Advanced Process Filtration Using Porous Metal Technology

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Objectives

1. Porous metal manufacturing
2. Porous metal process filtration design
3. Performance advantages
4. Plant operational improvements
5. Design limitations
6. Applications for porous metal
Mott Corporation – A Leader in Porous Metal Filtration and Flow Control

• **60 year track record** of making products used by the most demanding customers such as NASA, Samsung, and Medtronic.

• **Largest installed base** of porous metal filters/fluid controls in the world across every major industry ranging from the Mars rover to implantable medical devices.

• **Most extensive metal alloy selection** from 316L SS to Hastelloy® X, for the toughest operating conditions.

• **Material Characterization Center** is a hub for industry leading innovation, with the latest lab equipment and new technologies like additive porous manufacturing and computational fluid dynamics.
Porous Metal – From Powder to Product

**How is it made?**
- Made from Powder
- Compressed or 3D printed
- Fully Sintered & Rigid Structure
- Bubble Point Tested
- Media Grades Down to 0.1 Micron

**Porous Materials**
- Stainless Steels
- Hastelloy®
- Inconel®
- Monel®
- Nickels
- Titanium
- Developmental Alloys

Hastelloy is a registered trademark of Haynes International, Inc. Inconel and Monel are registered trademarks of Special Metals Corp.

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3D Printed Porous Metal – New Possibilities

**How is it made?**
- Spherical Powder
- Laser Sintered in Place
- Built Row by Row

**3D Printed Porous Advantages**
- Virtually No Geometry Constraints
- Dual Density Capable
- Can Integrate Support Structures
- Can Integrate Process Connections

**3D Printed Porous Disadvantages**
- Size Limited
- Material Limited
- Requires Engineered Development
Porous Metal Filter Elements – Robust, Reusable Elements for Difficult Filtration Environments

- Cleanable
- Durable
- Corrosion Resistant
- Self-Supporting
- Wide Variety of Connections
- 3000 psi Differential Pressure
- Cryogenic to 1700°F
- 0.1 to 100 Micron Porosity
- 0.020 inches to 120 inches OAL
- Designed for Specific Applications

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Three Types of Liquid Filtration Offer Solutions to A Variety of Process Scenarios

Dead End Filtration:
- Flow travels through a filter element, closed at one end, and permeates through the wall thickness of the element.
- Most common type of liquid filter.

Low Velocity Cross Flow Filtration:
- Typically arranged vertically like dead end but elements are open at both ends and the outlet is often connected back to the process stream as a recirculation loop.
- Used in scenarios with high density cakes or with cakes that may become impermeable at higher thicknesses.

High Velocity Cross Flow Filtration:
- Typically arranged horizontally with a high velocity pumped stream. Filtrate is pulled through the wall of the porous while feed and solids are retained in the inside.
- Used in scenarios with very low particle sizes or with solids that form impermeable cakes.
Liquid Filtration – Versatile Elements Designed for Inside-Out and Outside-In Filtration

- **Inside-out filtration**
  - even deposition
  - no bridging
  - element strength

- **Outside-in filtration**
  - traditional design
  - easier cake discharge

- Filter systems designed for either direction based on application specific performance requirements
Inside-Out Filtration Challenges the Status Quo
Porous Metal Filtration Can Achieve:

- Less than **20 ppm** solids
- **>98%** valuable filtrate
- **>98%** by weight catalyst recovery
- Improved uptime with **no rotating parts**

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Porous Metal Technology Addresses Concerns Over Worker Safety and Environmental Impact

Porous metal filter systems present many advantages to plant optimization, including but not limited to:

- **Improve worker safety**
  - Closed loop
  - Fully automated
  - Months or years without shutdown

- **Reduce waste**
  - Robust, reusable elements
  - Online and offline cleaning

- **Reduce operation costs**
  - No rotating parts
Porous Metal Systems are Not Suitable for all Process Conditions

Not every application is suited to the strengths of sintered porous metal filtration. Some of the following conditions should be carefully considered:

• High Solids Loading

• Highly Viscous Fluids

• Sticky or Easily Compressible Solids

• Low Temperature and Pressure Applications

• Demanding Footprint Area versus Required Filter Area
Graded Approach to Filtration Design Ensures Successful Commercial Operation

For new applications or first time porous metal filtration users, small and medium scale testing helps demonstrate successful filter operation before large capital investment.

