Continuous Pressure and Vacuum Filtration and Washing of Organic Cellulose and Biomass Products [1]

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INTRODUCTION

The processing of organic, cellulose-containing materials has been around for many years as engineers have developed clever chemistry or cultivated natural conversion processes to make products with characteristics, which were not naturally available. Age-old examples are paper, linen or in the field of “conversion” to alcohol and methane.

Currently, due to high oil prices along with the passage of the Renewable Fuels Standard (RFS) included as part of H.R.6, the Energy Independence & Security Act signed in December, 2007 calling for significant increase in ethanol usage nationwide from both grain based and cellulosic based sources, there is tremendous interest in developing efficient, cost-effective manufacturing processes to produce energy from cellulosic feed stocks.

Further, even if the main focus is not on energy production, well-established processes are being changed so that what used to be by-products are now becoming, if not primary products, at least valuable additional products. In addition, the combined effects of an excess of waste and a diminishing supply of basic raw materials focuses the attention of research workers on treating “waste” as a potential raw material for further processing, thus opening a whole new field of bio-processing, bio-energy and specialty chemicals.

This article will use actual process data to highlight the choice of pressure or vacuum filtration and cake washing techniques for these newly developed bioprocesses.

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BIOMASS

The word biomass is perhaps misleading since it has different meanings in different industries. Any suitable plant or the products of plants which contain cellulose can be labelled "biomass." Plants include, but are not limited to, trees, bushes, agricultural plants, weeds, vines, straw, flowers, kelp, algae and mixtures thereof. Commercial and agricultural waste products are also included such as stalks, paper, cotton, bagasses, corn cobs, corn stovers, starch, sugar cane, etc. Plants that have been partially decomposed, such as humus, peat, certain soft brown coal etc., may also fall into this category.

Nevertheless, in this article, biomass is defined as a mass of organic solids saturated by, or suspended in, a liquid, which may or may not be organic, and of which it is required that the liquid phase is separated, or replaced by other liquids to enable further processing. It is the filtration / separation in this process stage which is the focus of the discussion. In this article biomass does not mean digested sludge from sewage works.

Regardless of the type of biomass, most bioprocesses rely on reactions of solids and liquids, which later require to be separated. Because no liquid / solid separation process is 100% efficient, it is inevitable that some of the liquid phase will stay embedded in the solid phase and therefore require either mass transfer or evaporation.

The physical form in which the solid content can present itself is almost as varying as there are processes. It may be in the form of finely ground organic matter, it may be granules, fibres, chips or strips. It may be that it has been chemically digested and is amorphous or it may have the original structure. The liquid phase may be water-thin or very viscous. The temperature of the mixture may vary as well as the flow characteristics of the mixture itself may be free-flowing or barely pumpable. Finally, the percent solids and quantity may be large or moderate.

They have, however, one thing in common in that the solids do not like to give up their liquid content very easily and recovering or removal of the process liquors usually involves washing or leaching.

SOLID / LIQUID SEPARATION SYSTEMS

Filtration, pressure or vacuum, is the art of finding or creating a septum or substrate, which allows the liquid to pass through while retaining the solids. The driving force may be gravity, vacuum, pressure or compressive forces whereas a degree of evaporation is often possible using direct heat, indirect heat or electro-magnetic radiation.

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. Only a very limited amount of washing of the solids is possible.
2. Vacuum, which is in many ways mechanically the simplest driving force. 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. Given that the cake thickness is controllable, residual cake moistures can be obtained which are often equal to pressure systems.
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 BHS 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.

FILTRATION DRIVING FORCE

Basic Principles

To some extent one would expect that a high pressure driving force would be beneficial for liquid removal, but the effect is limited because organic solids are compressible. In some cases, then, vacuum filtration would be more efficient. As will be discussed later, some cakes can be handled by pressure or vacuum. This is one of the difficulties of biomass filtration.

With a compressible cake, the act of forcing liquid through the already collected solids (the cake) result in these solids being pressed together forming a dense matt. This dense matt, which requires a greater force to penetrate, thus produces a denser matt, which requires even higher forces which produce an even denser matt and so on. This problem multiplies exponentially with the thickness of the cake layer.

