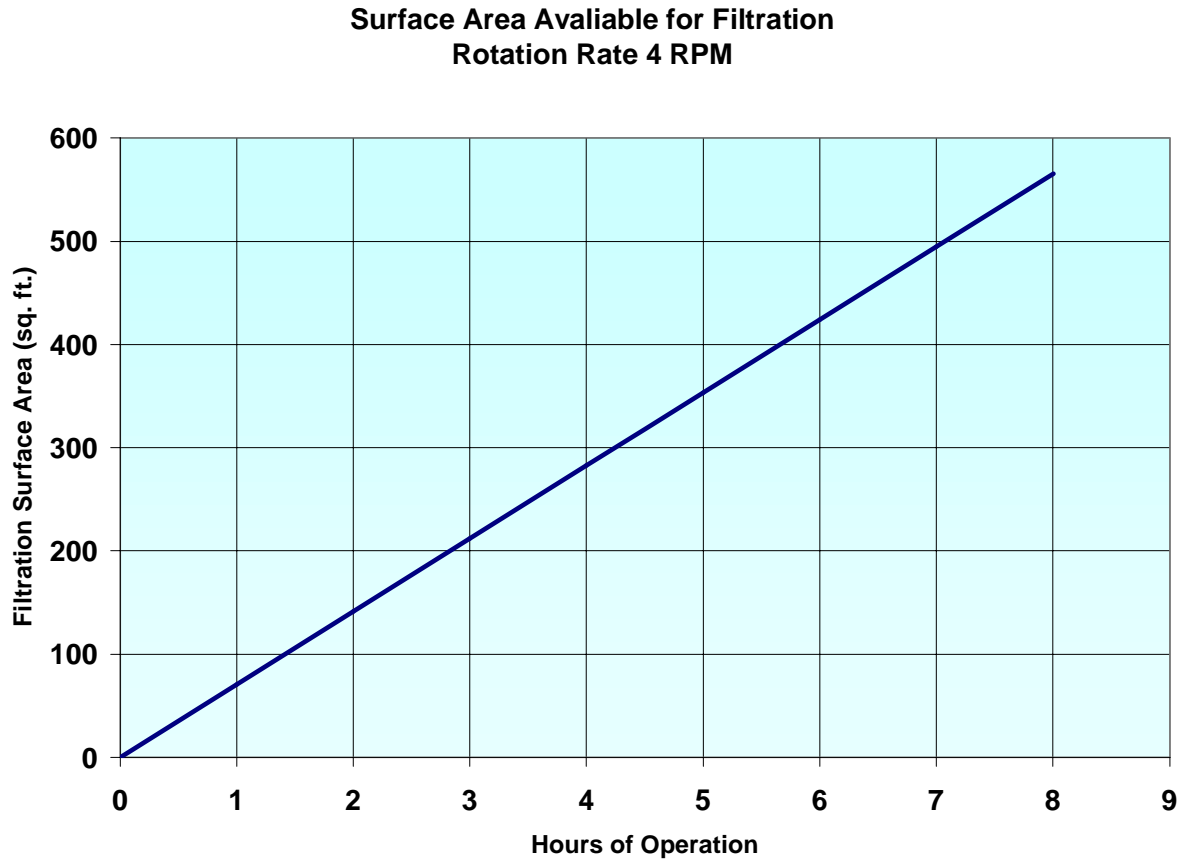


FIGURE 22

As can be seen, this small device has the equivalent filtration area of batch equipment many times its size.

Another measure of a filtration device is its batch processing capacity. Again, for the Disposable Rotary Drum Filter this measure is related to how long the device is operated to process a single batch of material. Figure 23 shows this processing capability.