1. Laboratory Testing
2. Pilot Testing
3. Pre-Fabrication Design Package
4. Implement Engineered and Lab Tested Solution

<1% of Capital Investment  ~5% of Capital Investment  ~5% of Capital Investment
Filter Feasibility Study – Valuable Performance Data with Small Capital Investment

Small-Scale Laboratory Testing Confirms:

- Feasibility of Application
- Particle Size Distribution
- Particle Shape and Composition
- Appropriate Micron Level
- Optimal Operating Flow
- Necessary Filtration Area
- Backwash/Backpulse effectiveness
Pilot Tests Provide Assurance for Complex Filtration Problems

Advantages of Pilot Testing:
- Tests exact element as a full-scale unit (size, shape, media grade, material)
- Tests occur onsite using process fluid
- Tests performed by end user experts with guidance from filtration experts
- System can be operated manually for control or fully automated for efficiency
- Provides valuable data for full-scale sizing and engineering
Design Engineering Phase - Remove the Guesswork from your Filtration System

- All of this translates to an optimized design for the end user before major construction activities begin. This means less overall cost and risk and a greater insight into expected level of performance.
Applications

Polyol/Resin Filtration Systems
Mott liquid filters for polyol/resin manufacturing processes

Extreme Temperature Specialty Chemical Filtration Systems
Mott filter systems for chemical processing production lines with extremely elevated operating temperatures

Crude & Purified Terephthalic Acid (PTA) Filtration Systems
Mott Filtration Systems for Terephthalic Acid manufacturing

Hot Gas and Biomass Filtration Systems
Mott gas-solids industrial filtration systems can remove greater than 99.999% of all solids depending on the application
Applications

**FCC/RFCC Filtration Systems**
Mott filter for FCC/RFCC slurry refining (Can meet 2020 IMO particulate requirements)

**Precious Metal Catalyst Recovery Filtration Systems**
Mott filtration systems for catalyst recovery applications, such as platinum, palladium, rhodium, and nickel

**Food & Oil Intermediates Filtration Systems**
Mott filters for food & oil intermediate chemical processing
Mott Corporation LSI filters excel at removing Alumina-Silica catalyst and other solids contaminants from FCC/RFCC main column bottom slurry feeds. With online clean in place backwashing and automated process control, Mott slurry oil filters achieve less than 100 ppm total suspended solids filtrate quality, ensuring the filtered oil can be used for blending or sold as valuable product into other applications. Backwashed slurry can be recycled back to the riser, decanted and concentrated, or sent directly to disposal or reprocessing depending on the individual refiner’s needs. Mott’s install list includes 20+ filters on 5 continents in both FCC and RFCC applications.

Technology Licensors: Shell, UOP, Axens
Applications

FCC/RFCC Filtration Systems
Mott filter for FCC/RFCC slurry refining (Can meet 2020 IMO particulate requirements)
Mott’s 3 liquid filter technologies are specifically designed to capture 99+% catalyst either for recycling or reclamation while achieving excellent filtrate quality. The Mott HyPulse® LSI can be designed for a variety of clean in place backwashes ranging from discharge of an approximate 15 wt. % slurry to an approximate 50 wt.% wet cake. For applications with significant submicron particles, the HyPulse® LSX cross flow filter achieves less than 50 ppm filtrate quality without worry of blinding media with small catalyst particles. For applications with dense particles such as Raney Nickel, the HyPulse® LSM gives the best of both worlds, allowing for a configurable filtration and backwash operation while taking advantage of the natural high particle density with gravity settling, handling high solids loading streams. All three technologies are designed to specific process conditions, can handle operating temperatures up to 1700°F, high operating pressure and challenging corrosive environments.

### Precious Metal Catalyst Recovery Filtration Systems
Mott filtration systems for catalyst recovery applications, such as platinum, palladium, rhodium, and nickel

<table>
<thead>
<tr>
<th>Precious Metal</th>
<th>Price Per Ounce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhodium</td>
<td>$4,800.00</td>
</tr>
<tr>
<td>Palladium</td>
<td>$1,560.97</td>
</tr>
<tr>
<td>Platinum</td>
<td>$668.10</td>
</tr>
<tr>
<td>RANEY Nickel</td>
<td>$113 - 470</td>
</tr>
</tbody>
</table>

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Mott HyPulse® LSI filters excel at removing catalyst, bleaching agents, solidified product, and other solid contaminants from a variety of alcohol, acid, or oil based processes. Whether its palladium-on-carbon catalyst from a hydrogenated oil stream or bleaching agents from edible oil or detergent precursors, the Mott LSI can be configured for automated, closed-loop operation with clean in place backwashing. Generally done without the need for additional filter aids, the Mott LSI can filter streams with catalyst less than 1 micron in size and with solids loading up to 5+ wt.%. The system clean in place backwash can be designed to discharge anywhere between an approximate 15 wt.% slurry to an approximate 50 wt.% wet cake.

