



## THINKING LIKE SHERLOCK HOLMES FOR PROCESS FILTRATION TECHNOLOGY SELECTION

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### INTRODUCTION:

Sherlock Holmes and Dr. John Watson are fictional characters of Sir Arthur Conan Doyle. Process engineers who live in the real-world can learn many things from the two of them for solving process filtration problems. This paper will intertwine the detective techniques (mindfulness, astute observation, logical deduction and others) of Holmes and Watson with the problem solving skills required to select process filtration systems.

One example that Holmes proves time and again is that there is no benefit to jumping to conclusions. The paper begins with a discussion of the bench-top laboratory tests that are conducted for problem analysis, technology selection and scale-up. The tests include pressure/vacuum/centrifugation, filter media, cake thickness, temperature and viscosity concerns, filter aids and similar process parameters. Testing will avoid “jumping to conclusions.”

Another technique used by Holmes and Watson is “recreating events.” Holmes talks through his theories out loud to Watson and only then do gaps and inconsistencies rise to the surface that were not apparent before. The paper continues with four case history examples discussing slurry testing, process analysis and then process filtration selection for pressure filtration, vacuum filtration, centrifugation and clarification. The case histories illustrate the methods followed from testing through decision-making.

Finally, the paper concludes with a general review of the problem-solving skills of Holmes and Watson such as the “occasional silence”, “employing distancing” and “learning to tell the crucial from the incidental.” These skills can be utilized by process engineers as a framework for “idea-generation” when analyzing an operating bottleneck issue or new process development problem. In all cases, by combining Holmes and Watson with accurate lab and pilot testing, the optimum filter selection can be realized.



## **LABORATORY TESTING AND WHY THERE'S NO BENEFIT TO JUMPING TO CONCLUSIONS:**

According to Holmes and Watson, it is important to train yourself to be a better decision maker. For example, using checklists, formulas, structured procedures; those are your best bet. Figure 1 shows a typical Experimental Test Routine.

### **Overview of Bench Top Testing for Pressure and Vacuum Filtration**

The BHS bench top testing is conducted using the BHS Pocket Leaf Filter, as shown in Figure 1. The test device is a BHS pocket leaf filter with a filter area of 20 cm<sup>2</sup> and a vacuum and pressure connection. 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 2. The steps in filtration testing are as follows:

First, it is necessary to clearly state the process description. This includes the slurry characteristics (particle size distribution, particle shape, density, etc.), washing of the cake (i.e. number of washes and wash ratios), drying / pre-drying of the cake (vacuum, pressure blowing, and mechanical pressing) as well as the upstream and downstream equipment. With this definition, the type of samples that need to be collected and analyzed can be determined.

Secondly, it is necessary to know what are the requirements for the operation such as solids/hour and cake quality (percent moisture, percent contaminants, etc.).

Thirdly, with the above in mind, the testing must determine the following objectives:

- Choice of a suitable filter cloth
- Vacuum or pressure filtration
- Wash ratios for the washing of the filter cake
- Drying techniques
- Cake thickness

### **Overview of Bench Top Testing for Centrifugation**

Centrifugation lab testing include static settling test, filtration rate test and spin settling rate test.

The static settling test will be able to determine the densities of the solid and liquid phases and if there are different densities then centrifugal forces can be applicable for separation.

The filtration rate tests are conducted with the BHS pocket leaf filter using vacuum. Depending upon the vacuum filtration rates, the type of centrifuge can be determined.



Finally, the spin rate test will determine the effect of G forces and the time to separate the slurry into distinct phases. A bench-top test tube spinner is used for these tests. The baseline testing is at a time of 90 seconds.

In summary, if none of the three lab tests produce a satisfactory separation, then another type of solid-liquid separation technology is required.

## **PROCESS FILTRATION SELECTION FOR PRESSURE FILTRATION, VACUUM FILTRATION, CENTRIFUGATION AND CLARIFICATION:**

According to Holmes and Watson, it is easy to succumb to certainty but every time you find yourself making a judgment upon observation, train yourself to stop and repeat. Then go back and restate from the beginning and in a different fashion and most importantly, out loud instead of silently, as this will save you from many errors in perception. Process engineers can benefit from discussing options with technology suppliers that can provide different filtration solutions.

