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SINTERED POROUS METAL FILTRATION SYSTEMS FOR PETROLEUM REFINING APPLICATIONS

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Abstract: Currently, petroleum products are the largest source of energy used in United States, with 90 percent of these products being fuels such as gasoline, coke, kerosene, aviation fuels, distillate, residual oil and liquefied petroleum gas. Refineries convert petroleum oil into finished products through physical, thermal and chemical separation processes. Other materials produced by refineries include non-fuel petrochemical products such as ethylene, propylene and benzene used to manufacture chemicals and plastics.

Stringent environmental regulations, safety concerns and productivity improvements often necessitate modifying existing refinery and petrochemical processing technology. Reformulation of gasoline to reduce auto emissions and EPA regulations concerning the handling of spent FCC catalyst have encouraged refineries to evaluate their catalyst management strategy. Advances in filtration technology and filter media support improvements in catalyst recovery applications which improve overall product yield, increase the market value of the filtered product, reduce wear and tear of downstream equipment and minimize operator exposure to hazardous materials. This paper will discuss filter-operating parameters of sintered porous metal media and filtration system design criteria for optimizing performance in the removal of catalyst fines from slurry oil.

INTRODUCTION

Petroleum refiners use a process called Fluid Catalytic Cracking (FCC) to convert heavy petroleum fractions into products such as gasoline, kerosene and feedstock for petrochemical processes. The conversion of crude oil fractions into higher value products requires the use of catalysts. The product stream from the FCC unit contains silica and alumina fines generated from catalysts used in the process. After distillation, these fines are concentrated in the heaviest fraction or slurry oil.

Filtration systems designed for the removal of catalyst fines from slurry oil utilizing sintered porous metal media were introduced in the mid 1980's. Filtration of slurry oil using an advanced filtration system design and sintered metal media continue to demonstrate long term filter operating performance in the separation of FCC catalyst fines from slurry oil to reduce the ash content. Unlike centrifuges or electrostatic techniques, the filtration media acts as a positive barrier to remove downstream catalyst contamination. Sintered metal filtration technology using inside-out filtration configuration provides a reliable method of achieving high quality slurry oil product by reducing catalyst content.¹ The backwash capability of the media provides an economic alternative to the use of settling tanks. Removal of the fines increases FCC product yield, improves the market value of the filtered product and reduces wear and tear of downstream equipment in addition to improving the catalyst recover and handling process.

There are numerous grades and manufacturers of catalyst since FCC was introduced in the early 1940's. Filtration feasibility testing continues to be an effective means in media selection and verification of filter operating parameters to confirm process scale-up design for commercial installations. Feasibility testing is recommended as catalyst fines vary in size, with a range from submicron to 30- 40 microns, and occasionally larger.

PRINCIPLE FEATURES AND PROPERTIES OF SINTERED METAL MEDIA

The primary characteristics of sintered metal media that make it well suited for refinery applications are strength, durability and pressure capacity. The inherent durability of metal filters allows for continuous, backwash operation for extended periods. Sintered metal media are manufactured by pressing pre-alloyed powders either as tubes or as porous sheet, followed by high temperature sintering. The combination of powder size, pressing and sintering conditions defines the pore size and distribution, strength and permeability of the porous element. The filter media is designed and engineered with a stable porous matrix, precise bubble point specification, close thickness tolerance and uniformity of permeability, which assure reliable filtration performance, effective backwash cleaning and long on-stream service life.

Pore size of sintered metal media is determined using ASTM E-128 standard procedure that relates pore size to the pressure required to expel a liquid from a capillary of a certain diameter by gas. The media grade designation is equivalent to the mean flow pore, or average pore size of the filter. Sintered metal media are offered in grades 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 40 and 100.

Typically, 316L stainless steel grades 0.5 and 2 media are recommended for refinery applications. The all-welded construction of porous media to hardware is an additional advantage for high temperature and the abrasive nature of the slurry oil. Other corrosion resistant alloys include: Stainless Steel 304 L, 310, 347, and 430; Hastelloy^{®2} B, B-2, C-22, C276, N and X; Inconel[®] 600, 625, and 690; Monel[®] 400³; Nickel 200; Alloy 20; Titanium.