Figure 1 illustrates this phenomenon. Normally one can expect a "best overall efficiency" if the cake thickness is kept well below its theoretical maximum and the driving force is not the maximum available. This is true in general, but especially so in those cases where the solids have to be washed, extracted or impregnated subsequently, which is almost always the case with biomass materials.

CAKE WASHING TECHNIQUES

Cake Washing / Extraction / Impregnation

Most biomass processes require cake washing to extract and recover the valuable liquid product. Alternatively, impregnation washing with a liquid, which contains additives in order to, impregnate the solids with these additives, may also be required.

Basic principles

The purpose of cake washing is to remove the residual cake liquor, either because it is valuable or because its presence is undesirable in the cake or both. Depending on the complexity of the cake structure, the possibilities include displacement or surface washing and leach washing.

There may be a third reason for washing, i.e. the wish to impregnate the cake solids with another chemical. The mechanics of this "Impregnation Wash" can be identical to those of the previous three.

A filter cake is made up of particles, which are closely packed together but never perfectly packed together such that there are spaces between them. The spaces form pockets, which are filled with liquor. Depending on how the solids are packed or stacked, a washing liquid is very effective or barely effective.

For stacked particles or puzzle type, the wash fluid will simply run off the particles and only wash off the outer surface but never reach the inter-particle fluid; whereas for more permeable cakes, the wash fluid would have reasonable access to the interstitial spaces, as well as being able to wash off the surface liquor.

However, the actual particle may contain liquor within its own structure, either because it is porous or because it has a cellular structure, as is the case with all undigested organic materials. In this case, the previous processes have hopefully, as much as possible, ruptured the cell walls so that the cellular liquor is mostly accessible. In some cases, however, there may remain a significant amount of cellular liquid, which can only be removed either by heat or osmosis.

Displacement wash

In a displacement wash, the goal is to push the "free" liquor from between the particles out of the cake, using another liquor, which acts like a piston on the former. For this to have a maximum efficiency the two liquids should ideally not be miscible. The success of a displacement wash is normally more a function of the right type of filter, than of the nature of the wash liquors.

Surface wash

However, even under ideal conditions the displacement wash would still leave the particles with a film of diluted process liquor, which would require a surface washing.

Washing times

The former two types of washing are barely time dependent, in so far that their time cycle is the time required to pass "X" volume of wash liquor through the cake at "Y" pressure, which in turn depends on the point on the filtration curve where the washing takes place. From the filtration curve in Figure 1, two (2) volume units would pass at the "optimum" point in one time unit, whereas at point time unit = 6, it would be ten time units. Increasing the pressure normally does not help because of the greater compaction of the cake resulting from the higher filtration pressure.

Leaching Wash with Counter-Current or Reflux Options

As the name implies, a leaching wash attempts to leach liquors held inside the particles into a leaner liquor. In the case of cellular materials this is really closer to an osmotic or an absorption process than a "washing" process. Because the absorption rate is usually quite small, large quantities of liquor have to be passed through the cake, which would result in large quantities of very dilute wash extract. To compensate for this a counter current washing train may well offer the answer, as shown in Figure 2.

Like any counter current system, the reactant will flow in the opposite direction of the main body so that wash liquor meets increasingly "richer" cake from which it absorbs some of the original liquor and thus becomes increasingly "richer" itself. Very considerable savings in wash volumes can be made this way, although it must be remembered that each step is part of the filtration process and thus requires time and therefore filter area.

It must further be understood that the efficiency is largely dependent on the ease with which the original liquor leaches into the wash liquor and in general the leaching is more effective into lean wash liquor than into liquor, which already carries some of the original liquor.

Alternatively, reflux washing is also possible. In this case, the washing filtrate is recirculated back over the same cake and thereby increasing the efficiency of the wash.

Reslurry Wash
There are, unfortunately, cases where the transfer rate is so slow that it would be senseless to try to carry out a leaching wash in a filter, since it would take up expensive process equipment for inordinate times. In this case the most economical solution is to discharge the filter cake after initial washing and after having reached a point where washing is no longer a function of filtration technology but simply a function of contact time. The cake then gets discharged, mixed with wash liquor to form a slurry and enters into a suitable soaking / leaching system.

