Operation of a Disposable Rotary Drum Filter

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Introduction

Batch filters like Nutsch, plate and frame, leaf, disc, horizontal plate, tube, and candle are widely used for cake filtration in the pharmaceutical, fine chemical, hazardous materials, and beverage industries. Although this batch equipment is acceptable, it usually comes at a high capital cost and involves extensive cleaning before and after use.

The mature nature of the cake filtration industry, and limited transfer of technology between existing batch processing industries and traditional Chemical Process Industries (CPI) results in a somewhat limited introduction of new equipment to compete with existing batch methods. In an effort to develop meaningful new equipment, existing ideas about the inherent limitations of methods used for batch-oriented processes had to be re-evaluated. The great efficiencies of continuously operated equipment developed over the past 50 years for use in the CPI also needed to be taken advantage of. The challenge was developing a piece of equipment that uses the advantages of continuous processing to minimize or eliminate many of the inefficiencies inherent in batch-oriented equipment, while still accommodating the unique requirements present in most of these systems. As we will see, this involved an innovative reevaluation of a traditional cake filtration unit operation conducted from the ground up.

The type of continuous cake filtration equipment chosen to be refashioned was one of the most common in the CPI, the Rotary Drum Vacuum Filter. This paper will concentrate on the currently available injection molded commercial device developed from this work, by outlining the testing done on this equipment, its potential markets, and configurations possible for its application.

The new device is called the Disposable Rotary Drum Filter.

Cost Effectiveness

The primary advantage of this new device is its cost effectiveness over traditional solid-liquid separation equipment currently used in the batch processing industries. The basic premise here is that by using a continuous piece of equipment to process a specific batch of material, one can use a much smaller size of equipment than traditional batch devices accommodating the same function. This smaller sized device immediately transfers into smaller capital cost for equipment. Along with this, since the amount of material being processed is relatively small, the continuous device can be so small that it can be made out of injection molded plastic, and be economically used as a single use, disposable device. As a result, the capital cost savings are compounded by the operational saving of eliminating pre and post cleaning. This cleaning is common and frequently very costly for batch equipment.

The types of batch equipment that the Disposable Rotary Drum Filter would compete with would include Nutsche, plate and frame, leaf, disc, horizontal plate, tube, and candle filters, as well as centrifuges in many applications. One way for a designer to evaluate whether the capacity of a certain piece of batch filtration equipment is appropriate to their application is to look at the total surface area available for filtration. Unlike batch equipment, the surface area available in this new device is dependent on the time it is allowed to operate. This is of course because, like all rotary drum filters, the filtration surface is continuously cleaned as the drum is rotated and the cake removed. Figure 1 shows the surface area available for filtration for this device as a function of time.