### **Case History-1: Pressure Filtration for Continuous Processing**

Process testing was conducted at the site's laboratory and in the plant. For the bench-top lab testing, the BHS pressurized pocket-leaf filter (PLF) with 20 cm<sup>2</sup> of filter area. For the continuous pressure pilot testing, a pilot RPF with 0.18 m<sup>2</sup> of filter area is installed, as shown in Figure 4.

The objectives of the PLF testing are as follows:

- Filtration time vs. filter media
- Filtration time vs. slurry feed mass
- Filtration time vs. differential pressure
- Filtrate quality vs. filter media
- Cake solids wash time and quality
- Cake solids discharge characteristics
- Production Scale-Up and Process Guarantee

The lab testing proved to be uniquely challenging both to feed the PLF as well as to maintain a pressure to keep the liquefied solvent. The plant engineers and BHS developed a confidential method to meet these challenges.

The PLF tests demonstrated that acceptable filtration and solids wash rates could be obtained for this product and acceptable solids levels were achieved for the mother liquor filtrate. Washing targets and drying quality parameters were also achieved.



Additional pilot plant tests with the BHS continuous pilot unit, RPF 0.18, were recommended to confirm the PLF lab tests. In these tests, BHS would be able to identify the necessary slurry solids percentage, cake solids thickness, solids wash time, solids drying time as well as cake discharge. Finally, the pilot testing will be the basis for the mechanical design of the RPF to ensure that the RPF can be designed for the process with a liquefied gas slurry.

While the actual data is confidential, the plant engineers and BHS process engineers gathered the following parameters from the pilot RPF 0.18 m<sup>2</sup> testwork.

Process Parameters:

- Slurry Feed Pressure:
- Slurry Feed Flow:
- Wash Pressure:
- Wash Flow:
- Dry Pressure:
- Drying Air Flow:

RPF Parameters:

- Drum Speed:
- Slurry feed rate, wash ratios and drying gas (rates and pressures):
- Cake blow back:
- Cloth blow back:
- Backpressure:
- Cake Thickness:
- Filter Cloth:

To fully evaluate the RPF performance, the site also compiled the following:

- Slurry solids concentration
- Filtrate quantity (mother liquor, wash, blow down, etc.)
- Filtrate yield
- Cake Moisture
- Total Cake quantity

Scale-Up From RPF 0.18 M<sup>2</sup> Pilot Data

- Calculate Specific Filter Performance from Pilot Testing  
= kg of dry solids/m<sup>2</sup>/hour
- Calculate Production Area Required from Filter Performance and Client Required Production Rate
- Using the drum speed, time for filtration, washing and drying and several other RPF factors, the specific filter area is calculated

## Pressure Filtration and Typical Scale-Up Calculation-Example Only

- The scale-up is based on 224 g slurry with 1:1 composition = 112 g dry solids
- Filtration time (4 seconds); washing time (8 seconds); drying time (15 seconds); these times are from the lab testing and used to scale up to a production unit; the pilot RPF testwork confirmed the scale-up.

Drum revolutions: 
$$n = \frac{3600 \frac{s}{h}}{(4 + 8 + 15)s} \cdot \frac{270^\circ}{360^\circ} \cdot 0,85 = 85 \frac{revolutions}{h}$$

270°: active angle

0.85: factor for separating elements

Specific filter performance: 
$$Q = 500 \frac{1}{m^2} \cdot 85 \frac{1}{h} \cdot 112g = 4760 \frac{kg \text{ dry solids}}{m^2 \cdot h}$$

Required filter area: 
$$A = \frac{20000 \frac{kg \text{ dry solids}}{h}}{4760 \frac{kg \text{ dry solids}}{m^2 h}} = 4,2 m^2$$

Selected filter: BHS Rotary Pressure Filter, type B16 with 5.4 m<sup>2</sup> is sufficient to operate 20,000 kg dry solids per hour.

