Improving Depth Filtration Capacity and Flux
A Solid-Liquid Separations Proof-of-Principle Protocol

Summary
This technical note describes a simple modification to conventional depth filtration protocols that, when implemented with conventional depth filtration hardware, significantly increases filtration flux and capacity.

This protocol is designed to produce a minimum improvement of 2X for both flux and capacity; however, optimization frequently enables improvements that exceed 10X (Figure 2). Contact Advanced Minerals at info@advancedmineras.com to receive optimization instruction.

Background
The process modification, known as dynamic depth filtration, uses a technique called body feed, in which Celpure® filter media is added to the feedstock before filtration (in contrast to conventional depth filtration, in which the media is fixed within a filter element).

Celpure media is a high purity (96-99% SiO₂) powdered filter media composed of diatoms (Figure 1), which are rigid, porous, and irregular in shape. These structural properties greatly enhance depth filtration. Diatomite already constitutes 20-80% of the media in many depth filters. Despite this, when diatomite is impregnated in a depth filter, its performance enhancing properties are under-utilized (Figure 2).

A Celpure body feed is maintained in suspension throughout the filtration and is therefore continuously deposited alongside the impermeable feedstock solids on the filter surface. These rigid and porous Celpure particles maintain separation of the impermeable solids, dramatically increasing the permeability of the accumulating filter cake. When optimized, Celpure media continually regenerates the filter, maximizing filtration flux and capacity (see the Pressure curve under Figure 3b). Without a Celpure body feed, there is an accumulation of impermeable debris within finite flow channels, and the result is a rapid pressure rise and a requirement for greater filtration surface area (see the Pressure curve under Figure 3a).

Protocol Objectives
- Increase overall flux of depth filtration by at least 2X
- Increase overall capacity of depth filtration by at least 2X

Figure 1. Typical shapes of diatoms (10–200 µm in diameter).
**Constant Flow Filtration:**
Depth vs. Dynamic Depth

**Figure 3a. Depth Filtration**
- Feedstock 3a. Debris only
- Depth filter housing
- Filter element
- Filtrate
- No flow channels between compressible debris

**Figure 3b. Dynamic Depth Filtration**
- Feedstock 3b. Body feed and debris
- The cake space is the space between the filter elements.
- Filter cake composed of feedstock solids and Celpure media
- Flow channels extend cycle

**Performance without body feed**
- Flow vs. Pressure vs. Time

**Performance with body feed**
- Flow vs. Pressure vs. Time
Protocol

Filter Hardware

Because this process increases the volume of solids retained, you must ensure that adequate cake height exists over the filter surface. To estimate the volume of solids produced, assume that for each gram of body feed added to the feedstock, a total of 3-4 cm³ of solids will be produced. For example, if your feedstock requires 20 g/L of body feed, and you are working with a 50-cm² filter, allow at least 1.2 cm of vertical space over the entire surface of the filter for each liter processed.

Most depth filter manufacturers offer units fitted with spacers between the elements to facilitate dynamic depth filtration.

Control Test

1. Using current depth filtration practices under constant flow conditions, determine the achievable flux, capacity, and filtrate clarity. Record the pressure and cumulative filtrate volume at five-minute intervals.
2. Terminate the filtration once the pressure reaches the limit, or the flow rate is unacceptable.
3. Save the filtrate for comparison to the Celpure Test.

Celpure Test

1. Assemble the filter according to current practices. If possible, replace the depth filter element with one having a retention rating no tighter than 2-20 µm. (Because Celpure media will control the filtrate clarity, the element selected must be sufficiently open so as not to inhibit the throughput.)
2. Fill the filter with a compatible solution, and void air from the unit. If current practices do not permit voiding air from the unit, this step may be omitted.
3. Choose an appropriate Celpure grade. In most cases, Celpure 1000 maximizes performance (Figure 4). If Celpure 1000 does not produce sufficient clarity, switch to a less permeable grade (Table 1).
4. Choose the initial body feed concentration by first centrifuging 10-mL of feedstock for 5–10 minutes at approximately 2,500 rpm. Then, visually estimate the volumetric percent of solids (packed debris), and refer to the Body Feed Calculator (Table 2) to determine the amount of Celpure media to add to the feedstock before filtration.
5. Add the appropriate Celpure body feed amount to a feedstock volume of at least 2X the Control Test volume. Use a stir plate throughout the filtration to uniformly suspend the Celpure media and feedstock solids.
6. Begin constant flow filtration at a flow rate of 2X the Control Test. Record the pressure and cumulative filtrate volume in five-minute intervals.
7. Stop the filtration once the pressure reaches the limit, or the flow rate becomes unacceptable.
8. Compare the Celpure Test filtrate to the Control Test filtrate. If the filtrate does not meet clarity standards, refer to Table 1 for a more appropriate grade of Celpure.