DRYING DISCUSSION

Unfortunately, the filtration industry has a habit of talking about "dry" filter cakes. The very non-specific criterion is usually "can the cake be handled by mechanical means, like conveyors, scrapers etc. without losing its shape or without "free" liquid. Therefore even "dry" filter cakes are never really dry, but always contain some or a lot of moisture.

Nevertheless many processes ultimately require bone-dry solids. In general it must be accepted that a filter is not a dryer and that its basic concept is almost the exact opposite of a dryer. It is therefore suggested that if at all possible the drying phase should be regarded as separate from the filtration. However, there are clearly cases where the possibility of being able to process the incoming suspension through all stages of dewatering, washing, extraction, impregnation and also drying would offer tremendous advantages. This may be reasons of hygiene, safety, health hazards, product degradation etc. For such cases a small number of filters can offer an incorporated drying step.

TYPICAL LABORATORY TESTING TO DETERMINE THE OPTIMUM VACUUM OR PRESSURE FILTRATION TECHNOLOGY FOR AN ACTUAL BIOMASS MATERIAL

Overview of Bench Top Testing
The BHS bench top testing is conducted using the BHS Pocket Leaf Filter, as shown in Figure 3. The testing will analyze cake depths, operating pressures, filter media, washing and drying efficiencies and qualitative cake discharge. The data collection sheets are shown in Figure 4.

1. Test purpose

Process description:
Biomass material shall be used as feed material for the production of a bioenergy product. The filter cake from the acidic slurry is reslurried with caustic soda solution and after heat treatment for a certain period of time; the slurry shall be filtered, either by vacuum or pressure filtration. The filter cake shall be washed with the wash filtrate being recirculated two times (three step counter current washing). The wash ratio shall be determined during the testing. Therefore the samples of filtrates and filter cake are collected and analysed. Specific limits for the content of impurities or product in the filter cake shall be determined separately and are not part of this testing.

Requirements:

Production capacity:	20 tons of dry solids / 24 hours
Slurry composition:	2 – 12 % solids per weight
Washing:	Three step, counter current, to be confirmed
Washing media:	DI water
Residual moisture:	As low as technically possible on the filtration selection

Objectives:
- Choice of a suitable filter cloth for this process
- Determine the vacuum or pressure filtration properties of the biomass
- Test several wash ratios for the washing of the filter cake
- Determine the moisture content of the filter cake

2. Test Equipment

The test device is a BHS pocket leaf filter with a filter area of 20 cm² and a vacuum and pressure connection. The testing was done at the bioenergy pilot plant. The slurry was prepared for each test using solid material that had been taken from the pilot process. All testing was done at ambient temperatures of 25°C.

3. Test Data and Test Results

While the test data is confidential, the lab testing of the biomass material for the filtration step has shown that the slurry can be easily processed on a continuous working BHS filter. Both vacuum and pressure tests were conducted and gave good results regarding filter cloth selection, filtrate clarity, filtration times, washing parameters and cake discharge.

4. Scale Up for Vacuum and Pressure Filtration

A. Vacuum filtration

The required production capacity is set to 835 kg/h of dry solids. This results in an amount of slurry of approximately 14 tons/ hours at 6% solid content. For the calculation, the wash ratio 1.5:1 is considered optimum based upon the testing.

Filtration Flux rate x:

$$x = \frac{m}{A_F * \sqrt{t_F}} = \frac{6}{20 \cdot \sqrt{10s}} \frac{g}{cm^2} = 0{,}95 \frac{kg}{m^2 s^{0,5}}$$

Based upon the above flux rate, the ratios of filtration areas, washing areas and drying areas are calculated. The result is a BHS continuous–indexing vacuum belt filter with a total area of 16 m² and eight (8) zones. The zone design is shown below.

Process Step	Number of zones
Filtration	1
Washing 1	1
Washing 2	1
Washing 3	1
Drying	3
Spare	1

B. Pressure Filtration

Similar to the scale-up for the vacuum filtration case, the required production capacity is set to 835 kg/ h dry solids. This results in an amount of slurry of approximately 14 tons/ hours at 6% solid content. For the calculation, the wash ratio 1.5:1 is considered optimum based upon the testing.