Filter Media Selection for Removal of FCC Catalyst Fines

Due to variations in slurry oil viscosity, catalyst particle size and slurry concentration of each refinery process the preferred method of selecting filter media is via laboratory or pilot trials. Feasibility tests verify filter-operating parameters such as particle removal efficiency, pressure drop vs. solids loading, recovery pressure after backwash and cycle length. Experience in similar service may be the basis for filter selection, taking into account the specific solids and liquid of the process and if actual test data cannot be obtained.

The particle size range of catalyst material varies with the operating performance of the FCC unit. FCC catalysts are broadly classified on the basis of the method of manufacture: silica or clay based and active alumina. The mechanical integrity of the catalyst combined with cyclone efficiency influence solids concentration and catalyst particle size distribution of the slurry oil. Optimum filtration results are obtained with a broad particle size distribution.

Cyclones are the first stage of catalyst fines removal in the FCC unit. Efficiently operating cyclones can remove sufficient fines from the reaction product to produce slurry oil with solids content of about 0.2% by weight (2000 ppm) or lower.⁴ Slurry oil concentration evaluated in laboratory and pilot tests is typically between 500-1500 parts per million (ppm) total suspended solids (TSS).

The variations of the FCC catalyst fines distribution are shown in Figure 1. Normal catalyst fines particle size distribution observed in FCC cyclones is typically a normal bell curve ranging from < 5 to 80 μm , with a peak in the 30 – 40 μm range. Bimodal distributions are the result of either attrition of the catalyst or damage to the cyclone or plenum.

Attrition of the catalyst causes the curve to shift to the left, with a peak in the 2 –3 μm range. Fracturing catalyst at a high velocity stream generates submicron particles. A shift to the right of the normal bell shaped curve with a peak in the range of 40 μm or greater is the result of full-range catalyst being drawn into the cyclone or plenum.⁵

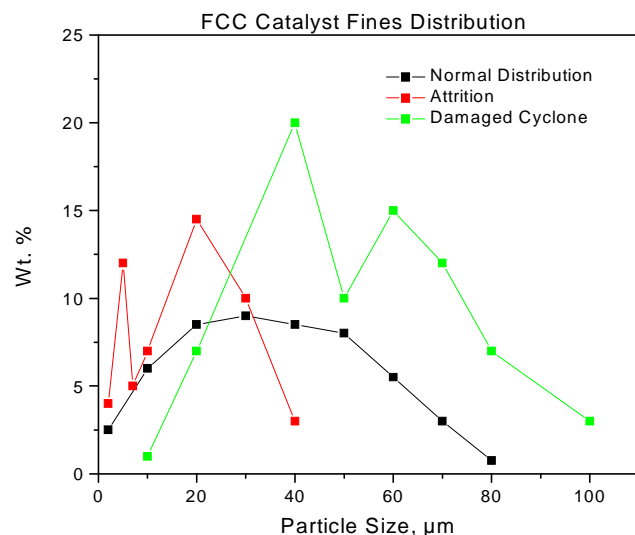


Figure 1. FCC catalyst fines distribution

Catalyst with a small mean particle size and narrow distribution will usually require a finer media grade and will filter more slowly. A larger mean particle size and broader distribution will work with a coarser media grade at a slightly higher operating flux.

Sintered metal media grades 0.5 and 2 are typically recommended for refinery applications. For applications with a catalyst particle size distribution that tends to shift to the left of the normal distribution, grade 0.5 media ensures that the catalyst particles are removed on the media surface preventing media plugging and ensuring removal efficiency.

Refineries have recognized improvements in filtration technology using sintered metal cartridge filters for catalyst removal. Filtration evaluation of slurry oil streams from more than 50 refinery locations continue to show significant variation in catalyst particle and distribution range. Samples evaluated to date have an average particle size range of 1- 40 μm , with a mean size (based on volume %) of 15 μm . Laboratory and pilot testing continues to be a reliable means to validate filter operating performance.

Table 1 summarizes several pilot studies conducted to evaluate filtrate quality using grades 0.5, 2 and 5 media. Testing with grade 0.5 media and fine catalyst of less than 10 μm in size resulted in filtrate quality (based on ash analysis) of less than 20 ppm TSS. Other refineries with larger catalyst fines have achieved similar filtrate quality with grade 2 media. Tests using grade 5 media had the highest ash content measuring 91 ppm TSS.