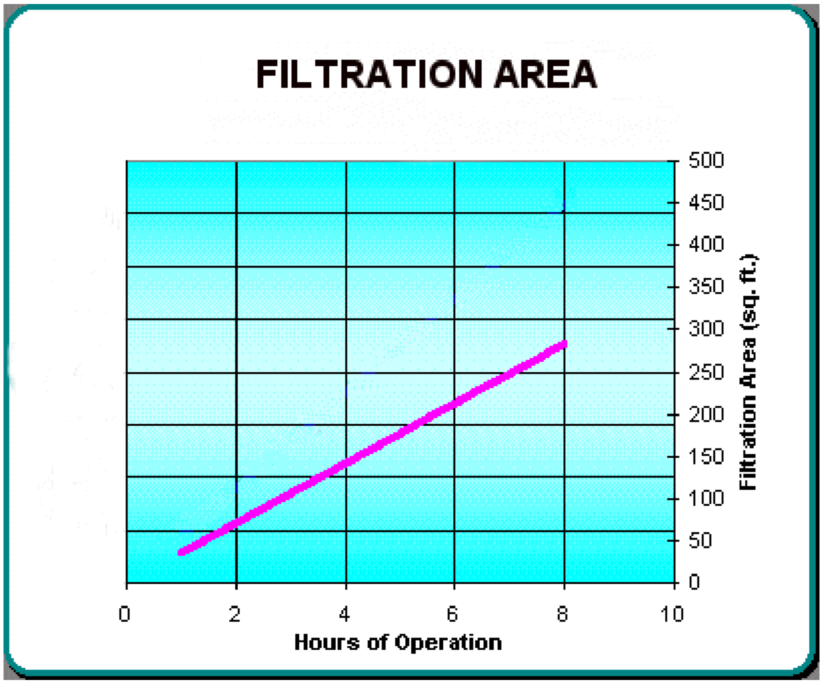

Figure 1

As can be seen, the surface area available for filtration for this new device can range from less than 50 sq.ft. to over 250 sq.ft. depending on the time it is allowed to operate. This filtration area is well within the range of most Nutsche filters and plate and frame filters used in pharmaceutical applications.

Traditional batch cake filtration equipment with this range of filtration areas could have capital costs from $10,000 to $50,000, with centrifuges costs being significantly higher. Along with these capital costs comes the operating costs of this batch equipment. In most cases the operating cost is primarily made up of the labor involved in cleaning the filter after its use, and preparing it for processing the next batch of material. The time required for this work will vary depending on the complexity of the equipment involved and the level of cleanliness required. In some cases this could be less than a hour, while in others, especially applications were a high level of cleanliness is required, it could take of two people 8 hours. In the case of centrifuges, the disassembly, cleaning, and re-assembly of the equipment could be much more complicated and time-consuming, extending over a period of days. Couple this with the added mechanical maintenance requirements of centrifuges, and the operating costs of this type of traditional equipment is driven even higher.

Based on this, the cost of just cleaning and maintaining a traditional piece of solid-liquid separation equipment between batches can range from a few hundred dollars on the low end, to over a few thousand dollars. These costs also may not include any consumables like filter media and miscellaneous replacement parts that may be required from time to time.

The object of the development of the Disposable Rotary Drum Filter was to produce a device that was cheap enough to be used only once yet still have a cost that is less than the typical operating cost of a traditional piece of equipment. The advantages of this approach are compounded by the fact that there is literally no capital cost associated with this new device.

Device Design

The function of the Disposable Rotary Drum Filter is based on the same principles as a traditional rotary drum vacuum filter. As with all rotary drum vacuum filters, a drum, covered with a filter media, is positioned on its side and partially submerged in a solid-liquid slurry. A vacuum is pulled on the inside of this drum. Liquid is pulled through the filter media and becomes the filtrate, leaving the solids in the slurry deposited on the filter media as a cake. Rotation of the drum along its axis causes sections of it to move out of the areas of submergence. At that time, the vacuum on the inside of the drum proceeds to dry the deposited solid cake. As the drum rotates further the cake comes in contact with a device that removes all or part of it from the filter media. The drum continues rotating past this point and the whole process repeats itself. This continuous operation allows the use of a piece of equipment with a theoretically infinite, or regenerated, surface area for filtration.

Although rotary drum vacuum filters have been used in wastewater treatment, chemical processing, pulp and paper, and many other facilities in the CPI, their applications have usually been restricted to processes having relatively large flow rates. This is due to the fact that the mechanical components needed to rotate the drum, the piping and configurations needed to transport filtrate from underneath the filter media to the center of the drum, and the valving required to control the vacuum inside the drum, can only be made so small. This translates into a minimum size for a device designed in the traditional fashion. Rotary drum vacuum filters traditionally do not have many applications in batch operations because the amount of volume to be processed is usually not large enough to allow this device to even reach steady state operation let alone operate for a period of time required to make its use economical. Compounding this, the complicated mechanical nature of these traditional devices made them difficult to enclose and clean, thus minimizing their potential for uses in industries like pharmaceuticals.