- Process Steam filtration
- Catalyst recovery from hydrogenation reactors
- Polishing of syrups, liquors, and other liquids
- Catalyst removal from flavor ingredients
- Activated carbon removal, decolorization
Mott HyPulse liquid filters have been helping specialty chemical companies produce high purity polymers and resins for years. Whether its removing residual catalyst, salts, or simply solidified or burnt product from the production stream, Mott HyPulse filters can operate at process temperature (up to 1700°F with Hastelloy® X), keeping fluid viscosity low and eliminating the need for heat exchangers to cool prior to filtration. Typical solids loading is less than 5 wt.% solids with 99+% capture of particles down to submicron in size. In high viscosity applications (10,000+ cP), Mott’s seamless tubes can be used to allow for differential pressures in excess of 1,000 psi in the filtration direction. Online clean in place backwashing is customizable to the process to allow for efficient solids discharge or to incorporate wash or soak steps to recover valuable product or dissolve unwanted captured solids.
With the availability of several dozen material choices, Mott Corporation’s HyPulse line of filters can be designed to extreme temperature applications. Mott porous metal 316L stainless filters are suitable for cryogenic applications down to single digit kelvin and in reducing environments up to 1000°F (811K). With the use of 310SS or various Hastelloy® grades, including Hastelloy X, Mott HyPulse filters successfully operate in environments up to 1700°F (1200K). In many cases, this means filtration can occur at the desired point in the process line rather than being forced to cool via heat exchangers to filter within limits of inferior technology. As with all Mott HyPulse filters, filtration is done in a closed loop, passive system with the capability of being completely controlled by a local PLC or integrated into the plant DCS system.

### Applications

**Extreme Temperature**

**Specialty Chemical Filtration Systems**

Mott filter systems for chemical processing production lines with extremely elevated operating temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum Oxidizing Temperature</th>
<th>Maximum Reducing Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>316L SS</td>
<td>750°F/399°C</td>
<td>900°F/482°C</td>
</tr>
<tr>
<td>Hastelloy C-276</td>
<td>850°F/454°C</td>
<td>1000°F/538°C</td>
</tr>
<tr>
<td>Inconel 600</td>
<td>1100°F/593°C</td>
<td>1500°F/815°C</td>
</tr>
<tr>
<td>Hastelloy X</td>
<td>1450°F/788°C</td>
<td>1700°F/927°C</td>
</tr>
</tbody>
</table>

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Mott has been the leader in both crude terephthalic acid (CTA) and purified terephthalic acid (PTA) for decades using both HyPulse® LSI and LSM technologies. Mott liquid filters are easily configurable to handle multiple wash and purge steps necessary in the CTA and PTA processes to ensure product quality. Mott filters reduce caustic acid consumption in the CRU, reduce organic loads to wastewater treatment and can recover up to 2 wt.% solids from CTA or PTA applications. For applications designed around corrosion metal control, the Mott LSI can act as an intermediate filter, removing precipitated corrosion metals before downstream processing. The average return on investment for a Mott LSI in a CTA or PTA application is 2 years.

Technology Licensors: BP Amoco, Envista, Yisheng, Formosa
### Applications

Crude & Purified Terephthalic Acid (PTA) Filtration Systems
Mott Filtration Systems for Terephthalic Acid manufacturing