Filtration Principle

Sintered metal filters are high efficiency, two-dimensional, straining type with particulate being collected on the media surface. The proper selection of media grade must balance the needs of the filtration application regarding particle retention, pressure drop and backwash ability. There are basically three process factors to consider: fluid velocity through the filter media, fluid viscosity and particle characteristics. The important particle characteristics are particle shape, size and density. Particles that are hard, regular shaped and form incompressible cakes such as FCC catalyst are well suited for surface filtration.⁶

Table 1. Pilot filtration testing using Mott grades 0.5, 2 and 5 media.

Feed Conc., TSS, ppm	Particle Size Range, μm	Avg. Particle Size, μm	Media Grade	Filtrate, TSS, ppm	Operating Flux, gpm/ft^2
1000	N/A	< 10	0.5	< 20	N/A
750 - 1000	N/A	10-12	2	10	0.25
500-1000	1-30	20	2	10-15	0.1 - 0.5
1200	1-190	30	5	91	0.5
1500	1-190	30	0.5	10	0.34

Filtration operation is based on constant flow, increasing pressure drop until the terminal pressure drop is reached. Terminal conditions will be reached when the catalyst cake

thickness increases to a point where the fluid flow pressure drop is at a maximum for a given flow and viscosity condition. The filter is then backwashed by pressurizing the filter with gas, then quickly opening the backwash discharge valve. This backwash procedure generates a momentary high reverse differential pressure, which effectively removes solids from the media surface. Reverse flows of clean liquid (filtrate) through the media assists in the removal of solids and flushes them out of the filter.

The uniformity in the pressure drop over time for repeated cycles in filtration operations using sintered metal media is shown in Figure 2. Uniformity in the rate of rise of the pressure drop indicates the feed slurry particle size distribution remains constant, as does the slurry concentration. The inside-out filter configuration, utilizing filtration media with uniform porosity, builds a uniform cake on the inside surface of the filter element that improves particulate removal and backwash efficiency. Recovery pressure after backwash increases slightly once media is conditioned, but should be within 2-3 PSI of the clean flow pressure drop. Filter media recovery pressure drop must be stable for consistent performance. Proper backwash methods and procedures must be followed for good media cleaning. Changes in the slurry oil temperature will increase viscosity and rate of rise pressure drop across the media, therefore design-operating temperatures should be maintained throughout filtration process.