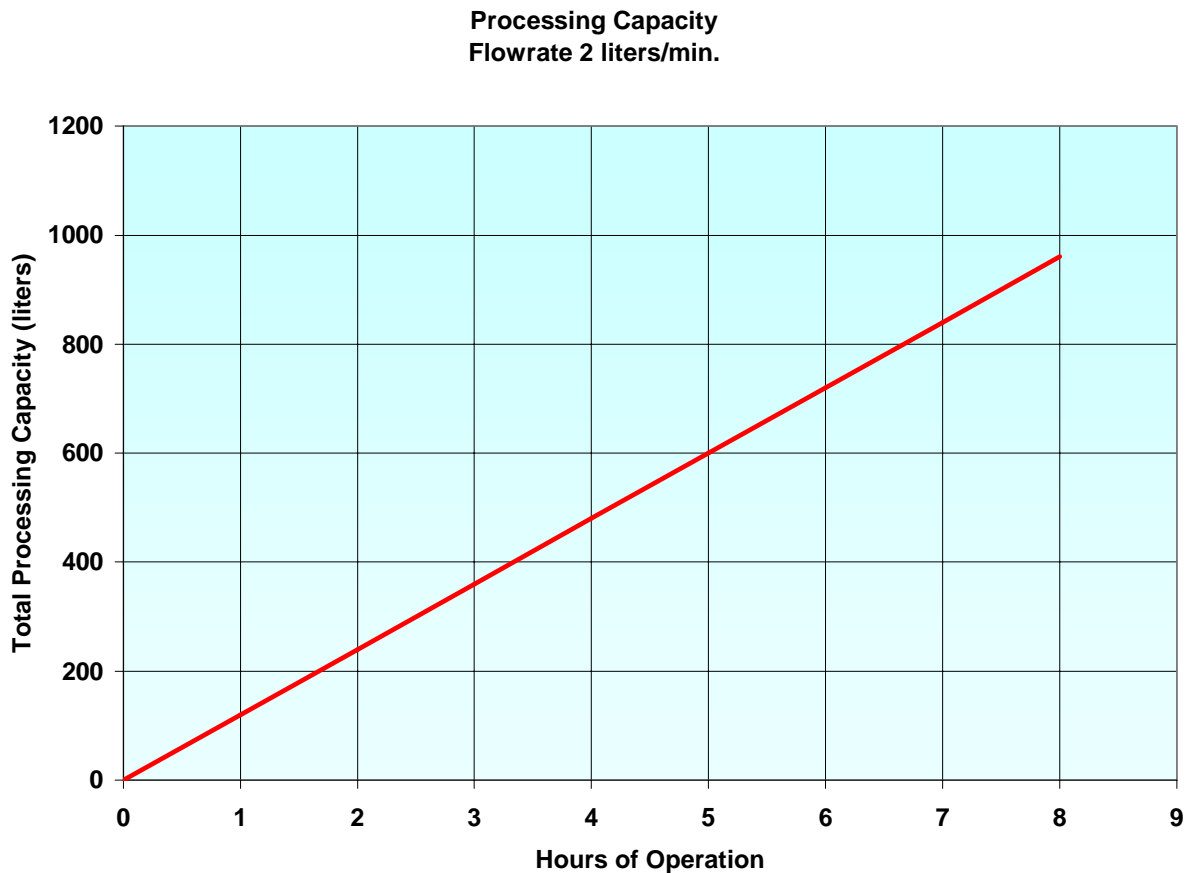


FIGURE 23

Although some of the quantitative data collected in this study was clouded by some unforeseen flaws in its execution, specifically the plugging experienced in the device, the overall robustness of the design was shown to be justified. Also, the study revealed some design deficiencies in the device were readily resolved.

This existing data could be expanded further by analyzing how this device operates theoretically compared with long established equations developed to predict the behavior of traditional vacuum drum filters. It is assumed that the new device may exhibit a significant departure from these equations since they were developed for equipment that is orders of magnitude larger than the one evaluated here.

Future studies on this device will expand its applicability in more areas of solids-liquid separation processing. Some of these future areas of study will include: The installation of a magnetic drive mechanism instead of a direct drive to enhance the isolation of the inside of the

device; the use of these devices in series to enhance cake washing and filtrate recovery; activated carbon impregnated filter media to enhance material purification; use of a variety of pore sizes for the filter media; changes in drum sizes to expand the device's areas of application; use of this device to simplify and enhance chromatography applications.

#### ACKNOWLEDGMENTS

This study was supported in part by a grant from the Washington Technology Center. Thanks should go to Professor Nicole Hoekstra of Western Washington University and Brian G. Thompson who conducted a majority of the experimental runs. We also thank Ideality Inc., Ric Landvatter and his staff for fabrication of the prototype used in the study, and Beacon Engineers Inc. for their technical support. Lastly, we would like to thank Porex Technologies for supplying the porous plastic filtration media for this prototype.

#### REFERENCES

McCabe, W.L., Smith, J.C., Harriott, P., *Unit Operations of Chemical Engineering*, 5<sup>th</sup> Ed., McGraw-Hill, New York 1993, pp. 1002-1011.

Schweitzer, P.A., *Handbook of Separation Techniques for Chemical Engineers*, McGraw-Hill, New York 1979, pp. 4-3 – 4-54.

Perry, R.H., Green, D.W., *Perry's Chemical Engineers' Handbook*, 7<sup>th</sup> Ed., McGraw-Hill, New York 1997, pp. 18-81 – 18-102.