Specific total filter performance flux rate:

$$Q = 90\frac{1}{h}\cdot\frac{6g}{20cm^2} = 270\frac{kg}{m^2h}$$

Required filter area:

$$A = \frac{835\frac{kg}{h}}{267\frac{kg}{m^2h}} = 3{,}1\, m^2$$

The result is a BHS rotary pressure filter a total filter area of 3.2 m², with an arrangement shown below.

Process Step	Degrees of Rotation
Filtration	57
Washing 1	57
Washing 2	57
Washing 3	57
Blow Drying	57
Cake Discharge and Cloth Cleaning	75

5. Selection and Discussion of Vacuum and Pressure Filtration

Both of the technologies, the BHS vacuum belt filter as well as the BHS rotary pressure filter can be selected for the processing of the biomass material. Following this section, there is a brief discussion of each of the technologies.

The design of the rotary pressure filter assures that the cake is always saturated in between filtration and the different washing steps. There is no risk of air getting inside the cake and maximum washing efficiency is achieved. Only during the blow-drying step is the moisture in the cake mechanically removed.

On the belt filter, the zone arrangement and positioning of the washing devices on the filter can be used to assure saturated cake during the washing procedure. As another option it is also possible to work with sucking of the liquid in between the washing steps in case that this increases the washing efficiency. The belt filter offers the flexibility to easily adjust the zone arrangement by moving the washing devices.

Finally, due to the higher dewatering pressure difference, the residual moisture of the filter cake is approximately 3 % lower with pressure filtration than with vacuum filtration.

The choice of the preferred technology in this case might also consider the required surrounding components. In case of the belt filter these are mainly the vacuum pump including pressure side separator for the operation liquid, the filtrate separators (three pieces) and the filtrate pumps for the transportation of the wash liquids from the filtrate separators back onto the filter. For the rotary pressure filter, a feed pump for the slurry will be required that is able to provide the filtration pressure, filtrate pumps for the circulation of the wash liquids and a pressure gas system (e.g. compressor, pressure control etc.) to allow for the dewatering of the filter cake.

In summary, the decision resides with the other process parameters of the operation including washing efficiency, downstream equipment as well as the economics of the installation. The client continues the evaluations of both options.

FILTRATION TECHNOLOGIES

High-Solids Slurries: Continuous Vacuum Operation

High-solids slurries can be defined as up to 50 – 55% solids in the slurry feed. An example of a continuous, thin-cake technology is the BHS Continuous – Indexing Vacuum Belt Filter. This technology consists of fixed vacuum trays, continuously feeding slurry system and indexing or step-wise movement of the filter media. The filter media is indexed by pneumatic cylinders located on the exterior of the unit. The pneumatic operation and fixed trays eliminates a motor and variable speed drive, there are no rails/rollers, no rubber carrier belt and flexible pressure-vacuum rated hoses are not required. For cloth movement, the vacuum is broken by butterfly valves and the cloth moves (indexes), by pneumatic cylinders, in the space above the vacuum trays. The belt moves along but never touches the trays, which allows for long filter cloth life.

For the process operation, due to the stepwise operation of the belt, washing and drying efficiencies are maximized, as the belt is stopped and the mechanism of “plug-flow” for gases and liquids is in effect. Drying can be by vacuum, steaming, hot gas and mechanical pressing. Pressing is effective with biomass materials due to thier compressibility. Pressing can be combined with blowing for vacuum-convection drying.

Finally, because the trays are fixed, the mother liquid and the wash filtrates can be recovered individually and recirculated and/or recovered and reused which allows for a more efficient overall operation as previoulsy described in the "Cake Washing Techniques" section.

High-Solids Slurries: Continuous Pressure Operation

In some cases, for high solids applications, the slurries can be better handled using pressure filtration rather than vacuum filtration. The BHS Rotary Pressure Filter technology provides for continuous production in a single unit.

Filtration is conducted via pressure of up to 90 psig. Positive displacement washing, reflux or counter-current washing follows filtration. Of course, multiple washing steps as well as solvent exchanges, steaming and extraction can also be accomplished. Finally, the cake is dried by blowing hot or ambient-temperature 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.