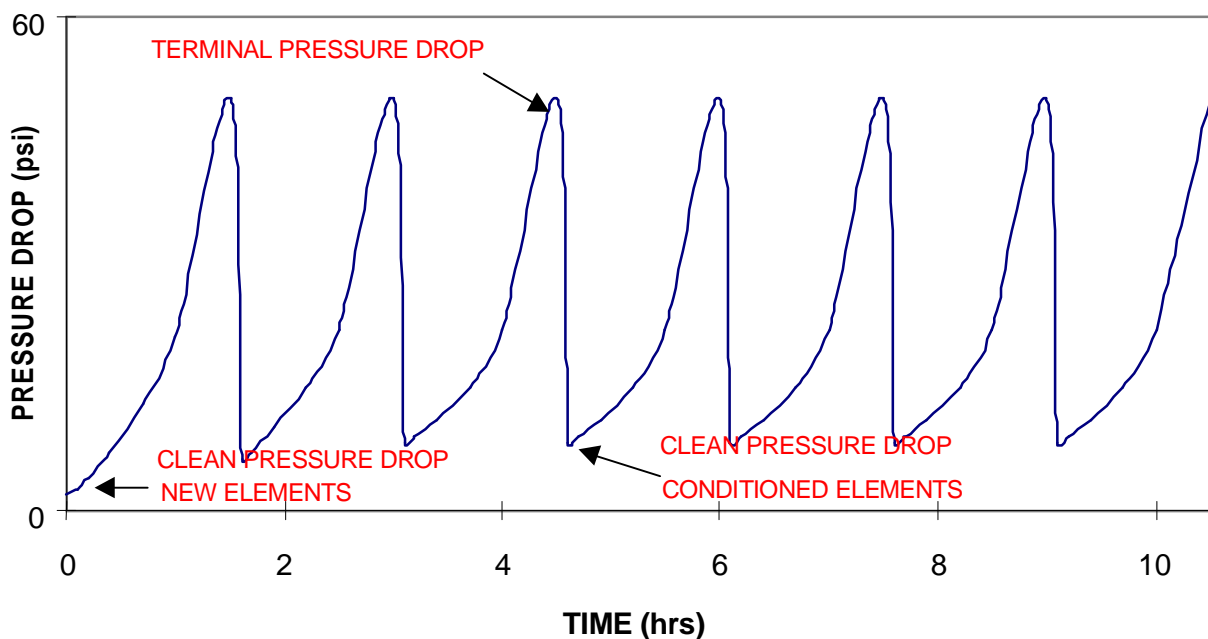


Figure 2. Pressure profile for multiple cycles using Mott grade 0.5 media

FILTER SYSTEM DESCRIPTION AND OPERATION

The inside-out filter housing configuration (Mott Hypulse® LSI ⁷) allows solids to be introduced to the filter on the inside surface of the tubular filter element. The filtration unit consists of the vessel shell, a welded-in tube sheet, filter elements that are threaded into the tubesheet and a spider plate that secures the top of the element bundle. Figure 3 shows the filtration unit during forward flow. Standard design uses cartridges fabricated from rolled and welded sheet to a 2 inch diameter x 70 inch overall length filter element which provides the highest filtration area for housing diameters greater than 16 inches, with the minimum backwash volume per ft² filter area. 2" diameter elements require filter cakes to be less than 0.5 inch thick. Collapse and burst ratings of the 2 inch diameter filter elements are listed in Table 2.

Backwash procedure can be modified to suit the process requirements. The design allows for two basic options: Full shell (gas over liquid backwash) and empty (drained) shell backwash for maximum yields. ⁸ Each backwash mode offers the capability to use a different backwash liquid other than filtered slurry. Options include light cycle or heavy cycle oil. The choice depends on the need to clean the elements and where the backwash is sent for disposal.

The strong, corrosion resistant and permanent filtration media allows for continuous and safe operation of filter systems in the refinery industry. Maintenance on the filters for normal routine operations is minimal. Elements can be cleaned in place or removed from service for commercial cleaning to remove tars and gums. Use of back-washable sintered metal filters enables the design of filtration systems with the least amount of moving parts and minimizes operator exposure to hazardous materials. These filter systems are operated and controlled remotely and can be integrated with the control system of the plant.

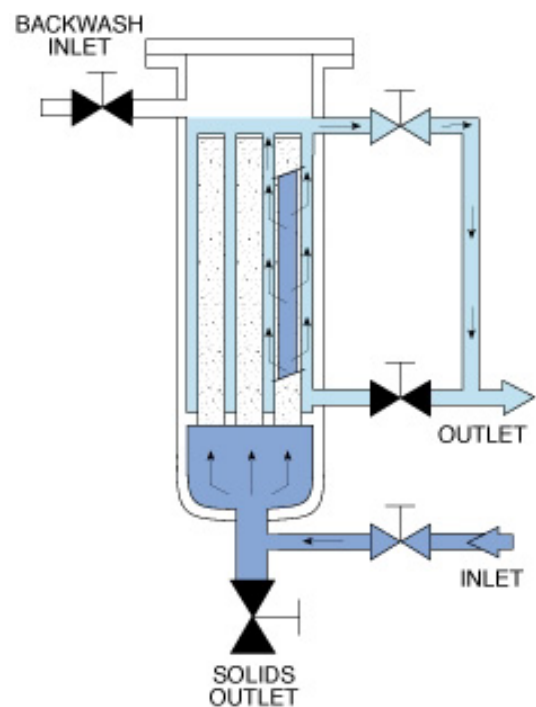


Figure 3. Inside-out filter configuration

Table 2. Element collapse and burst pressure of 2 inch diameter cartridges.

