“SYMPHOS 2015”, 3rd International Symposium on Innovation and Technology in the Phosphate Industry

Thickening, Filtration and Clarification in the Phosphoric Acid Industry

Roger Summerhays\textsuperscript{a}, Abilio Gaspar\textsuperscript{b}

\textsuperscript{a} WesTech Engineering, 3665 South West Temple, Salt Lake City, Utah 84115, USA
\textsuperscript{b} WesTech Engineering, Rua Marques de Paranaguá, 360, Consolacao, Sao Paulo, 01301-000, Brazil

Abstract

Whenever thickening, filtering and clarifying concentrates or residues, the question is: “What is the best equipment to choose?” This presentation gives guidelines to help evaluate equipment options.

Keywords: Liquid solids separation; sedimentation; dewatering; clarification; thickening; filtration; clarifier; thickener; vacuum filter; horizontal belt filter; drum filter; table filter.

1. Introduction

Phosphoric acid plant design begins with desired production rate in tons of $P_2O_5$, and addressing the primary equipment in the flowsheet, namely the reactor and slurry filter. For the last fifteen years the trend has been to build larger production plants to 1,000 – 1,500 tonnes $P_2O_5$ per day. Some well-known engineering companies that have developed plant flowsheets include:

- Jacobs
- Prayon
- Rhône-Poulenc,
- Nissan,
- Mitsubishi, and
- Siape
Other engineering companies and consultants offer their own flowsheets, which could also be included. Approximately 40% of current operating systems use the Prayon process. However, like any industrial plant, each of these processes can be customized to suit the end user’s needs based on many variables like economic considerations, ore variability, and environmental factors. This presentation is focused on the selection of sedimentation and filtration equipment once the overall process has been determined.

As shown in Figure 1. Thickening and Filtration Steps in Phosphoric Acid Processing, there are thickening, filtration and clarification steps throughout the process. This paper will present design recommendations for each application along with operating experiences and include important design considerations for thickeners, clarifiers and filters.

![Diagram of Phosphoric Acid Processing](image)

**Figure 1. Thickening and Filtration Steps in Phosphoric Acid Processing**

### 2. Clarifier – Thickener Selection

Proper thickener and clarifier selection depends on process goals, feed slurry composition, and life cycle costs. In phosphoric acid, thickeners concentrate the phosphate rock slurry prior to the reactor and clarifiers remove fine gypsum from the phosphoric acid product. Although these two applications are different, the design approach is similar. Slurry characteristics drive various materials of construction from painted carbon steel to exotic stainless steel compounds, as well as rubber lined tanks with abrasion resistant carbon bricks.

The primary goal for clarifiers and thickeners is to evenly distribute the feed in the tank so that the liquid-solids separation takes place across the entire tank. A key component of any thickener is the feedwell, which has the following functions:

- Control energy and momentum dissipation
- Feed de-aeration
- Feed dilution (if required)
- Optimize flocculation conditions
- Evenly distribute the feed stream in the thickener or clarifier tank.

It is critical to distribute the incoming thickener feed in an even and concentric manner to prevent short circuiting of fine unsettled solids into the overflow launder. WesTech’s EvenFlo™ feedwell design addresses these issues.[1]

The EvenFlo™ feedwell shown in Figure 2, dissipates energy and evenly distributes feed in the thickener. Feed enters the inner chamber. Head loss is induced through a narrow opening which eliminates the rotational momentum. The inner chamber directs flow to the bottom outer shelf in the feedwell and forces the feed to change direction a second time. As a result, the feed exits the feedwell and enters the thickener in an evenly distributed flow pattern. The EvenFlo™ feedwell design ensures steady state flow into the thickener tank across a wide range of feed flow rates. Feed flow variations only change the head level in the inner chamber while even flow distribution continues into the main portion of the feedwell and then into the thickener tank.