In order to alleviate these inherent problems, the Disposable Rotary Drum Filter was designed with small scale operation in mind. The target being to develop a piece of equipment that could be used in larger scale laboratory and pilot plant/small scale production environments, areas where traditionally only batch cake filtration equipment was used. In order to design a continuous device for this type of application it would have to be very small. For the initial prototype and the first production units of this filter a drum size of 3 inches in diameter and 4.5 inches long was used. This gives a total drum face surface area of 42.4 in^2 or 0.295 ft^2. With about 33% of the drum surface submerged at any one time, this gives a filtration area of about 14 in^2 or 0.097 ft^2. Of course, since the filter operates continuously, the total filtration area is also a function of the amount of time that the filter is in operation, and the rotation rate of the drum as shown in Figure 1. This drum size resulted in a overall size for the complete device of 7 inches long by 6 inches in diameter. Testing of the first production models, Figure 2, produced found this device had a slurry processing rate of 1 to 3 liters/minute. This allowed the device to have a batch processing capacity of upwards of 900 liters (240 gallons) if operated over an 8 hour period. On the lower range, operating for only one hour would enable it to process a batch size of about 120 liter (32 gallons). This wide range of operation encompasses most of the target market originally envisioned.

Figure 2, Disposable Rotary Drum Filter in Operation

The operational flow sheet for the Disposable Rotary Drum Filter is analogous to other rotary filters like vacuum drum and vacuum disc filters, and is outlined in Figure 3.

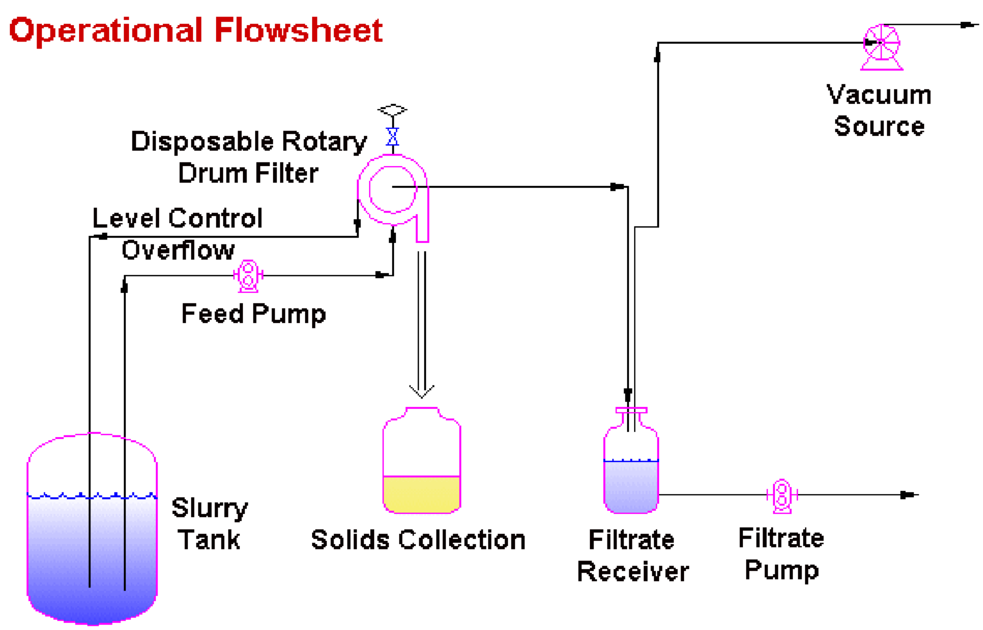

Figure 3

Note that the only real differences between this and large scale equipment is that the solids collection container can be smaller and has the ability to be fully enclosed, and the filtrate/vacuum system is simplified. Instead of having vacuum receiver(s), a moisture trap, and a barometric seal leg, the filtrate receiver provides all these functions. This is possible of course since this system is so small compared to traditional large industrial applications.

In order to allow this new device to be made so small, a few major simplifications were incorporated into its design.

