SOLID-LIQUID FILTRATION TRENDS FOR PARTICLE FINES REMOVAL IN MANUFACTURING ENVIRONMENTS

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Biography

Barry A. Perlmutter is President and Managing Director of BHS-Filtration Inc., a subsidiary of BHS-Sonthofen GmbH. Barry has over 30 years of technical and marketing experience in the field of solid-liquid separation, filtration, centrifugation and drying. He has published and lectured worldwide and has been responsible for introducing and creating growth for many European companies into the marketplace. He has a BS in Chemistry from Albany State, NY, MS from the School of Engineering at Washington University, St. Louis and an MBA from the University of Illinois.

ABSTRACT

In the manufacturing of chemicals, petrochemicals, pharmaceuticals, bioenergy etc., after the initial mixing-reactions, there is always the necessity to remove the mother liquor from the process slurry. In some cases, the liquid is the valuable component, in some cases it is the solids and in other cases it is both compounds. The nature of the requirements will determine the type of equipment needed for the separation process.

Generally, after the initial mixing - reactions, there will be bulk separation to remove the larger product solids or unwanted solids. This is the easy step. As processes have become more sophisticated and quality requirements increased, there is a trend to be able to remove the residual particle fines from the slurries. These fines are very small, typically in the 1 – 5 micron range and smaller and are very low in concentration down to ppm levels.

This paper provides a brief overview of crude separation equipment and then continues with a detailed view of technologies that can remove – recover small particle fines. The general term for this is "clarification" technologies and this will cover alternatives to traditional bag and cartridge filtration systems.

The paper concludes with a review of the installations in chemical, refinery, bioenergy and pharmaceutical plants to provide engineers with new and creative ways of thinking to evaluate process filtration problems and solutions.

SOLID / LIQUID SEPARATION FOR PROCESS SYSTEMS

Filtration, pressure or vacuum, is the art of finding a filter media which allows the liquid to pass through while retaining the solids. The driving force may be gravity, vacuum, or pressure.

The ultimate solid phase is always drier than that from gravitational systems and a great deal of processing can often take place in the actual filtration stage, especially with regard to the conversion or exchange of the residual cake moisture.

The driving force, causing the liquid to exit while leaving the solids behind, can be divided into four groups:

1. Gravitational, which is really little more than draining, but can be very useful to reduce large quantities to more manageable proportions. They can be batch operated or, more usual, continuous.
2. Vacuum, this is in many ways mechanically the simplest driving force available. Vacuum filters can be batch operated but are normally continuous. In general, the solid (cake) thickness can be controlled within close limits; there are few limits to materials of construction and some of vacuum filters offer the best solids washing possibilities.
3. Pressure, with or without compression, which obviously involves mechanical constraints. All pressure filters are batch-operated units with one exception, the exception being the Rotary Pressure Filter. Cake washing can be excellent and the final cakes are usually as dry as can be expected without heat input.
4. Centrifugal, which can sometimes offer a compromise between vacuum and pressure filtration. Centrifugal filters can be continuous in operation or they can operate in an automated continuous batch-mode. The nature and behavior of the solids play a great part in the success or failure of centrifugal filters. Cake washing can be good depending on the type and the behaviour of the solids.

TYPES OF FILTRATION SYSTEMS

With the above in criteria in mind for chemical and pharmaceutical production operations, there are several basic choices for a process engineer. These are segmented by particle size removal as well as whether or not the filter will discharge the cake batch-wise or continuous.

BATCH FILTERS

Autopress: This horizontal pressure filter is tubular in construction and operates as a contained filter press. Circular plates with welded metal or synthetic media are contained in a pressurized housing. This allows for pressure filtration, cakes washing and vacuum or pressure drying. After the cycle is completed, the housing is moved and automatic cake discharge is via scraper knives that move between the plates

Bag filters: A bag with a connection for a high pressure inlet held captive in a metal cage. Filtrate runs through the bag and the solids stay inside.

Basket strainer: Similar to the bag filter, except that the strainer may be the filter medium in which case the solids have to be dug out, or the basket may be lined with a bag, for easy cake solids disposal.