## Case History-2: Vacuum Filtration

Bench top laboratory tests are valuable in selecting a solid/liquid separation device. For this process, the initial lab tests suggested a vacuum belt or rotary filter would achieve cake quality equal to or better than the current centrifuge with a major reduction in processing time. The footprint would be comparable to the current centrifuge and the unit would be suitable for conversion to a continuous process. After further discussions, the decision was to select a vacuum belt filter for pilot testing.

There are five objectives in running a pilot test filter:

1. To verify the time for formation of the cake and the initial saturation prior to dewatering of the cake
2. To evaluate the effect of cake thickness on the dewatering time
3. To investigate alternate ways to improve cake dryness (i.e. compression, gas blowing) that may eliminate the drying step
4. To evaluate the quality of the cake (dryness) and its effect on release from the filter media (Some initial tests would be required to make an initial selection, but 2-3 cloths may need to be tested in the pilot unit to verify release characteristics)
5. To evaluate wash ratio needed to remove solubles and color bodies



The initial laboratory test data suggest that a full-scale continuous-indexing vacuum belt filter with from 0.5 to 1.5 m<sup>2</sup> of filter area would be suitable for the current process operations and reduce cycle time in half or better. The BHS 0.1 m<sup>2</sup> vacuum belt filter was selected for test, and would allow for a feed rate of 0.5 gpm. The layout is shown in Figure 5.

Suggested testing order and condition changes:

1. Using a pocket filter and various samples of cloth, pull a vacuum of 20 in.hg. until no liquid is flowing. Invert the filter and observe the cake release. Describe it qualitatively (soupy, chunks, fine powder). Scrape out any remaining material and weight it separately from the material that was released. Select 2-3 cloths for the pilot testing from these tests. (optional) During the experiment measure how much time it takes for the cake surface to become dry and the dewatering time.
2. The estimated filtrate throughput for a 7 mm cake during cake formation and at the end of cake formation for vacuum filtration was measured. Since there are 10 zones, in the BHS filter, samples from the second or third zone would be taken to evaluate the moisture after cake formation (dry surface). It may be necessary to stop the unit for this evaluation so it should only be done occasionally. Cake thickness can be checked at this time. The other zones can be sampled to determine the rate of dewatering after cake formation and wash ratio.
3. A wash ratio comparable to the centrifuge operation should be used for the previous tests. In the next series, the wash ratio could be varied to evaluate removal of solubles as well as the effect on cake stickiness.
4. While maintaining the same cloth indexing-time, the feed rate can be increased and decreased to vary the cake thickness.
5. Throughout these tests the visual quality of the cake, especially at the discharge should be evaluated.
6. The test unit has an optional compression zone that could be employed. It is also possible to evaluate gas blowing with and without compression.

The results of the testing illustrated that the BHS continuous-indexing vacuum belt filter would be able to produce a cake with better washing and drying compared with the existing centrifuge operation.



### Case History-3: Centrifuge Selection

The choice of centrifuges (filtering or sedimentation) is dependent upon particle sizes, density of the solids and liquids and the process and application. Filtering centrifuges have a rotating perforated basket or bowl with filter media while sedimentation centrifuges have a rotating non-perforated bowl.

The initial testing is as follows:

- Preliminary data to determine centrifuge type and the initial parameters for pilot tests
  - Bench centrifuge tests
  - Filter bucket (specialized filtration bucket)
  - Vacuum filtration (Buchner or pocket filter)
- Cake moisture versus G-force and time
- Effect of cake thickness on time to reach moisture goal
- Effectiveness of wash
- Optimizing conditions (extensive pilot tests)
- Evaluate ways to avoid cake cracking
- Sliding and conveying properties of cake (shear)

In terms of filtering centrifuges, the choices are between batch and continuous feed. Continuous feed and liquid flow can be either continuous moving cake or intermittent moving cake. As for batch feed (fixed cake, batch liquid flow), the choices are the type of feed (Vertical, inclined, horizontal axis) and the type of discharge.

