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HOT GAS FILTRATION USING SINTERED METAL FILTERS

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ABSTRACT

Filtration systems utilizing sintered metal media have proven to be an effective, reliable and economical choice for gas/solids (particulate) separation in numerous industrial gas filtration applications in the chemical process, oil refining, petrochemical and power generation industries. Applications require particulate removal to protect downstream equipment, for product separation, for catalyst recycling, for contaminate removal, or to meet environmental regulations. Today these processes are requiring separation of increasingly finer particulate along with more reliable filter media. Filters fabricated from sintered metal media offer unique performance characteristics for gas/solids separation in these demanding environments. These filters can provide particulate capture efficiencies of 99.9% or better using either surface or depth media. Operating temperature can be as high as 1000^{o} C, depending on the selection of metal alloy. Along with the filtration efficiency consideration, equally important criteria include corrosion resistance, mechanical strength at service temperature, cake release (blowback cleanability), and long on-stream service life. The design of particulate separation systems to meet these criteria is critical to achieving successful, cost effective operations.

Gas filtration is the process of removing solid particles from a gaseous fluid using a porous media with the ultimate objective to achieve a pre-determined level of fluid purity. Sintered metal media combine many different properties, ranging from its outstanding filtration and cleaning characteristics and its excellent chemical and thermal resistance to its mechanical strength. The two main dynamic modes of filtration, i.e., depth filtration and surface filtration, must be considered and exploited in the appropriate design and selection of optimal filter media. In the case of depth filtration, the particles are captured inside the media, while in surface filtration they are retained, as the term explains, at the surface where subsequently a cake of particles is formed. The life of such filter media (filter operating life) depends on the particulate characteristics (e.g., size, shape, composition) and the filter's particulate holding capacity, corresponding pressure drop and ability to be cleaned, either on or off-line.

The benefits of using either sintered metal powder or sintered metal fiber filters are described in this paper for industrial applications requiring semi-permanent filtration in especially demanding applications including corrosive environments at high temperatures and pressures. Filter operation and performance are discussed for selected applications, including fluid catalytic cracking (FCC) and continuous catalytic reforming/regeneration (CCR) process operations.

INTRODUCTION

The chemical process industries must strive to meet ever more demanding economic and environmental challenges that result from market globalization, environmental regulations, rising costs, demands for more efficient processes, and changing workforce requirements. Products and processes involving solids (particulate) handling are ubiquitous in these industries, thereby requiring particle separation solutions.

Numerous types of industrial process equipment, employing different technologies for gas/solids separations, are available for the myriad of processes requiring gas/solids separation. These separation technologies include filtration (metal and ceramic elements, fabric bag houses), cyclones, electrostatic precipitators and scrubbers. Each has its own degree of effectiveness and cost. In applications where high removal efficiency is critical, filtration has no equal. The reason for this is simple. Compared to other methods, filtration is the only one that provides a positive barrier between the process and the "solids free" stream whereby the particulate matter is removed from the gas stream through mechanical separation. Filtration can improve product purity, increase throughput capacity, eliminate effluent contamination (minimizing or preventing air pollution), provide protection to valuable equipment downstream of the filter and/or allow for recycling of process catalysts.

Sintered porous metal filter media offers unique performance characteristics for gas/solids separation. Precision porous metal media, with its precise bubble point control, and excellent uniformity of permeability assures reliable filtration performance, effective blowback cleaning and long on-stream service life. Furthermore, filtration systems, utilizing sintered metal media, have proven to be an effective and economical alternative to other separation equipment susceptible to pressure spikes, high temperatures, and aggressive environments.

Advances in filtration technology and filter system designs, with their unique operating capabilities, have resulted in the development of continuous processes to replace old batch process technology. Cost savings include less hazardous waste for disposal and labor savings from new technology. Fully automated filter systems can be integrated into plant process controls. Sintered metal filtration systems have proven performance in the recovery of catalysts, products for chemical processing and pharmaceuticals applications, rock quarries, metal mining industry, power generating facilities, coal and coke handling operations, and many other applications.

SINTERED POROUS METAL FILTER MEDIA

Sintered porous metal media, fabricated from either metal powder or metal fiber, are widely used for industrial gas and liquid filtration in various processes found in the chemical process, petrochemical, power generation and semiconductor industries where filtration is required to protect downstream equipment, for process separation, or to meet environmental regulations. Filters with semi-permanent media are cost effective, since such units lend themselves to minimal downtime, closed and automatic operation with minimal operator intervention, and infrequent maintenance. The proper selection of filter media with appropriate pore size, strength and corrosion resistance enables long-term filter operation with high efficiency particle retention.