Basket centrifuge: A metal basket rotating at centrifugal speeds and a cloth bag is fitted inside the basket. The drive mechanism runs the basket up to high speeds and feed is poured into the basket. Filtrate runs through the basket and is collected in an outer mantle. When sufficient solids have collected inside the bag, the machine is stopped and the solids removed or it is slowed down to allow a mechanical scraper to remove the bulk of the solids (a "heel" stays behind). In a horizontal version, the Peeler Centrifuge, the bulk of the cake can be removed without slowing the machine.

Cartridge filters: Pressure vessels inside which are fitted a number of filter cartridges. Almost without exception the flow is from the outside inwards. Cartridges are available in cleanable or (much more common) disposable form. A very wide variety of materials, textures, pore size and physical sizes are available.

Filter press: The original filter presses were of the "plate and frame" construction. Modern presses use almost exclusively "recessed plates". A very wide variety of sizes, configurations, plate supports and degrees of automation exist.

Leaf filter: Leaf filters consist of a pressure vessel inside which a number of filter leafs are vertically mounted. The leaves are normally metal and fitted with a synthetic media. For removal of the solids different arrangements exist, ranging from opening the bottom of the vessel to mechanically spinning or vibrating the cake into a chute.

Membrane presses: The membrane press is basically a filter press but instead of having drainage grooves in the plates, the plates are fitted with an elastomer sheet (which has the drainage grooves) and which sheet can be inflated. By inflating the sheet at the end of the filter cycle any residual moisture will be expelled and the cake itself will be squeezed, usually resulting in better cake moisture figures.

Nutsche filter: Circular or rectangular filters with a drainage bottom onto which a filter medium is fastened. If the drainage section is connected to a vacuum source the filters are often open top. If they are closed at the top, they can be pressurized and thus benefit from a higher driving force.

Tube press: These may be vertical or horizontal and consist of a metal tube and inflatable membrane. Inside this membrane is mounted a central filter core consisting of a drainage tube with a filter medium. The feed is introduced into the tube under pressure, filtrate exits from the central filter core. After filtration and / or washing the membrane is inflated to squeeze the cake solids to extremely low residual moisture values. To discharge the cake, the membrane is relaxed, the bottom section of the tube opened and the tube slightly or totally withdrawn allowing the cake solids to drop off or to be scraped off.

CONTINUOUS FILTERS

Disc Filter: These consist of a flat disc mounted on a hollow shaft. The disc is made of metal and has on either side an open cloth support structure which connects with the hollow shaft which carries the filtrate. A filter cloth is fastened to the disc and the hollow shaft connects to a vacuum source. The disc, usually 30 % submerged, rotates slowly in a feed trough where it picks up the solids, which can later be scraped off just prior to re-entry into the feed trough.

Rotary Pressure Filter: The Rotary Pressure Filter is a continuously operating unit for pressure filtration, cake washing and drying of slurries up to 50% solids. The filter has a rotating drum inside a housing. The drum has cells within which are cell inserts fitted with the filter media. Filtration is conducted via pressure of up to 6 bar. Positive displacement washing or counter-current washing follows filtration. Multiple washing steps as well as solvent exchanges, steaming and extraction are accomplished. Finally, the cake is dried by blowing hot or ambient gas through the cake. The Filter has a uniquely designed discharge system, which provides for atmospheric discharge from pressure filtration. After automatic cake discharge, the filter cloth is washed; the clean filter cloth the re-enters the feeding / filtration zone thereby continuing the process. All solvent and gas streams can be recovered separately and reused in the process to minimize their consumption.

Pusher Centrifuge Horizontally mounted filtering centrifuge with a filter cage made of metal bars the smallest opening of which is about 100 micron. Inside the cage is a "pusher" arrangement, basically a sturdy ring which lies very close to the filter medium. The ring is connected to a central shaft which rotates at the same speed as the filter cage but reciprocates (approx 1 – 3 cm) causing the collected solids to be pushed out of the machine. Multi stage machines exist. In these the solids are pushed onto the second or third stage which is each time of a larger diameter. The higher linear velocity as well as the tumbling action can be beneficial for dewatering and / or cake washing, although it may cause the crystals to fracture.