Major differences between the filtering centrifuges are

#### Batch

- Clear liquid
- Cake heel
- Wider size and feed concentration range (100 ppm to 50%)
- Can be inerted
- Can be used at high temperature

#### Continuous

- Liquid clarity poor
- Total discharge
- Feed > 15%
- Best above 10 micron
- Not suited for volatile liquids and hazardous or abrasive solids
- Operates at ambient temperatures

Why select a filtering centrifuge:

- Drier cakes than other centrifuges (generally)
- Compact relative to their throughput
- Fully automatic operation
- Particles from 1 micron to 2 mm (coarse – best)
- Fragile solids may have attrition issues
- Wide range of feed concentrations (non-abrasive solids)
- OK for moderately hazardous solids and volatile liquids
- When low moisture required
- Minimal washing required
- High in first cost; gives moderate clarity to the liquid

Why not select a filtering centrifuge:

- If the solids are only required in slurry form
- If coarse solids will screen or free drain to the necessary moisture content
- If fine compressible solids are to be filtered, washed and dried
- If coarse to medium sized solids have exacting washing requirements but require only moderate dewatering
- If feed solids content is low and the particles are very fine
- If the use of filter aid is contemplated

As for sedimenting centrifuges:

- Uses difference in density to separate solids
- Also used to separate liquids
- Has limited washing capability
- Wide range of feed concentrations
- Requires uniform feed
- Potential for particle breakage
- May have more wear than filtration devices
- Often wetter cake produced

In summary, the centrifuge selection depends upon the process characteristics and the laboratory testing to select the type and design.





## **Case History-4 Clarification for Batch Pressure Filtration: 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 after 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 catalyst. Current production is 3000 gallons in 4 – 5 hours.

The results and conclusions showed that the filtration flux rate from the BHS laboratory tests ranged between 10-30 L/m<sup>2</sup>/min at approximately 20 psi feed pressure. The sock filter cloth is polyester with an air permeability of 1.0 cfm/ft<sup>2</sup>.

The tests illustrate that one (1) BHS candle filter with 10 m<sup>2</sup> of filter area can process the complete 3000 gallon batch in a cycle time of 4.3 hours and replace the manual plate filter and bag filter. Figure 6 shows the dry cake discharge which meets the quality requirements.

### **CONCLUDING REMARKS & TAKEAWAYS:**

Holmes and Watson provide a unique view of problem solving. The world of a process engineer is a distracting place and Holmes and Watson know that without the occasional silence, as in *The Hound of the Baskervilles*, there can be little hope for success. Engineers can benefit from conducting lab testing at the technology supplier's site to have time to think about the process issues, at hand. Finally, Holmes and Watson excel at "deduction from facts and deduction difficulties." All that matters are what the premises are (process definition, requirements and testing objectives) and how the testing "unwinds the crucial from the incidental" (what is the critical process parameter) and finally ending up in the logical conclusion (optimum process filtration solution).

In summary, it is important to view the entire project from many different perspectives. These include knowing the process, observing the testing, deducing the solution only from what is observed (and nothing more) and learning from your colleagues and the technology supplier's successes and failures. It is always difficult to apply Holmes' logic but as Holmes' states "you know my methods, now apply them." Engineers must practice these habits such that even under stress to solve a process problem, these stressors will bring out the very best thought patterns that are needed.



## References:

1. All information about Holmes and Watson are taken from Maria Konnikova's *Mastermind-How to Think Like Sherlock Holmes* (Viking Penguin (USA) Inc. 2013).
2. All information about centrifuges is taken from Healthsite Associates, Tom Blackwood, presentation, St. Louis Engineers Club, 14 November 2013.
3. Testing: The logical way to select a centrifuge, Mike Vastola, TEMA Systems.
4. Davies, E. (1965): Selection of Equipment of Solid/Liquid Separations.