SUMMARY

Cellulose and biomass filtration, washing and drying is very unpredictable and even minor differences in feedstock, washing or cake moisture requirements can require a different process solution. As previously described, both vacuum and pressure operations provided basically equivalvent process results. The process decision will then be the combined overall efficiency, total installed capital cost, operating cost, space requirements, ancillary equipment and above all the reliability and cost-effectiveness which will result in the optimum filter selection.

Ultimately, there is no substitute for accurate and professional test work under realistic conditions. This almost certainly means that tests have to be done by the technical staff of the filter manufacturer, preferably one who manufactures both vacuum and pressure filtration technologies, either in their laboratory or at the client’s site, since they will have the right test equipment, the expertise of doing the test and the expertise to interpret the results. For this, close cooperation between the plant operations and engineering staff and the filtration vendor is necessary along with detailed and professional laboratory and pilot plant tests.

Barry A. Perlmutter is currently President and Managing Director of BHS-Filtration Inc., a subsidiary of BHS-Sonthofen GmbH. BHS is a manufacturer of thin-cake filtration, washing and drying technologies. Barry has over 25 years of engineering and technical business marketing experience in the field of solid-liquid separation including filtration and centrifugation and process drying. He has published and lectured extensively worldwide on the theory and applications for the chemical, pharmaceutical and energy / environmental industries and has been responsible for introducing and creating growth for many European companies and technologies into the marketplace. He received a BS degree in Chemistry from Albany State University, NY, MS degree from the School of Engineering, Washington University, St. Louis and an MBA from the University of Illinois. Barry served on the Board of Directors of the American Filtration and Separations Society (AFS) and is a member of several internationally recognized societies.

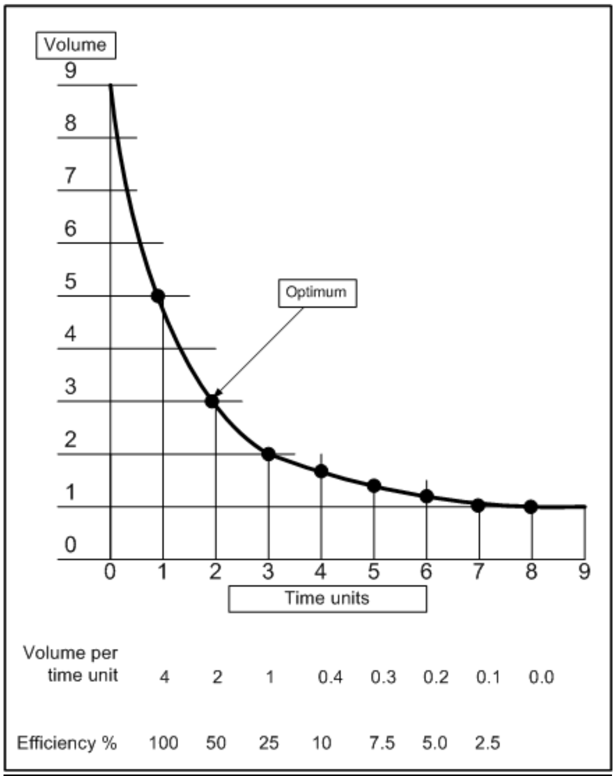

Figure 1: General filtration curve showing as filtration continues, the cake grows thicker and denser, while the efficiency decreases