Rotary Vacuum Drum Filter: The original rotary drum filter consisted of a cylindrical drum, fitted with a drainage grid on the outside over which a filter cloth was stretched. The drum had perforations and was connected to a vacuum source. The drum itself was mounted on a horizontal shaft and submerged for about 30% in a feed trough. The vacuum caused the liquor phase to be sucked through the cloth, leaving the solids behind as a filter cake. The cake was scraped off just before re-entering the feed trough.

Vacuum Belt Filter: The two main types are carrier belt and tray (fixed or indexing). These filters have a continuous belt as the filter medium which is subjected to a vacuum source. Feed is introduced at one end, where it is normally allowed to settle under gravity for a few seconds, causing the coarser fraction to form its own pre-coat. The suspension is then subjected to full vacuum. Since the cake thickness can be controlled by adjusting the speed of travel or indexing time, the optimum cake thickness to obtain the required residual moisture and / or cake washing efficiency is achieved. The horizontal configuration makes this filter one of the most efficient cake washing filters.

CLARIFICATION OF SLURRIES & RECOVERY OF SOLIDS

In the previous section, batch and continuous filtration systems were discussed. As processes have become more sophisticated and quality requirements increased, there is a trend to be able to remove the residual particle fines. These fines are very small, typically, smaller than 1 – 5 micron range and are very low in concentration down to ppm levels.

Candle Filters and Pressure Plate Filters are installed for clarification and recovery applications from liquids with low solids content. The candle filters are vertical candles while the pressure plate filters are horizontal plates. The cake structure as well as the process parameters determines the optimum thin-cake technology.

Description and Operation of the Candle Filter

Candle Filters provide for thin-cake pressure filtration, cake washing, drying, reslurry and automatic discharge as well as heel filtration in an enclosed, pressure vessel. Units are available from 0.17 m^2 up to 200 m^2 of filter area per vessel.

Filter Candles & Media

The filter candles, as shown in Figure 1, consist of three components: single-piece dip pipe for filtrates and gas, perforated core with outer support tie rods and filter sock. The filtrate pipe is the full length of the candle and ensures high liquid flow as well as maximum distribution of the gas during cake discharge. The candle can be a synthetic, stainless steel or higher alloys. The outer support tie rods provide for an annular space between the media and the core for a low pressure drop operation and efficient gas expansion of the filter media sock for cake discharge. The filter media is synthetic with a clean removal efficiency to less than 1 micron (um). As the cake builds up, removal efficiencies improve to less than 0.5 um.

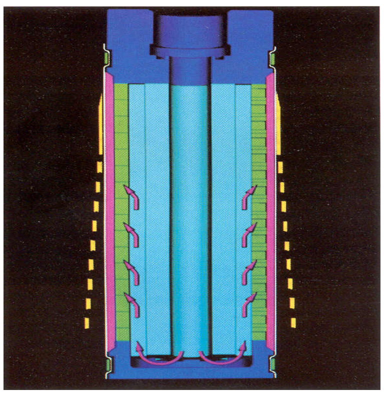

Figure 1: BHS Candle Showing Gas Flow to Expand the Filter Media Sock for Cake Discharge

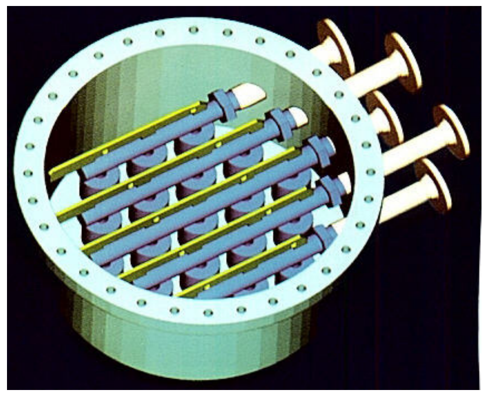

Figure 2: BHS Candle Filter

Filter Vessel & Candle Registers

The candle filter vessel is constructed of stainless steel or higher alloys. Within the vessel are horizontal manifolds called candle registers. Each candle is connected to a register with a positive seal to prevent bypass. Each register may contain from 1-20 candles depending upon the filter size. The registers convey the liquid filtrate in the forward direction as well as the pressure gas in the reverse direction for filter media sock expansion. Each register is controlled with automated valves to ensure optimum flow in both directions. Figure 2 illustrates the candle filter vessel.