### CTA Mother Liquor Product Recovery

<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>LOCATION</th>
<th>FLOW (GPM)</th>
<th>FILTER SIZE</th>
<th>STARTUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samnam</td>
<td>Yosu, Korea</td>
<td>100</td>
<td>2 x 24” LSM</td>
<td>2003</td>
</tr>
<tr>
<td>KP Chemical (CIA)</td>
<td>Ulsan, Korea</td>
<td>85</td>
<td>2 x 24” LSM</td>
<td>2004</td>
</tr>
<tr>
<td>KP Chemical</td>
<td>Ulsan, Korea</td>
<td>40</td>
<td>1 x 20” LSM</td>
<td>2004</td>
</tr>
<tr>
<td>CAPCO/BP</td>
<td>Kaohsiung, Taiwan</td>
<td>50</td>
<td>2 x 24” LSI</td>
<td>2005</td>
</tr>
<tr>
<td>Sinopec</td>
<td>Yizheng, China</td>
<td>25</td>
<td>1 x 16” LSM</td>
<td>2005</td>
</tr>
<tr>
<td>Sinopec</td>
<td>Shanghai, China</td>
<td>40</td>
<td>1 x 20” LSM</td>
<td>2005</td>
</tr>
<tr>
<td>Xianglu (XLP)</td>
<td>Xiamen, China</td>
<td>66</td>
<td>1 x 30” LSI</td>
<td>2006</td>
</tr>
<tr>
<td>Formosa Chem</td>
<td>Ningbo, China</td>
<td>100</td>
<td>1 x 30” LSI</td>
<td>2008</td>
</tr>
<tr>
<td>Sinopec</td>
<td>Luoyang, China</td>
<td>50</td>
<td>3 x 44” LSI</td>
<td>2009</td>
</tr>
<tr>
<td>Jialong</td>
<td>Shishi, China</td>
<td>130</td>
<td>1 x 48” LSI</td>
<td>2010</td>
</tr>
<tr>
<td>Samsung</td>
<td>Ulsan, Korea</td>
<td>35</td>
<td>2 x 20” LSM</td>
<td>2009</td>
</tr>
<tr>
<td>BP/Amoco (CIA)</td>
<td>Geel, Belgium</td>
<td>120</td>
<td>1 x 40” LSI</td>
<td>2010</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Ningbo, China</td>
<td>100</td>
<td>1 x 48” LSI</td>
<td>2011</td>
</tr>
<tr>
<td>Xianglu (XLP)</td>
<td>Xiamen, China (L2)</td>
<td>275</td>
<td>1 x 66” LSI</td>
<td>2012</td>
</tr>
<tr>
<td>Formosa (CIA)</td>
<td>Long De, Taiwan</td>
<td>80</td>
<td>1 x 30” LSI</td>
<td>2012</td>
</tr>
<tr>
<td>Hengli</td>
<td>Dalian, China (L1,L2)</td>
<td>750</td>
<td>1 x 54” LSI</td>
<td>2012</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Dalian, China (L2)</td>
<td>150</td>
<td>1 x 54” LSI</td>
<td>2012</td>
</tr>
<tr>
<td>Honggang</td>
<td>Jiansu, China</td>
<td>200</td>
<td>1 x 66” LSI</td>
<td>UC</td>
</tr>
<tr>
<td>OPC</td>
<td>Taoyuan, Taiwan</td>
<td>300</td>
<td>2 x 54” LSI</td>
<td>UC</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Ningbo, China</td>
<td>175</td>
<td>1 x 60” LSI</td>
<td>2013</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Zhuhai, China (L3)</td>
<td>160</td>
<td>1 x 42” LSI</td>
<td>UC</td>
</tr>
<tr>
<td>Hengli</td>
<td>Dalian, China (L3)</td>
<td>375</td>
<td>2 x 54” LSI</td>
<td>2014</td>
</tr>
<tr>
<td>Shengda</td>
<td>Sichuan, China</td>
<td>125</td>
<td>1 x 54” LSI</td>
<td>UC</td>
</tr>
<tr>
<td>Hanbang</td>
<td>Jiansu, China</td>
<td>375</td>
<td>2 x 54” LSI</td>
<td>2015</td>
</tr>
<tr>
<td>Formosa (CIA)</td>
<td>Ningbo, China</td>
<td>80</td>
<td>1 x 30” LSI</td>
<td>2019</td>
</tr>
<tr>
<td>Billion</td>
<td>Fujian, China</td>
<td>450</td>
<td>2 x 72” LSI</td>
<td>2020</td>
</tr>
</tbody>
</table>