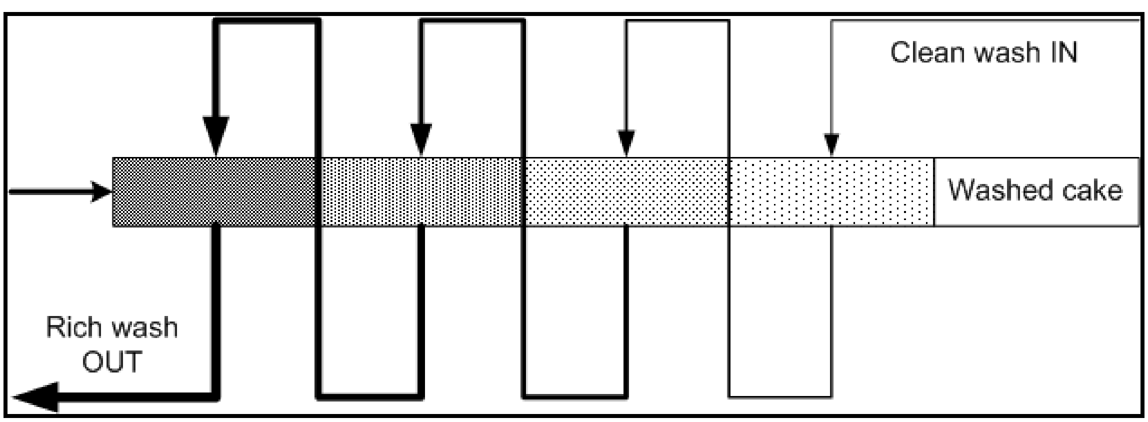

Figure 2: Typical counter current washing train

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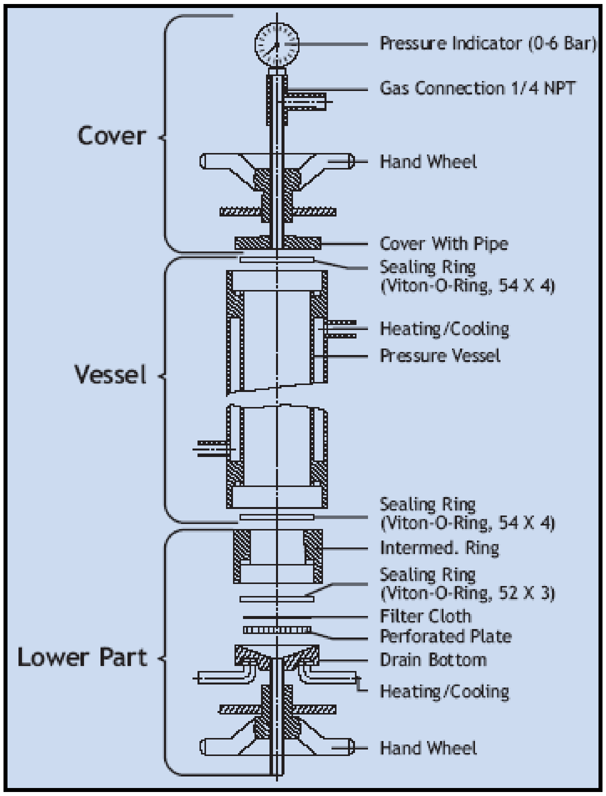


Figure 3: BHS Pocket Leaf Filter

Customer:		Test Number:
Date :		Run #
	Filter Media	
	Suspension	
Filling	Volume of Slurry	
	Density of Slurry	
	% Solids in Feed	
	Temperature	
Filtration	Vacuum or Pressure	
	Volume of Filtrate	
	Time for Filtration	
	% Solids in Filtrate	
Wash 1	Wash Material	
	Pressure	
	Volume of Filtrate	
	Time for Filtration	
Wash 2	Wash Material	
	Pressure	
	Volume of Filtrate	
	Time for Filtration	
Wash 3	Wash Material	
	Pressure	
	Volume of Filtrate	
	Time for Filtration	
Drying	Pressure	
	Temperature	
	Flow Rate	
	Time for Drying	
	Pressing Pressure	
Cake	Weight	
	Thickness	
	% Residual Moisture	
	Dry Cake Weight	
	Cake Discharge OK?	

Figure 4: Data Collection Sheet for BHS Pocket Leaf Filter

BHS FILTRATION

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

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:

BHS is organized both locally and globally. BHS-Filtration Inc., headquartered in Charlotte, North Carolina is responsible for North America and Mexico.

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:

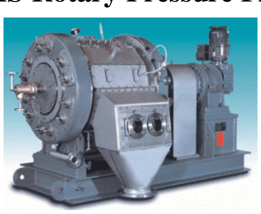
- Rotary Pressure Filter
- Continuous-Indexing Vacuum Belt Filter
- Candle Filter
- Pressure Plate Filters
- Autopress, an Automated/Contained Specialized Filter Press

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 1% and trace amounts.

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