Automatic Process Cycles

Filling: The slurry feed enters the bottom of the filter vessel.
Filtration: The slurry is either pumped or pressurized from the reactor into the vessel. Cake will deposit on the outside of the candle; the separated filtrate will flow through the filtrate pipe and the registers. This process continues until one of the following conditions is achieved: maximum pressure drop, maximum cake thickness, minimum flow or time.
Washing: Displacement washing or recirculation washing.
Drying: Blowing gas, steam or "shock" drying.
Heel (Falling-Film) Filtration: The liquid remaining in the vessel cone after filtration or washing is completely filtered.
Cake Discharge: Gas flows sequentially through each of the candle registers, down each of the filtrate pipes and then is distributed by the perforated core. The filter media sock gently expands by the gas flow and pressure allowing for cake discharge, as shown in Figure 1. Alternatively, the cake can be discharged as a slurry.

Description and Operation of the Pressure Plate Filter

The pressure plate filter has similar operating characteristics to the candle filter. The filter design is shown in Figure 3.

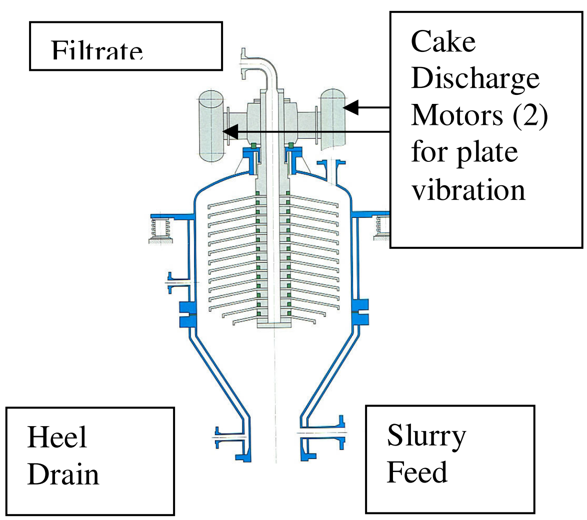

Figure 3: BHS Pressure Plate Filter

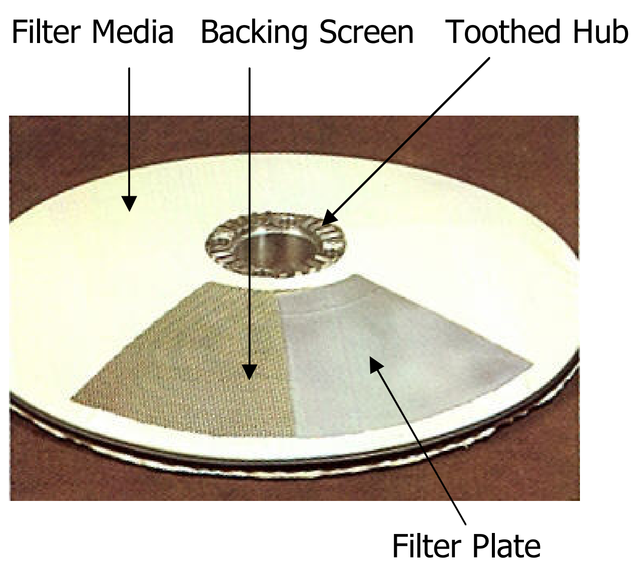

Figure 4: Filter Plate

Automatic Process Cycles

Filling: The slurry feed enters the bottom of the filter vessel.

Filtration: The slurry is pumped under pressure into the vessel or via gas pressure through the reactor. Cake will deposit on the top of the plates. The separated filtrate will flow through the plates to the center main filtrate outlet. This process continues until one of the following conditions is achieved: maximum pressure drop, maximum cake thickness, minimum flow or time.