2.1. CFD Comparative Study

The illustrations in Figure 3 below show the CFD results when EvenFlo™ and conventional feedwell configurations are compared side-by-side using the same flow rate and feedwell diameter. The velocity indicated on the left column is the magnitude of the thickener flow region shown in the images to the right. The distribution of solids is less concentric for the side feed and bottom shelf (conventional) designs. The EvenFlo™ design controls the velocity, producing an even flow and uniformity in the feedwell. The images below are taken from the top view of the thickener model.[2]
Figure 3. Performance of EvenFlo™ and Conventional Feedwells
2.2. Confirmation of CFD Results

AMIRA\(^3\) independently analyzed the EvenFlo\(^TM\) feedwell design and concluded the following:

- “The EvenFlow [sic] feedwell offers a novel way to convert the feed rotational energy into a nearly radial flow.”
- “Feedwell design achieves good momentum and energy dissipation.”
- “Feedwell design consistently produces even discharge flow over a range of flow rates.”
- “The solids and flocculant are well mixed and well dispersed within this zone.”
- “The flocculant addition strategy is very effective.”
- “Whether the creation of the recirculation or flocculating zone was intended in the feedwell design, but it was very effective.”

Their model in Figure 4 shows solids exiting the inner chamber where flocculent is added in a brief, high velocity region. Then flocs quickly grow in the main zone of the feedwell and then are evenly discharged.

2.3. Underflow Solids

Higher density underflow solids reduce water losses or water usage in many instances. This must be tempered with consideration to the underflow rheology.

Figure 5 shows the relationship between yield stress and thickener type.

Yield stress is defined as the stress that must be applied to the slurry before it starts to flow. The higher the underflow solids, the higher the yield stress produced. HiDensity\(^TM\) and DeepBed\(^TM\) paste thickeners were developed to produce higher yield stress underflow solids.
2.4. Installation Experience

Through the years, WesTech has provided many clarifiers, high rate thickeners, paste thickeners, vacuum filters and table filters to the phosphate industry. Below is a recent, innovative solution that WesTech recently installed. This plant receives pumped phosphate rock slurry through a 200 km pipeline. WesTech has installed four independent trains of DeepBed™ paste thickeners with slurry tanks, flocculent dosing systems and pumps as shown in Figure 6. The overall objective of the paste thickeners is to receive a 55 wt% solids concentrate slurry and provide a steady narrow spec stream of approximately 65 wt% underflow solids that meets specifications. Feed dilution to approximately 15-17 wt% solids is required for optimum flocculent consumption and settling.

In addition, the system was designed for a 40% turn down of feed solids loading. For such a large variation in the specified feed flow rates, a conventional feedwell design is insufficient. Excessive variation in flow rates through a conventional feedwell can result in inconsistent flow patterns to the sedimentation zone, poor flocculation due to inadequate mixing, short-circuiting of solids to the overflow, and an uneven distribution of settled solids. It is imperative, regardless of varying flow rates, that the feed energy be properly absorbed by the feedwell and re-directed evenly to the sedimentation zone. For this reason, WesTech proposed our patented EvenFlo™ feedwell. This feedwell has two different feed lines (50% design flow each) to allow for varying flow rates.

During testing, WesTech found that the yield stress was moderately low for the target 65 wt% underflow solids. However, the yield stress climbs rapidly above 65 wt% solids. It is possible to produce higher-than-design underflow density if the material is held too long in the thickener. Specifically, each paste thickener includes the following:

- Rake mechanism fitted with dewatering pickets to produce the target density within the design solid retention time.
- Heavy-duty drive with a K-factor of 300 for a robust paste thickener design. Each rake mechanism has four low profile rake arms and the rake blades extend from the arms on posts to reduce the drag and properly transport the solids to the discharge nozzles.
- 45 degree floor slope to enhance discharge of the underflow.
- Underflow recirculation pumps to keep the material in the thickener active by withdrawing the underflow and returning it to several locations in the thickener.
- Underflow density is monitored with a proving loop. Underflow is not fed forward to the Rock Slurry Tank until the underflow density reaches the selected concentration. In the event that the density of the underflow is higher than the selected concentration, an external dilution system fine tunes the density as it is transferred forward.