1. Simplified Filter Valve. Instead of the common complicated internal piping and rotary valve or filter valve found in most rotary vacuum filters, a simple orifice plate is used to differentiate the vacuum exposure of sections of the drum that are in and out of the feed slurry. Although this design eliminates the possibility of having a cake wash and a blow-back, it allows it to be made much smaller then ever possible before.
2. Simplified Slurry Agitation. In most vacuum drum filters some type of agitation in the slurry trough is required to keep the solids from settling out. In this new device a diverter plate in the slurry inlet increases the velocity enough to replace mechanical agitation. The elimination of any mechanical addition enables a simplification, allowing minimum design size and cost while enhancing reliability.
3. Simplified Seals, Bearings. Since this device is designed to process batches of material, its operating life is limited to 1 to 8 hours. This allows the drum to rotate on simple plastic hubs molded into the device. This coupled with simple elastomeric shaft and vacuum seals produces a mechanically small and inexpensive unit.
4. Self-supporting Filter Media. The filter media, or septum, for this device is a tube of porous plastic. This configuration allows the filter media to support itself, simplifying the overall design. This also allows many different types of porous plastic to be used, thus increasing the types of processes in which the device can be used.

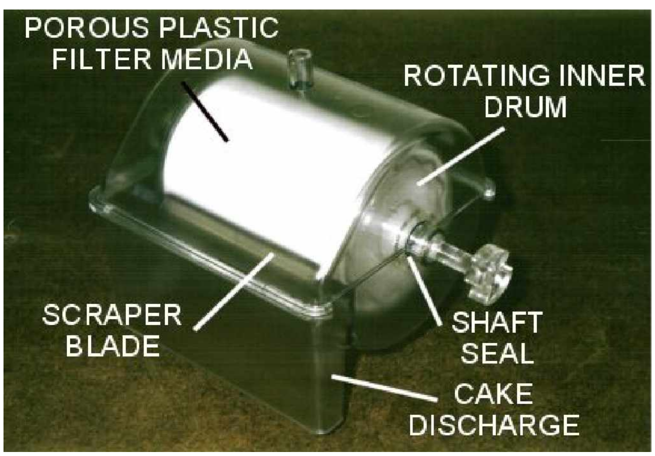

Figure 4

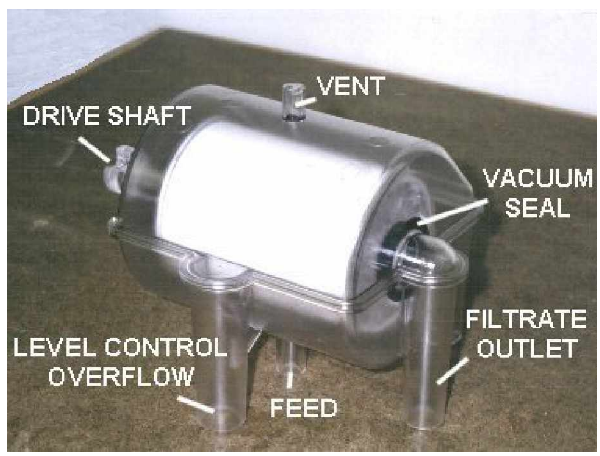

Figure 5

These simplifications not only allowed this new device to be small, but also allowed it to be constructed so that it is could be totally enclosed. This allows it to be used in applications that require control of the material being processed to protect it and/or the personnel. This opens up a variety of applications in the pharmaceutical, fine chemical, and food industries. This simplified design also accommodates construction out of cheap injection molded materials so that it is viable as a single-use, disposable device.

Product Testing
Initial testing of a prototype of this device was detailed in a paper presented at the AFS Annual Meeting in May of 2001, entitled, "DESCRIPTION OF A DISPOSABLE ROTARY DRUM FILTER APPROPRIATE FOR USE WITH SMALL VOLUME HIGH VALUE PRODUCTS." Results of that testing lead to the development of the final injection molded production model of this device discussed and tested here. Initial testing was done on the first run of these filters to determine their overall filtration capacity and the "robustness" of the commercial design. This testing consisted of the filtration of aqueous suspensions of Diatomaceous Earth (DE).