Washing: Displacement washing or recirculation washing.

Drying: Blowing gas, steam or "shock" drying.

Heel Filtration: The liquid remaining in the vessel cone after filtration or washing is completely filtered.

Cake Discharge: As shown in Figure 5, the motors on the top of the filter operate at different frequencies and the plates gently vibrate for cake discharge. The plates vibrate in the vertical and horizontal planes and the solids are conveyed in an elliptical pattern to the outside of the vessel. Gas assist helps in the discharge process. There are no rotating plates, gears or bushings and mechanical seals are not required.

Description and Operation of the Pressure Plate Filter (Continued)

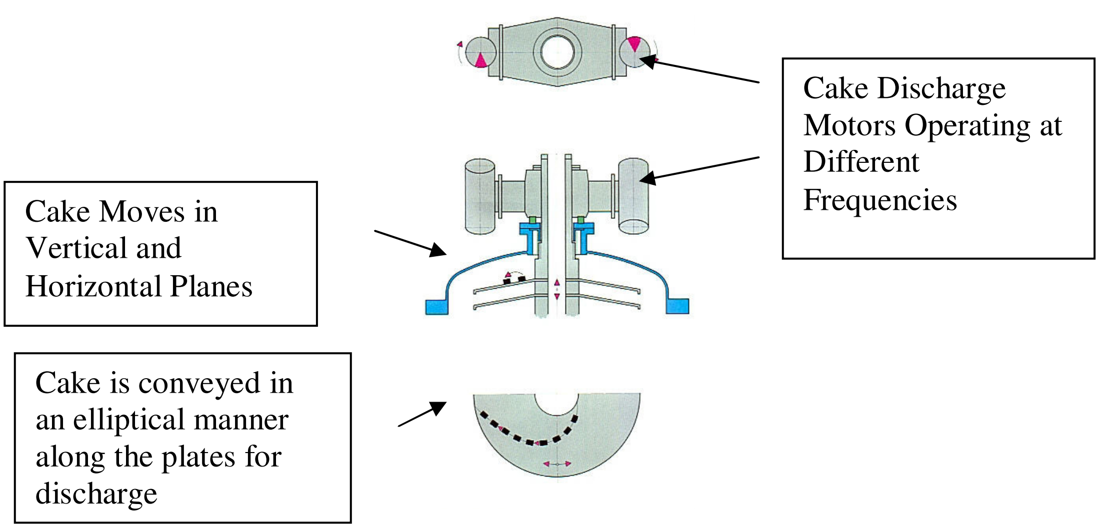

Figure 5: Cake Discharge in the Pressure Plate Filter

SELECTION OF CANDLE VERSUS PRESSURE PLATE FILTER TECHNOLOGIES: CAKE STRUCTURE AND PROCESS PARAMETERS

The major difference between the two technologies depends on the cake structure that is formed. Some cakes are better handled in the horizontal and some in the vertical.

Cake Thickness and Filtration: The candle filter is limited to cake structures that can be formed to about 5 – 20 mm. The pressure plate filter can handle cakes up to 75 mm. Both units can conduct filtration up to 150 psig.

Filter Media: The candle filter uses only synthetic media with a clean removal efficiency from 1 –3 micron range and finer down to 0.5 microns. The pressure plate filter can also use metal media. For the pressure plate filter, the clean micron range removal efficiency is also 1 – 3 microns and finer.

Cake Washing: If the process requires washing of the solids, then generally the pressure plate filter is a better alternative. If washing is not as critical, then the candle filter may be the optimum technology for clarification and recovery.

Heel Filtration: The remaining liquid in the vessel (liquid heel) after filtration or washing can be removed from the candle filter or pressure plate filter by circulation, heel filter in the cone of the vessel, or additional heel filter plates in the pressure plate filter.

Cake Drying: The candle filter can produce cakes with approximately 10% moisture. This moisture level depends upon the specific cake but the moisture lower limit is that moisture just above the cake cracking point. The pressure plate filter can produce bone dry cakes.

Cake Discharge: Both designs can easily discharge most cakes equally with no residual heel.

