Thinking like Sherlock Holmes **for process filtration technology selection**

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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 article 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 article 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.

Another technique used by Holmes and Watson is 'recreating events'. Holmes deliberates on his theories aloud to Watson; only then do gaps and inconsistencies that were not apparent before, rise to the surface. The article continues with four case history examples discussing slurry testing and process analysis, followed by process filtration selection for pressure filtration, vacuum filtration, centrifugation and clarification.

Finally, the article 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 used by process engineers as a framework for 'idea-generation' when analysing 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 realised.

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 and structured procedures are your best bet.

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 on page 20. The test device is a BHS pocket leaf filter with a filter area of 20 cm² and a vacuum and pressure connection. The testing will analyse cake depths, operating pressures, filter media, washing and drying efficiencies and qualitative cake discharge. The data collection sheets are shown in Figure 2 on page 20. 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 (ie, 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 analysed can be determined.

Secondly, it is necessary to know what the requirements are for the operation, such as, for example, solids/hour and cake quality (percent moisture, percent contaminants, etc). Thirdly, with the above in mind, the testing pretty much determines the following objectives:

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

Overview of bench top testing for centrifugation

Centrifugation lab testing includes a static settling test, a filtration rate test and a spin settling rate test. The settling test will be able to determine the densities of the solid and liquid phases and if there are different densities, then centrifugal forces may 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 judgement 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 who can provide different filtration solutions.

Case History: Pressure filtration

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^2 of filter area was used. For the continuous pressure pilot testing, a pilot RPF with 0,18 m^2 of filter area is installed, as shown in Figure 3 on page 21.

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 gas as a 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 observed for the mother liquor filtrate. Washing results and drying quality parameters were also achieved.

Additional pilot plant tests with the BHS continuous pilot unit, RPF 0,18, are 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

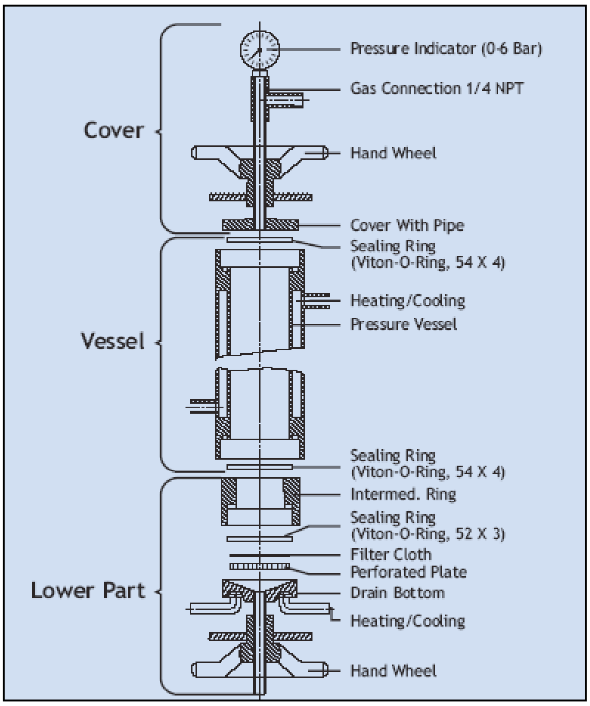

Figure 1: BHS Pocket leaf filter

Customer:	Test Number:
Date :	Run #
	Filter Media
	Suspension
Filling	Volume of Slurry
	Density of Slurry
	% Solids in Feed
	Temperature
Filtration	Pressure/Vacuum
	Volume of Filtrate
	Time for Filtration
	% Solids in Filtrate
Wash 1	Wash Material
	Pressure/Vacuum
	Volume of Filtrate
	Time for Filtration
Wash 2	Wash Material
	Pressure/Vacuum
	Volume of Filtrate
	Time for Filtration

Customer:	Test Number:
Wash 3	Wash Material
	Pressure/Vacuum
	Volume of Filtrate
	Time for Filtration
Drying	Pressure/Vacuum
	Temperature
	Flow Rate
	Time for Drying
	Pressing Pressure
Cake	Weight
	Thickness
	% Residual Moisture
	Dry Cake Weight
	Cake Discharge OK?

Figure 2: Data collection sheet for BHS Pocket leaf filter

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^2 testwork.

Process parameters:

- Slurry feed pressure:
- Slurry feed flow:
- Wash pressure:
- Wash flow:
- Dry pressure:
- Drying air flow:

RPF parameters:

- Drum speed:
- Separating elements:
- 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^2 pilot data

- Calculate specific filter performance from pilot testing
- = kg of dry solids/m^2/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:

Drum revolutions:

$$n = \frac{3600\frac{s}{h}}{(4+8+)s} \cdot \frac{270°}{360°} \cdot 0{,}85 = 85\frac{\text{revolutions}}{h}$$

270°: active angle
0,85: factor for separating elements

Specific filter performance:

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


Figure 3: BHS rotary pressure filter, RPF 0,18 M2, pilot filter

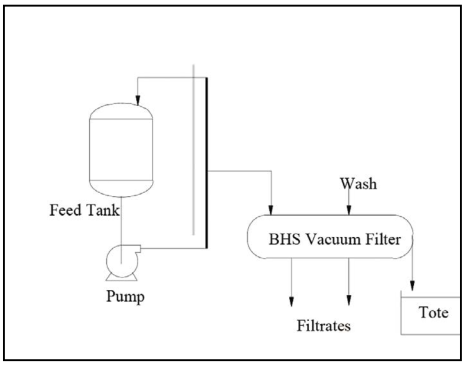

Figure 4: Pilot vacuum belt filter layout


Figure 5: Dry cake after discharge

Required filter area:

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

Selected filter: BHSRotary Pressure Filter, type B16 with 5,4 m^2 is sufficient to operate 20 000 kg dry solids per hour.

Case History: Vacuum filtration

Bench-top laboratory tests are valuable in selecting a solid/liquid separation device. 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 (Figure 4).

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 (ie, 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 of the cloth, 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 colour bodies.

The initial laboratory test data suggested a full-scale filter with from 0,5 to 1,5 m^2 of filter area would fit into the current process operations and reduce cycle time in half or better. A BHS 0,1 m^2 vacuum belt filter is available for the test, which would allow for a feed rate of 0,5 gpm.

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. 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 rate, 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 would be evaluated.

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 is that the BHS continuous-indexing vacuum belt filter will be able to produce a cake with better washing and drying compared with the existing centrifuge.

Case History: 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 (specialised 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
- Optimising 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 clarification: Replacing a manual plate filter and bag filter combination

This specialty chemicals manufacturer produces various resins that require filtration. Current production includes a neutralisation 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, to reduce the maintenance and operation on the two filters and to recover a dry catalyst. Current production is 3 000 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^2/min at approximately 20 psi feed pressure. The sock filter cloth is polyester with an air permeability of 1,0 cfm/ft^2.

The tests showed that one BHS candle filter, Figure 5, with 10 m^2 of filter area can complete the cycle in 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

Concluding remarks and 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 is 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 put the project together 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 practise these habits such that even under stress to solve a process problem, these stressors will bring out the very best thought patterns needed.

References

For list of references contact the editor at chemtech@crown.co.za