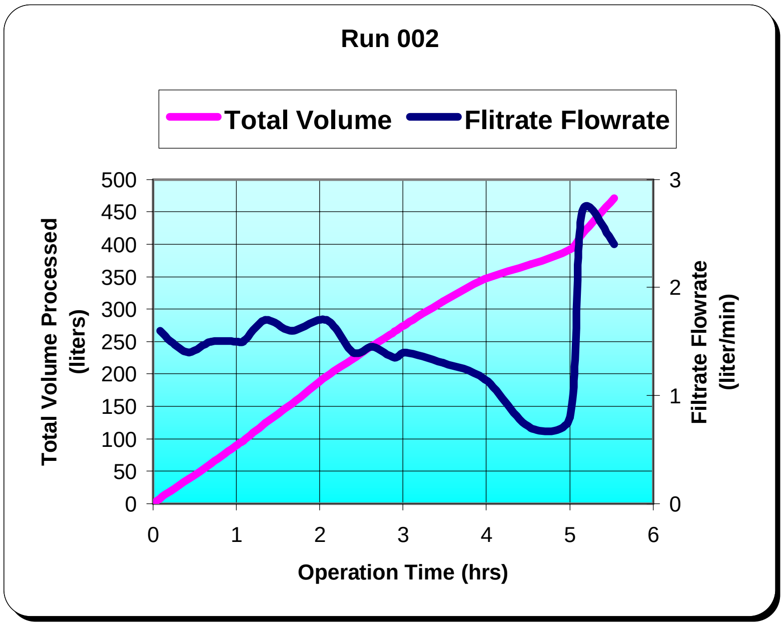

Figure 6

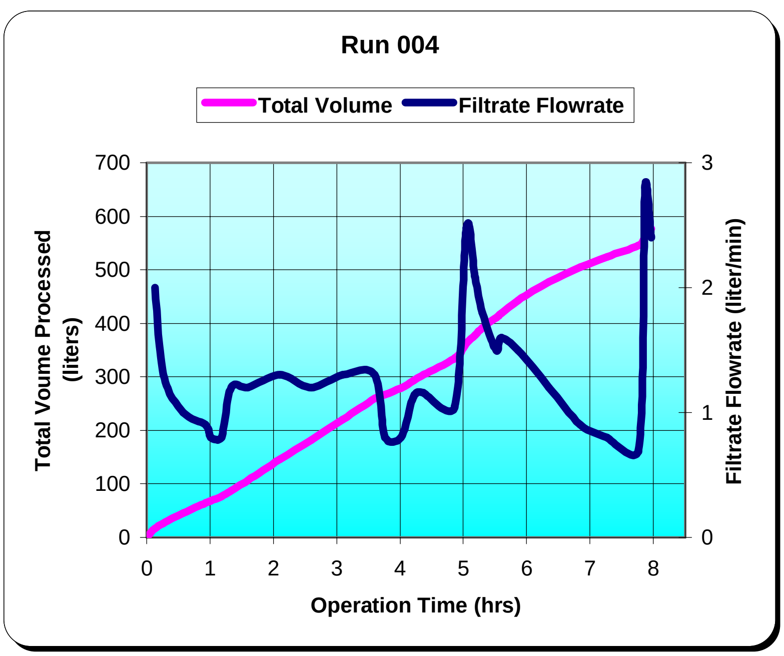

Figure 7

Figures 6 and 7 document two sample runs done on these filters. These figures denote the changes in filtrate flow rate with time during operation, and the total cumulative amount of filtrate processed through the filter. As can be seen from 450 liters to over 550 liters were processed during these test runs. The filtrate flow rate during these runs varied from about 0.7 liters/minute to almost 3 liters/minute. Some of the variation in these flow rates can be attributed to fluctuations in the vacuum applied to the device, but there is still a consistent downward trend as filtration proceeded. During operation of the device, it was noticed that a consistent cake was formed within 2 to 5 minutes of operation. Even though a consistent cake was visible, the flow rate through the filter continually reduced as operation progressed. This is best seen in Figure 6 where the filtrate flow rate reaches a low point after about 4.5 hours of operation. Plugging of the pores of the filter media or septum, or filling of all the spaces in the DE cake on the drum could be two reasons for this lowering of processing rate.

The steep rises in filtrate rate seen in both figures occurred after the cake was removed from the drum. This was not done manually, there would be not way to do that with this device, instead this removal was accomplished by removing the vacuum from the device and allowing the feed flow rate and rotation of the drum to continue. The Level Control Overflow on the device accommodated the feed rate and by continuing to rotate the device, the caked on the drum quickly fell off completely within a few revolutions. Vacuum was then reestablished and the filtration continued at greatly increased flow rates. As seen, these flow rates started falling again, but this technique provided a way to generate a "clean" filtration surface easily and without jeopardizing the integrity of the device or the material being processed. It is not known how this operation effected the clarity of the filtrate immediately after it was conducted, but the overall filtrate clarity did not seem to be effected. This also implies that the majority of the processing rate reduction was due to the filling of voids in the filter cake itself and not the plugging of the porous plastic filter media or septum.