3. Vacuum Filtration

Selecting proper vacuum filtration equipment is key once the process is determined. Many papers addressed this over the years and several applicable papers are referenced. We share our experience of the last thirty years and summarize the advantages and disadvantages of each type of filter so decision-makers may be better informed.

An analogy for the decision-making process is choosing a car for the trip from Casablanca to Marrakech. Assume you could select one of three vehicles:
• Mercedes C-Class
• Porche 911
• Volkswagen Passat

All will get you to your destination, but not in the same way, especially in terms of initial investment, maintenance cost or reliability; all of which are part of the total cost of ownership over the life of the car. Similarly, choosing a filter for production of phosphoric acid poses somewhat the same dilemma. There are currently three types of filters available for the application:

- Horizontal Belt Filters
- Table Filters
- Tilting Pan Filters

All produce phosphoric acid but not in the same way, especially considering capital investment, maintenance cost and operational experience. The temptation is to select the lowest capital cost because it offers a very clear differentiation between options. Quality of the equipment, immediate installation costs, and future costs of maintenance and production are much less obvious at the start. To avoid the trap we will review each type of filter, its advantages and disadvantages. Comparing operation of a filter type in one plant to the operation of another type in a different plant is of limited value because of the difference in ore characteristics (e.g. Western Rock vs. Togo Rock), and even more so because of different plant maintenance and operating practices; however Tables 1, 2 and 3 provide a reasonable comparison of general characteristics.

3.1. Horizontal Belt Filters

Table 1 Horizontal Belt Filter Summary

<table>
<thead>
<tr>
<th>Technical Advantages:</th>
<th>Economic Benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td>High filtration rates[^1]</td>
<td>Low capital investment</td>
</tr>
<tr>
<td>Effective filtrate extraction</td>
<td>Higher filtration rates</td>
</tr>
<tr>
<td>More challenging with wider belts</td>
<td>Operating costs[^1]</td>
</tr>
<tr>
<td>Multi-stage cake washing</td>
<td></td>
</tr>
<tr>
<td>Excellent cloth washing on both sides</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Disadvantages:</th>
<th>Economic Disadvantages:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited filtration area</td>
<td>Improper drainage belt and/or curb selection can lead to high maintenance</td>
</tr>
<tr>
<td>Few qualified belt suppliers</td>
<td>Power costs from vacuum leakage, particularly if seals are not maintained</td>
</tr>
<tr>
<td>Elastomer selection (material and supplier) is critical to a reliable filter</td>
<td></td>
</tr>
<tr>
<td>Extra care required in hemihydrate</td>
<td></td>
</tr>
<tr>
<td>Some will not use in hemihydrate</td>
<td></td>
</tr>
</tbody>
</table>
3.2. Table Filters

Table 2. Table Filter Summary

<table>
<thead>
<tr>
<th>Technical Advantages</th>
<th>Economic Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good cake washing and dewatering</td>
<td>Acid clarity</td>
</tr>
<tr>
<td>Minimal acid dilution</td>
<td>Maintenance costs</td>
</tr>
<tr>
<td>Maximum filtration area</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Disadvantages</th>
<th>Economic Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cycle times (maximum 0.75 rpm)</td>
<td>Capital investment</td>
</tr>
<tr>
<td>Incomplete cake discharge</td>
<td>Operating costs</td>
</tr>
<tr>
<td></td>
<td>Particularly when high scale</td>
</tr>
<tr>
<td></td>
<td>Cloth blinding</td>
</tr>
<tr>
<td></td>
<td>Cannot wash continuously</td>
</tr>
</tbody>
</table>

3.3. Tilting Pan Filters

Figure 8.