Figure 4. Maximize performance with the grade that produces the least resistance to flow. These flow curves were generated with a blood product filtration.

### Table 1. Listed in order of increasing permeability (Celpure 65 grade is the least permeable). Maximize throughput with the grade that produces minimal acceptable clarity.

<table>
<thead>
<tr>
<th>Celpure® Grade</th>
<th>99% Retention (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>&lt; 0.20</td>
</tr>
<tr>
<td>100</td>
<td>&lt; 0.30</td>
</tr>
<tr>
<td>300</td>
<td>&lt; 0.65</td>
</tr>
<tr>
<td>1000</td>
<td>&lt; 2.0</td>
</tr>
</tbody>
</table>

### Table 2. These body feed rates are for proof-of-principle only. Optimized rates will typically be ½ to ⅕ these initial rates. If your solids concentration exceeds 20%, contact Advanced Minerals. In general, solids concentrations of up to 50% are easily clarified with Celpure media; however, processes approaching this upper limit are best evaluated on a custom basis.

<table>
<thead>
<tr>
<th>Feedstock Solids (Volumetric %)</th>
<th>Body Feed (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 2</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
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<td>16</td>
<td>96</td>
</tr>
<tr>
<td>18</td>
<td>108</td>
</tr>
<tr>
<td>20</td>
<td>120</td>
</tr>
</tbody>
</table>
Further Study
This protocol allows you to demonstrate flux and capacity improvements over your current depth filtration process. While it is best to contact Advanced Minerals before further study, the following principles can be used to begin optimization.

OPTIMIZATION PRINCIPLES
With dead end filtration (Figure 3a), the accumulating solids exert a rapid flow rate decay. The body feed technique minimizes this by maintaining separation of the impermeable solids with well-characterized, permeable Celpure particles (Figure 3b). Therefore, to maximize the benefits of the body feed technique, make certain that the resistance to flow is primarily influenced by the permeable Celpure particles rather than the impermeable feedstock solids.

Other than cake height limitations, the primary limiting factor of this process appears when destabilization of the filter cake permeability occurs via compressive forces. The main indicator of this is when the differential pressure exhibits nonlinear increases. This is typically caused by one of the following:

- The differential pressure exceeds 30-40 psi.
- The flux is too great.

Therefore, the goal is to maximize the process capacity and flux up to, and just before, the point at which a nonlinear pressure increase is observed.

MAXIMIZE PROCESS IMPROVEMENTS
Begin optimization by verifying that the initial flux rate produces a linear pressure increase. For example, if the pressure is 10 psi after processing 150 mL, an additional 150 mL should not produce greater than 20 psi.

The next step is to attain the desired capacity (L/m²) by establishing a maximum cake height at a given flux rate. This final step should be based on your process objectives:

- To minimize Celpure media usage and maximize capacity, reduce the body feed concentration until the differential pressure exhibits a nonlinear pattern.
- To maximize flux, increase the flux rate until the differential pressure exhibits a nonlinear pattern.
- To achieve a balance of these objectives, apply a combination of body feed reduction and flux rate increases.

Glossary

BODY FEED
Filter media suspended in the feedstock before and during filtration.

CAKE HEIGHT
Vertical height of the retained solids on the filter element.

DIATOM
See Diatomite.

DIATOMITE
A sediment obtained from diatomaceous earth, greatly enriched in biogenic silica in the form of the siliceous frustules of diatoms, a diverse array of microscopic, single-cell algae. Diatomite products have an intricate and highly porous structure composed primarily of silica.

DYNAMIC DEPTH FILTRATION
A filtration technique in which filter media is suspended in the feedstock and continually regenerates the filter surface. This differs from dead end filtration, in which the media is fixed within the filter element.

FILTER AID
Inorganic mineral powders or organic fibrous materials, used in combination with filtration hardware to enhance filtration performance. Commonly used filter aids include diatomite, perlite, and cellulose. Some of these materials have been in use for over 75 years.

FILTER CAKE
Retained solids and Celpure media on the filter element.

PRESSURE-PRECOAT FILTRATION
A method of solid-liquid separation using a pressure precoat with diatomite filter aid that has been used for over 75 years. One premise is that the retained solids have minimal permeability with this method of filtration; otherwise, dead end filtration would suffice. The filter aid is the essential feature that serves two functions: it increases permeability in the accumulating filter cake, and it improves liquid drainage. With the method described in this protocol, the precoat is replaced by the depth filter element.