In addition to determining the overall functionality of this commercial unit, a few other important operating limitations were found during this initial investigation. The first was what vacuum levels are needed to form a satisfactory cake on the filter media or septum. It was found that at least 4 to 5 inches Hg vacuum is required to form a satisfactory cake on the drum surface. At this vacuum level an air flow of about 4 ACFM is present through the cake on the filter drum. These values are only valid for the DE slurry that was tested in this device, but they give a starting point of what is required of the vacuum source that is to be used. Of course, higher vacuum levels will generate higher filtrate rates and require a higher capacity on the vacuum source. For this version of the device, mechanical concerns limited the maximum vacuum that can be applied to the unit to about 10 inches Hg. Future designs will eliminate some of these limitations and allow higher vacuums to be used increasing the processing rates and enlarging the range of applications in which this device will be applicable.

As noted above an inlet distributor was used to produce agitation in the bottom trough housing of this filter, keeping the solids there in suspension so that they could be filtered through the rotating drum. At an inlet flow rate of about 3 liters/minute a minimum amount of accumulation of solids was noticed in the bottom of the housing. If the inlet slurry flow rate was increased to about 4 liters/minute, all solids accumulation disappeared. With the distributor in place the area available for flow for the inlet slurry is 0.156 inches^2. This gives an inlet velocity of 1.63 feet/second at 3 liters/minute, which represents the minimum velocity required to provide adequate agitation in the trough of the device. At an inlet velocity of 2.17 feet/second, corresponding to a flow of 4 liters/minute, the agitation is such that no solids are present in the bottom of the device. Actual performance of this distributor will be different with solids that have different particle size distribution and density than the DE used here.

The last parameter quantified in this testing was the capacity of the Level Control Overflow for this device. This overflow insures that the liquid level remains high enough to cover about 33% of the drum. There is a limit as to how much flow this port on the filter can accommodate. Exceed this value and the liquid level in the device gets too high and slurry can start flowing out the Cake Discharge Chute, contaminating the dry cake that is being collected. It was found that overflow rates of up to 3.9 liters/minute could be accommodated by this overflow without causing process upsets, by keeping this overflow rate below 3 liters/minute insured upsets would not occur.