Clean-In-Place (CIP)/ Steam-In-Place (SIP): Both units conduct CIP / SIP operations in identical manners by filling and circulating cleaning fluids while blowing gas in the reverse direction to the filtration direction, which creates a turbulent mixture or a quasi-ultrasonic cleaning effect. The pressure plate filter further enhances this operation with plate vibration.

APPLICATION 1:
REPLACING A MANUAL PLATE FILTER AND BAG FILTER COMBINATION

This specialty chemicals manufacturer produces various resins that require filtration. Current production includes a neutralization step which yields metal salts. These salts are filtered out with a manual plate filter followed by a bag filter for polishing. Two solvent washes follow the filtration step to recover as much resin as possible. After washing, the filters are steamed and opened. The solids are disposed manually for each batch and the filter paper is replaced. The goals are to eliminate exposure to heptane, reduce the maintenance and operation on the two filters and to recover a dry, as possible, catalyst. Current production is 3000 gallons in 4 – 5 hours.

Results & Conclusions

The filtration flux rate from the BHS laboratory tests ranged between 10-30 L/m^{2}min at approximately 20 psi feed pressure. The filter cloth for the sock is polyester with an air permeability of 1.0 cfm/ft^2.

The tests showed that one BHS candle filter with 10 m^2 of filter area can complete the cycle in a time of 4.3 hours and replace the manual plate filter and bag filter.

The cycle time is as follows:

Cycle Times			
	Filling	5	min
	Filtration	10	min
	Wash	4	min
	Drain	10	min
	Dry	5	min
	Vent	2	min
	Discharge	5	min
	Reserve	9	min
	TOTAL	**50**	**min**

Figure 6: Dry Cake After Discharge

APPLICATION 2:
REPLACING A FILTER PRESS FOR A HOT SLURRY FILTRATION

This specialty chemicals manufacturer produces various grades of polyols from ethylene glycols that require filtration of small particles in the 1 – 2 um range. Current production includes a manually-operated filter press at 200 – 250 degrees F. The goals are to eliminate operator exposure, reduce the maintenance and operating costs for the filter press and to increase the polyols yield. Current batch sizes are 45000 pounds of slurry.

Results & Conclusions

BHS conducted the lab tests in the BHS laboratory in Charlotte, North Carolina. The slurry temperature was between 200 – 250 degrees F at a pressure of 90 psig. The filter cloth for the sock was successful using PTFE or PEEK material.

The tests showed that one BHS candle filter with 27 m^2 of filter area can complete the required batch is three (3) cycles, each of 6-hours. The cycle time is as follows:

Cycle Times			
	Filling	12	min
	Precoat	8	min
	Filtration	60	min
	Drain	15	min
	Dry	3	min
	Vent	2	min
	Discharge	15	min
	Reserve	5	min
	TOTAL	**120**	**min**

Figure 7: Jacketed Candle Filter with Register-Filtrate Piping & Junction Box

APPLICATION THREE:
REPLACING CENTRIFUGE & CARTRIDGE FOR TIN HYDROXIDE SLURRY

This process was previously done with a centrifuge which did not provide much separation at all and the fines were causing issues in the downstream operation at their sister plant.

Process Observations:

Precoating with Hyflo (5 lbs) and water – filtrate goes to sump

Precoating based on volume and then switch over to feed slurry (0.4 – 0.5% body feed)

Filtration - Pressure built to around 20 psi in about 30 minutes, batch size is approximately 3000 lbs. (10-15 gpm)

Washing with water- 40 psi until filtrate looks clean with 12 um PEEK filter sock

Draining- initially through candles first (25 psi) and then the heel drain

Drying – Blowing of gas for 5 minutes at 20 psi

Cake discharge – dry cake with a cake thickness of 15-20 mm

Results:

The BHS candle filter with 10 m^2 of filter area replaced the centrifuge and cartridge polishing filter. The results are below.