Media Grade	Collapse Pressure, PSID	Burst Pressure, PSI
0.5	107	503
2.0	180	420

Filter Design Specifications

Filter housings are ASME coded pressure vessels built according to requirements of the process, with standard filter systems of 24, 36 and 42-inch diameter housings. Table 3 describes filter design considerations such as filtration area, backwash volume and barrels per day capacity. The 36" and 42" systems are single vessel installations operating on a continuous basis with interruptible flow. The 24" system is a triple filter system operating on a continuous basis as shown in Figure 4. One filter operates on-line, one is on stand-by, and one is a spare used during maintenance periods. The unique design incorporates inside-out flow through the filter elements for increased pressure drop capability, reduced filter complexity and operational flexibility. Standard design is 600°F at 300 psi with 100 psi differential pressure.

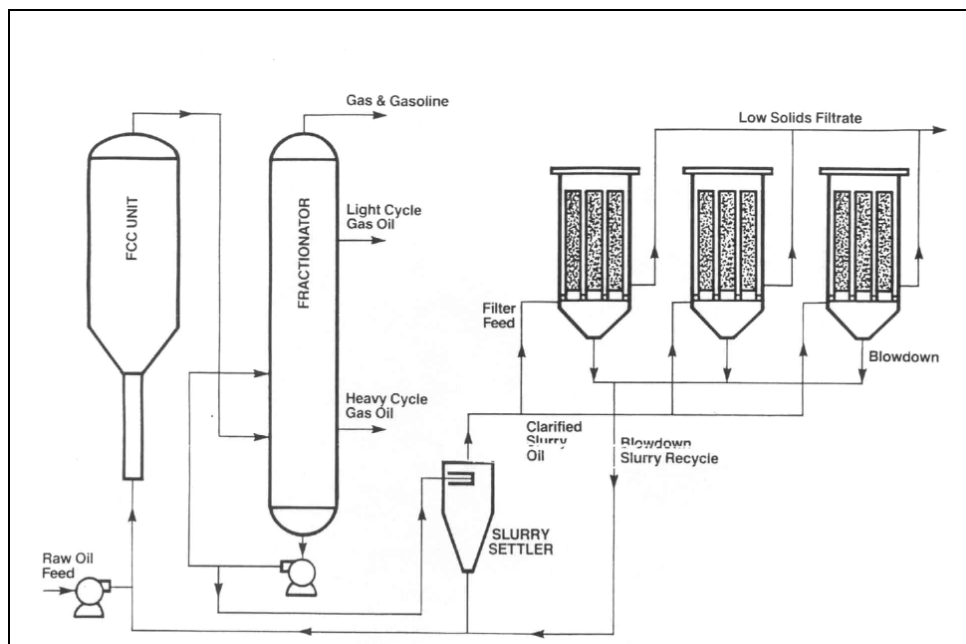


Figure 4. FCC Filter System Schematic

Table 3. Filter Design Parameters (Standard 2" OD x 70" length elements).

Housing Diameter, Inches	Number of Elements	Filtration Area, ft ²	Backwash Volume Full Shell, Gal	Backwash Volume Empty Shell, Gal	Max. Capacity, BPD*
24	61	174	150	70	3600
36	151	432	380	180	8900
42	199	570	564	261	11,700

*Maximum capacity barrels per day (BPD) based on flux rate of 0.6 gpm/ft².

APPLICATIONS

Backwash Filter Performance: Case Study 1

Pilot studies at a commercial refinery used a 10 GPM (340 BPD) automated pilot filter (Figure 5) to verify filter operating performance and media selection in tests conducted during a two-month trial. The filter was cycled continuously between filtration and backwash, with more than 2500 cycles performed. Backwash liquid was intermediate cycle gas oil. Tests were conducted to maximize the number of cycles during the test period.

Figure 6 shows a uniform pressure profile comparing the rate of rise in pressure drop over time of grade 2 media after 1, 4 and 30 days. Slurry oil concentration ranged from 500-1000 PPM. Average particle size was about 20 μm . The filtration cycle was about 40 minutes with terminal pressures of 37-40 PSI. Recovery pressure after backwash ranged from 2-5 PSI. Filtrate quality was less than 25 PPM TSS with most cycles < 10 ppm or less.