Commercial Applications
Initial commercial applications of this device are targeted for industries that deal in small-volume, high-value products. These industries would include the pharmaceutical and biotech industries as well as some processes in the fine chemical industries. Specific applications would include those that are now done in batch equipment like disc or plate and frame filters or semi-continuous equipment like centrifuges, like separation of cell debris from a fermentation broth. Further downstream in the process, this equipment can be used to recover precipitated or crystallized product from a purification step. Also, any application that traditionally uses a filter aid would likely be an applicable candidate for use of the Disposable Rotary Drum Filter.

Although the Disposable Rotary Drum Filter does not have the capability for cake washing within the device, simply running two of these devices in series can accomplish this same task, as shown in Figure 8.

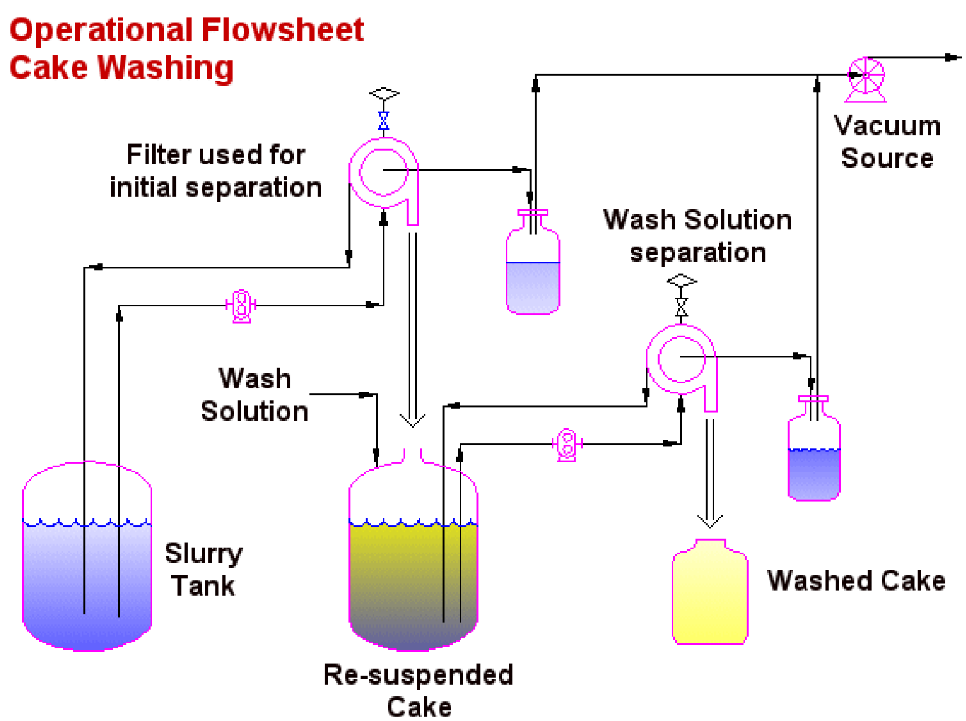

Figure 8

In this configuration, cake from the initial separation is re-suspended in wash solution then processed through the device again. This configuration could be used with one or two filters. If two are used, the system could be run continuously as shown. If one is used, then the cake would have to be held in the re-suspension tank, then run through the original filter after the initial separation was complete. Using this technique, a system that needs cake washing can be easily accommodated.

One extended application, outside that typically considered for vacuum drum filters, would be single stage chromatography for use specifically in biotech applications.

Because of the small size of this new device and the limited equipment needed to operate it, the whole system if very portable. This would lend itself for use in remote or field sites as may be seen in environmental and remediation applications.

Conclusions

The entrance into the filtration market of the Disposable Rotary Drum Filter opens up processing and cost reduction possibilities that have not been seen before. This device's small size and economical cost allows users to greatly reduce the capital cost associated with solid-liquid separations in traditionally batch industries. In addition to this, the enclosed nature of this device and its disposability enhances the control of the processes at hand, minimizing operator contact, protecting themselves as well as the product. Although this device was originally designed for high-value applications, its ease of use and large processing capacity for its size and cost, will allow it to find uses in a great number of solid-liquid applications.

References

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