**Figure 1: Davies' Experimental Test Routine**

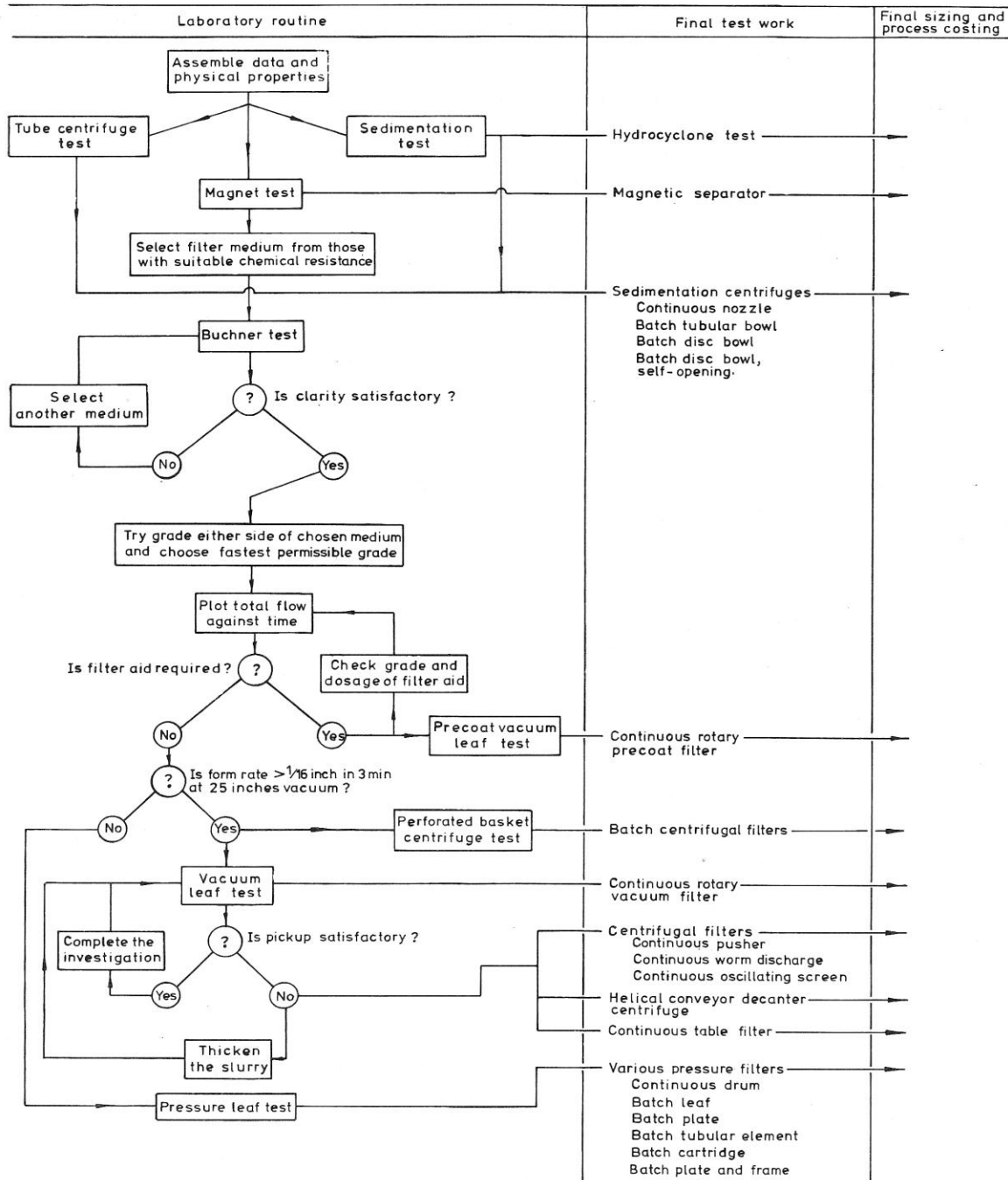
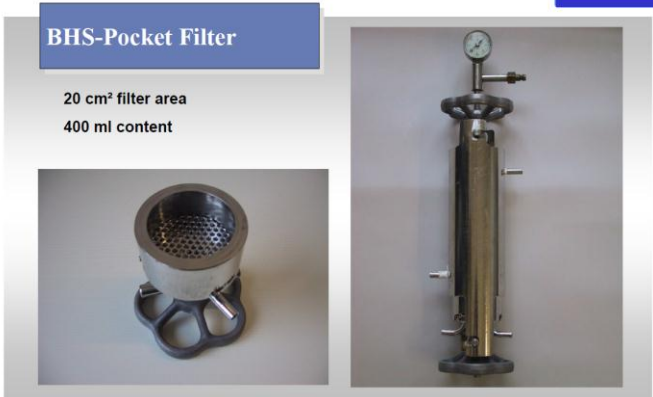
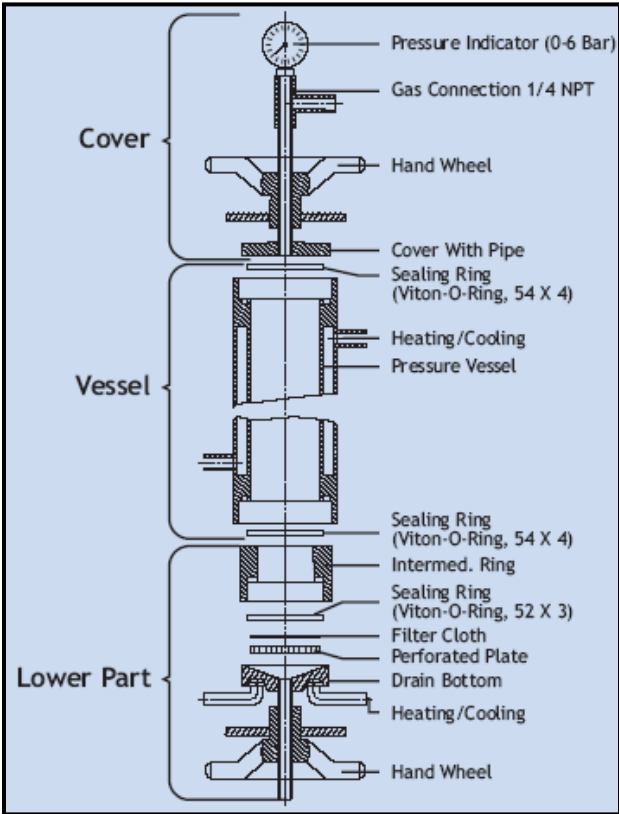