Cycle Times			
	Filling	5	min
	Precoat	10	min
	Filtration	45	min
	Wash	5	min
	Drain	10	min
	Dry	5	min
	Discharge	5	min
	Reserve	5	min
	TOTAL	**90**	**min**

APPLICATION FOUR:

REPLACING A FILTER PRESS USING PAPER MEDIA

This specialty lube oil process, for final clarification, is conducted in a filter press using a paper media at 170° C, and using carbon, lime or celite as a body feed. There are five (5) grades of lube oils and cleaning between each campaign is required. The material is dried with nitrogen and the solids are removed and burned in the power plant as fuel. The process has the manual problems associated with a filter press plus the safety concerns of being burned with hot oil. The average particle size distribution (PSD) is 0.7 um.

Results:

The pilot testing demonstrated that the oil slurries could be filtered to meet the customer's specifications, that the resultant cake could be dried to the customer's desired moisture content, and that the cake could be automatically discharged satisfactorily from the candles. The purchased system was a 10 m^2 jacketed BHS candle filter using PEEK filter socks for the current five (5) products with expansion possibilities.

APPLICATION FIVE:

DUAL STAGE CANDLE AND PRESSURE PLATE FILTERS FOR FINES REMOVAL AT REFINERIES, GAS PLANTS AND GREY WATER FOR COAL GASIFICATION

The fines generated in grey water as well as by cat crackers and cokers are generally less than 1 um in size and very low concentration. For these large flows, upward to 800 gpm, simple bag or cartridge filters or filter presses cannot be used. For these applications, BHS has developed a dual-stage process using candle filters for concentrating and then followed by a pressure plate filter for the final filtration, cake washing and drying. The benefits include increased reliability, much lower consumption (25% less) of compressed air/gas for drying and cake wash water. A typical example and photo is below.

Process & Results:

Total Flow: 94 gpm
Design Solids Load: 28 lb/hr (600 ppm)

- Two (2) Candle Filters, each with 20 m^2 of filter area, for concentration
- One (1) Pressure Plate Filter, 4 m^2 of filter area, for final filtration, cake washing and drying

Figure 8: Complete Skid Package with Candle Filters, Plate Filter, Tanks, Pumps and PLC Controls

SUMMARY

There are many choices for the initial filtration steps in a process. The take-away is that one filtration system may not achieve those quality requirements. Engineers must evaluate all outcomes to make an informed and successful decision. A secondary filtration system for fines removal, while adding capital expense to the project may result in an overall more reliable and optimum process solution. While not discussed in this article, laboratory and pilot testing is critical for a successful decision and project.

BHS FILTRATION

BHS Thin-Cake Pressure and Vacuum Filtration Technologies
For Batch or Continuous Operations From High Solids to Clarification

BHS-Sonthofen GmbH, founded in 1607, is a leader in technology and innovation. Among other areas of mechanical process engineering, BHS specializes in thin-cake (3 mm - 180 mm) filtration, cake washing and drying technologies.

BHS serves three major market segments as follows:

- Chemical: Fine, Specialty, Agricultural, and Others
- Pharmaceutical: Bulk and Final Products
- Energy / Environmental: Refinery, Power Plants, Bioenergy, and Wastewater

Specialized Applications & Centres of Excellence:
For specialized applications, BHS is organized globally with centres of excellence. These centres include, for example, aromatic acids, cellulose derivates, pharmaceuticals, dewatering of gypsum, refinery and bio-energy applications.

Product Technologies & Capabilities
The BHS technologies and expertise are thin-cake (3 mm – 180 mm) filtration, cake washing and drying. The five-patented BHS technologies are as follows:

- Rotary Pressure Filter
- Vacuum Belt Filter: Continuous-Indexing & Rubber Belt
- Candle Filter
- Pressure Plate Filter
- Autopress, an Automated/Contained Specialized Filter Press

These technologies are installed for pressure or vacuum filtration, for batch or continuous operations from high solids slurries (up to 60% solids) to clarification applications with solids to less than 0.5%.

Process Lab Testing & On-Site Pilot Testing
BHS conducts preliminary tests in our worldwide laboratories or at your facility. On-site tests with pilot rental units continue the process. Finally, BHS completes the project with a complete technical solution. Contact us today.

BHS Rotary Pressure Filter

BHS Duplex Candle Filter

BHS Vacuum Belt Filter