### PTA CRU (Catalyst Recovery Unit)

<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>LOCATION</th>
<th>FLOW (GPM)</th>
<th>FILTER SIZE</th>
<th>STARTUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Du Pont</td>
<td>Cape Fear, USA</td>
<td>100</td>
<td>4 x 36” LSI</td>
<td>1990</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Decatur, USA</td>
<td>20</td>
<td>3 x 20” LSI</td>
<td>1998</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Zhuhai, China</td>
<td>25</td>
<td>4 x 24” LSI</td>
<td>2002</td>
</tr>
<tr>
<td>CAPCO/BP</td>
<td>Taitung, Taiwan</td>
<td>45</td>
<td>1 x 30” LSI</td>
<td>2002</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Kuantan, Malaysia</td>
<td>20</td>
<td>2 x 18” LSI</td>
<td>2003</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Zhuhai, China</td>
<td>35</td>
<td>2 x 40” LSI</td>
<td>2006</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Geel, Belgium</td>
<td>80</td>
<td>4 x 36” LSI</td>
<td>2007</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Dalian, China (L1)</td>
<td>70</td>
<td>2 x 30” LSI</td>
<td>2009</td>
</tr>
<tr>
<td>Jialong</td>
<td>Shishi, China</td>
<td>70</td>
<td>2 x 30” LSI</td>
<td>2010</td>
</tr>
<tr>
<td>Petkim</td>
<td>Aliaga, Turkey</td>
<td>10</td>
<td>1 x 24” LSI</td>
<td>2011</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Ningbo, China</td>
<td>125</td>
<td>2 x 50” LSI</td>
<td>2011</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Hainan, China</td>
<td>50</td>
<td>2 x 40” LSI</td>
<td>2014</td>
</tr>
<tr>
<td>Yisheng</td>
<td>Dalian, China (L2)</td>
<td>100</td>
<td>2 x 50” LSI</td>
<td>2012</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Zhuhai, China (L3)</td>
<td>30</td>
<td>4 x 32” LSI</td>
<td>UC</td>
</tr>
<tr>
<td>BP Amoco</td>
<td>Mangalore, India</td>
<td>30</td>
<td>4 x 32” LSI</td>
<td>2014</td>
</tr>
<tr>
<td>Pengwei</td>
<td>Chongqing, China</td>
<td>500</td>
<td>1 x 60” LSI</td>
<td>2018</td>
</tr>
<tr>
<td>Honggang</td>
<td>Jiansu, China</td>
<td>500</td>
<td>1 x 60” LSI</td>
<td>2018</td>
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<tr>
<td>Xingfengming</td>
<td>Xiaoxing, China</td>
<td>1400</td>
<td>3 x 60” LSI</td>
<td>2020</td>
</tr>
<tr>
<td>Billion</td>
<td>Fujian, China</td>
<td>500</td>
<td>1 x 60” LSI</td>
<td>2020</td>
</tr>
<tr>
<td>Indorama</td>
<td>Decatur, USA</td>
<td>30</td>
<td>4 x 36” LSI</td>
<td>2020</td>
</tr>
</tbody>
</table>

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Mott offers three types of gas-solids process filtration systems for hot temperature, corrosive environments.

GSP (Gas Solids Plenum) process filters offer traditional outside-in filtration of process gases and steam, for applications where cost-effectiveness and ease of use are high priorities. Upon reaching a given differential pressure or cycle time, the feed is discontinued and the backflow cycle is engaged. Hypulse® GSV (Gas Solids Venturi) process filters use inside-out filtration technology and are ideal for continuous filtration. Porous elements are pulsed in sections and cleaned while the unit remains on-line. Lastly, the GS (Trap Filter) process filter is a simple trap filter design for low solids loading and high flux rates.

- FCC Catalyst Hopper Vent – UOP, Univation Licensors
- CCR Platforming – Axens, UOP Licensors
- FCC 4th stage Flue Gas – UOP, Conoco, Shell Licensors
- Poly Silicon
- Industrial Gas, Syngas
- Biomass, waste-to-energy

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Hot Gas and Biomass Filtration Systems
Mott gas-solids industrial filtration systems can remove greater than 99.999% of all solids depending on the application.
In Conclusion:

Porous Metal Filtration:
- Filtration down to sub-micron particles
- Improves operator safety through closed-loop technology
- Reduces environmental impact
- Increases throughput by reducing manual maintenance and downtime
- Suitable for a wide range of temperatures, pressures, and applications

Best method for choosing a filtration solution:
- Filter feasibility of feed sample at your filtration provider
- Design consultation by project engineers
- Small scale pilot testing when applicable
- Commercial scale design and engineering prior to fabrication
Thank you for your attention

Questions?

For additional information or questions:
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