FIG. 4.1 DAVIES' EXPERIMENTAL TEST ROUTINE

**Figure 2: BHS Pocket Leaf Filter**



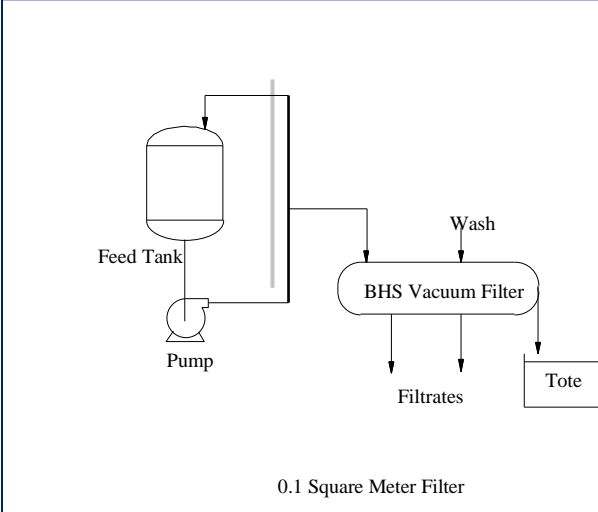
**Figure 3: Data Collection Sheet for BHS Pocket Leaf Filter**

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

**Figure 4: BHS Rotary Pressure Filter, RPF 0.18 M<sup>2</sup>, Pilot Filter**



**Figure 5: Pilot Vacuum Belt Filter Layout**



**Figure 6: Dry Cake after Discharge**