Increase in solids concentration will shorten cycle time as pressure drop increases at a faster rate. This effect can be overcome somewhat by increasing the cycle terminal pressure drop. If the increased solids concentration is due to the addition of large particles increased solids cake permeability may result, which will increase the solids loading capacity at the same pressure drop.

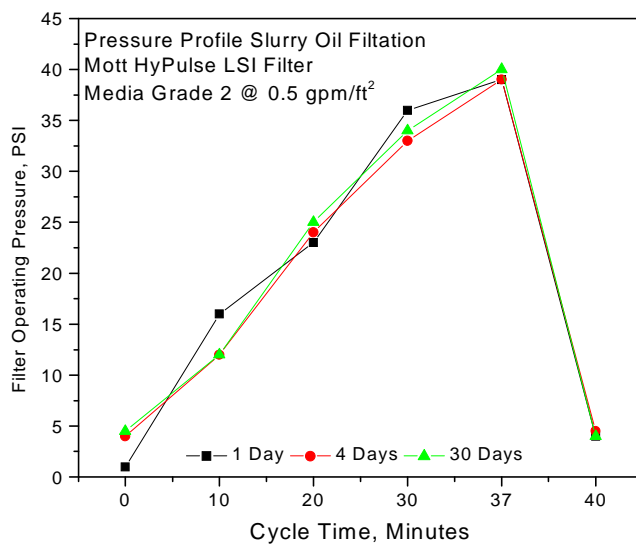


Figure 6. Pressure profile comparison



Figure 5. Automated Filter

Table 4. Filtration cycle time and backwash sequence

Backwash Sequence Description	Cycle Time
Filter forward flow to 60 PSID	80 minutes
Drain Filtrate Shell	1.5 minutes
Fill with LCO	1.5 min
Pressurize	0.25 minutes
Backwash and Drain	0.25 minutes
Total Time	83.5 minutes

Filter Operating Efficiency: Case Study 2

Online and throughput efficiency of backwashable sintered metal filter were evaluated using both full shell and empty (drained) shell backwash methods using an automated filter system. The filtration unit consists of 24" diameter filter housing with standard 2" diameter elements, having a total filtration area of 174 ft². Filter operation parameters were 40 GPM with solids load to filter of 0.75#/min. Filter design operating flux is 0.23 gpm/ft². The filter cycle time and backwash sequence is described in Table 4.

Filter efficiency is also measured as throughput efficiency, or amount of product processed as filtrate compared to the amount of product or feed delivered to the filter. This is defined as:

$$E_T = (V_{FIL} / V_{FD}) \times 100\%$$

Where: E_T = efficiency of liquid recovery
 V_{FIL} = volume of filtrate recovered
 V_{FD} = volume of feed to the filter

Online efficiency is measured as forward flow cycle time divided by entire filtration cycle time (including backwash) or $80/83.5 \times 100 = 95.8\%$ efficiency.

The filtration unit is designed to minimize loss of product, which consists primarily of the backwash and recovered solids. Throughput efficiency comparing full shell and drained shell backwash is described in Table 5. The total volume processed (40 GPM x 80 minutes) was 3200 gallons.

Table 5. Throughput Efficiency

	Full Shell	Drained Shell
Backwash Volume, gallons	150	70
(V_{FIL} / V_{FD})	3050/3200	3130/3200
Throughput Efficiency	95 %	98%

Filter Operating Experience – Commercial Installations

In 1985, the first continuous use of a sintered metal filter using inside-out (LSI) HyPulse® filtration technology developed by Mott Corporation demonstrated the suitability of sintered metal media for high temperature filtration of slurry oil for a carbon fiber development process. Slurry oil came from tankage where large particles had settled and oil had cooled to 350°F, increasing the viscosity to 9 cp. The filter operated reliably for many years producing clean oil with solids content of less than 20 ppm. The filter was eventually shut down because of low product demand.

Since then, refineries around the world have become aware of the benefits of filtration using sintered metal media for catalyst fines removal in slurry oil service. The largest systems to date are located in the United States and China.