Figure 9.
Table 3. Tilting Pan Filter Summary

<table>
<thead>
<tr>
<th>Technical Advantages:</th>
<th>Economic Benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Good cake washing and dewatering</td>
<td>• Acid clarity</td>
</tr>
<tr>
<td>• Minimal acid dilution ( ^7 )</td>
<td></td>
</tr>
<tr>
<td>• Maximum filtration area</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Disadvantages</th>
<th>Economic Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Low cycle times</td>
<td>• Capital investment ( ^7 )</td>
</tr>
<tr>
<td>– Maximum 0.5 rpm</td>
<td>• Operating costs</td>
</tr>
<tr>
<td>• Many rotating parts</td>
<td>– Particularly when high scale</td>
</tr>
<tr>
<td>• Less compact than table filter for the same active filtration area</td>
<td></td>
</tr>
</tbody>
</table>

3.4. Vacuum Filtration Summary

Table 4. Dewatering Filter Summary

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Production</th>
<th>Purchase Price</th>
<th>Install Costs</th>
<th>Oper Costs*</th>
<th>Maint Costs</th>
<th>Life Cycle Costs</th>
<th>Cake Wash Efficiency</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td>Mid</td>
<td>Mid-High</td>
<td>High</td>
<td>Mid</td>
<td>Low-Mid</td>
<td>Mid-High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Tilting Pan</td>
<td>Mid</td>
<td>High</td>
<td>High</td>
<td>Mid</td>
<td>Mid-High</td>
<td>Mid-High</td>
<td>Mid</td>
<td>Low</td>
</tr>
<tr>
<td>Horizontal</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>Mid</td>
<td>Low-Mid</td>
<td>Low-Mid</td>
<td>High</td>
<td>Mid</td>
</tr>
<tr>
<td>Belt</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>Mid</td>
<td>Low-Mid</td>
<td>Low-Mid</td>
<td>High</td>
<td>Mid</td>
</tr>
</tbody>
</table>

Again, it is difficult to select one type filter as a panacea, but in general terms, the conclusions are:

- Horizontal belt filters provide economically high performance in the short term.
- From a strictly technical perspective, the tilting pan typically leads, but at a higher price.
- In processes without high scale build-up and needing virtually no acid dilution, a table filter may be a reasonable compromise between the two.

Maximum possible filter sizes are listed in Table 5 – Filter Sizes as follows:

Table 5 – Filter Sizes

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>Largest Installed Size</th>
<th>Largest Possible Size</th>
<th>Estimated Phosphoric Acid Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Belt Filter</td>
<td>110 m(^2)</td>
<td>254 m(^2)</td>
<td>150</td>
</tr>
<tr>
<td>Rotary Table Filter</td>
<td>284 m(^2)</td>
<td>338 m(^2)</td>
<td>200</td>
</tr>
<tr>
<td>Tilting Pan Filter</td>
<td>240 m(^2)</td>
<td>330 m(^2)</td>
<td>150</td>
</tr>
</tbody>
</table>

4. Conclusions

Equipment selection should be based on plant needs, expected plant life, best engineering solutions, and lowest life cycle costs. In the global market, it is especially important to ensure equipment meets the necessary quality standards.

Questions to ask when choosing equipment are:

✓ Quality of the equipment?

\( ^* \) Cloth life can dramatically impact operating costs. If cloth blinding is a problem, the belt filter may have a significant advantage. If cloth blinding is not, the smaller amount of cloth required for table and pan filters and the fact that the cloths don’t move can work to the advantage of those filters.
Quality of service and spare parts availability?
- Global coverage
- Experience and knowledge of personnel

Expected equipment life?

Maintenance costs?
- Labor and parts

Equipment operating costs?
- Cloths, power, water, etc.

Capital cost of the equipment?

Installed cost of equipment?

After a few years of operation, no one will remember if an inexpensive filter was purchased. Everyone will remember high maintenance and operating costs.

It is important to select experienced, knowledgeable partners who:
- Exhibit honesty and integrity,
- Provide superior service,
- Do the right thing the first time,
- Take pride in their products, and
- Achieve productivity through innovation and hard work.

Such a supplier is worth much more than the all of the economic differences discussed above, and they should be able to guide you to the best solution for your flowsheet.

References

[3] AMIRA International LTD. Level 2 271, William Street, Melbourne, Australia