Throughout the 1990's numerous LSI filtration systems have been installed for FCC slurry oil filtration at numerous refineries worldwide the largest employing (3) 66" LSI filters. A schematic of a triple filter system is shown in Figure 7. Filtration cycle time ranges from 2 to 16 hours operating at 30 & 60 PSI, respectively in the filtration of 1000 ppm slurry oil. Extended cycle times were obtained by running two filters simultaneously, but staggered in cycle time, with the third being on stand-by for utilization when one of the other filter units is backwashed. The filter design uses a full shell backwash. Efficiency of the recovered product using two filters on line exceeds 99.8%⁹.

Since 1997, several refineries in China have installed LSI filtration systems for catalyst removal in resid fluid catalytic cracking (RFCC) units. A filtration system with (2) 24" LSI filters was installed in a RFCC unit with 1.4 million metric tons (mt) per year capacity and an output of slurry oil of 180 mt/day. The filter is controlled by local PLC that communicates with refineries distributed control system (DCS) to enable the operator monitor the filtration in the control room. The slurry oil has an average 3,000-5,000 ppm solids concentration. Cycle time varies from 2-8 hours. The filtrate solids content is under 50 ppm. The system is running continuously since then supplying a local company with clean filtrate to produce carbon black.

Another unit has 1.2-million mt/year capacity but only has about 75-mt/day slurry oil output. The system utilizes (3) 20" LSI filters controlled by local PLC. Each filtration unit is capable of handling entire flow, or two filters can run simultaneously to optimize

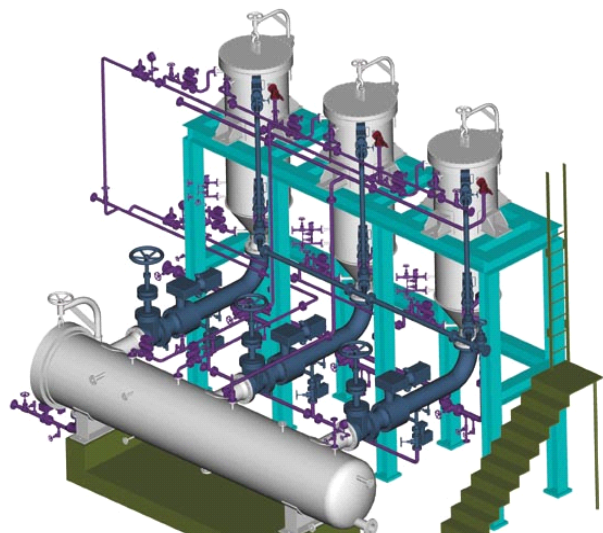


Figure 7. Schematic of triple filter system

product yield. The unit operates mostly during the winter months to supply the clean slurry oil to replace fresh crude as fuel oil for heating in the oilfield and local residential area. Average slurry oil concentration is 4,000-6,000 ppm, and is occasionally over 10,000 ppm under unstable conditions. Cycle time varies from 30 minutes to 4 hours depends on the operating conditions and solids concentration.

SUMMARY

Sintered metal media has demonstrated its suitability in a highly efficient catalyst removal filter system for slurry oil service. Commercial FCC installations using grades 0.5 and 2 media are capable of producing quality clean oil product with suspended solids content of less than 20 PPM. Filtrate quality of RFCC is typically about 50 ppm. Filtration offers a slurry stream of higher product value that can be used as a clean fuel blend component, feed stock for needle coke or high-grade carbon black slurry oil stream.

Filtration utilizing a unique housing configuration that allows feed to be fed to the inside of the filter cartridge optimizes both operating efficiency and backwash efficiency of the filter. Proper media selection, along with filtering within specified operating parameters, provides product recovery up to 99.8% efficiency. The inside-out filter configuration minimizes backwash volume that is either recycled back to the reactor or handled as a waste product. Backwash volume is 0.5 to 1 gal/ft², depending on whether filtrate is drained from the shell or used as backwash. On a capacity basis, for 1000 BPD processed, 20-50 BPD go back to the reactor as backwash. This is a low rate in comparison to other types of backwash filters used in this application.

A benefit of the filter system design is the scale-ability of the filtration unit to handle high flow rates and solids capacities without complicated changes to hydraulic flows. Filtration systems are suitable for both batch and continuous processes. Optimum sizing and high pressure drop capacity result in quick filter turnaround.

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