Sintered porous metal media meets these criteria and offers high removal efficiency to meet tighter emission standards for today’s industrial applications. The development of specially designed and engineered sintered porous metal media with a stable porous matrix, precise bubble point specifications, close thickness tolerances, and uniformity of permeability assures reliable filtration performance, effective blowback cleaning and long on-stream service life.

The properties of metal filters, fabricated from various metal alloys, for gas filtration applications allow the use in extreme conditions: high temperature, high pressure and corrosive atmospheres. The primary benefits of sintered metal filters are: strength and fracture toughness, high pressure and temperature capabilities, high thermal shock resistance, corrosion resistance, cleanability, all-welded assembly, and long service life.

Sintered metal media can be considered as semi-permanent media with an all welded construction. An advantage of metal filters is that they are welded to metal hardware to obtain strong sealed joints. The media can withstand pressure spikes with no evidence of media migration. The inherent toughness of the metal filters provides for continuous, back pulsed operation for extended periods. For high temperature applications, additional criteria such as creep-fatigue interactions and high temperature corrosion mechanisms need to be addressed. Filters with semi-permanent media are cost effective, since such units lend themselves to minimal downtime, closed and automatic operation with minimal operator intervention, and infrequent maintenance.

Filter cartridges fabricated from sheet or tubes have an all welded construction. The filter media is designed and engineered with a stable porous matrix, precise bubble point specifications, close thickness tolerances, and uniformity of permeability, which assure reliable filtration performance, effective backwash cleaning and long on-stream service life.

Sintered Metal Powder Media

Sintered metal powder filter elements have been commercially available for more than 40 years. They are made from various alloy powders to meet corrosion and strength requirements.

Sintered metal powder media are manufactured by pressing pre-alloyed powder either into tubes or as porous sheet, followed by high temperature sintering. A scanning electron photomicrograph of typical media is shown in Figure 1.

The combination of powder size, pressing, and sintering operations defines the pore size distribution, strength, and permeability of the porous media. Pore size of sintered metal media is determined using ASTM E-128. 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. The filtration rating in gas ranges from 0.1 to 100 μm absolute.

The sintered metal powder media are available in different alloys - including stainless steel 316L, Hastelloy® B, C-22, C276, N and X; Inconel® 600, 625, and 690; Monel® 400; nickel 200; alloy 20 and titanium - to handle wide-ranging corrosion and temperature environments.

Sintered metal powder media offer a temperature range of 750 to 1750°F depending on alloy material and atmospheric conditions (oxidizing or reducing). Temperature limitations of sintered porous metal in an oxidizing environment are not due to strength of material, but due to oxides that form at elevated temperatures. The specific void volume of the oxide is much greater than the parent metal, which results in plugging of the pores in the media. In a reducing or neutral atmosphere, temperature limitations are due to strength of the material at elevated temperatures.

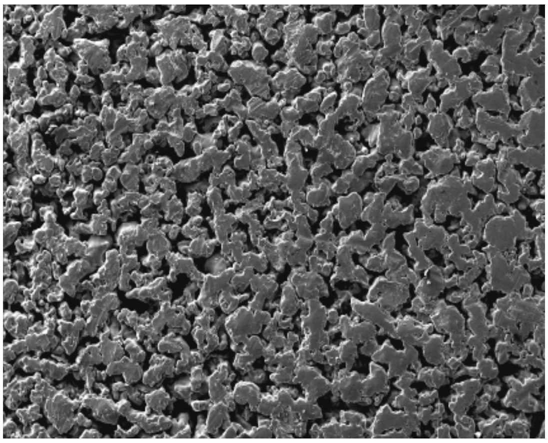

Figure 1. Photomicrograph of sintered metal powder metal media.

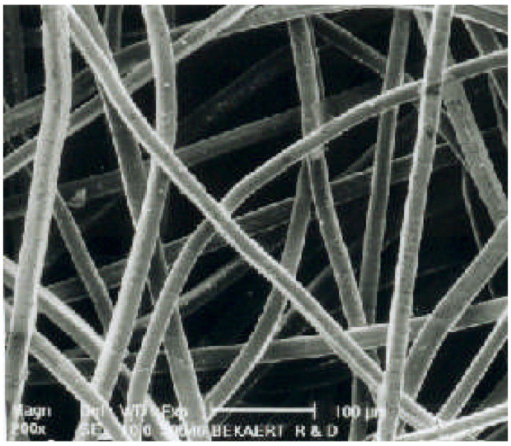

Figure 2. Photomicrograph of sintered metal fiber media
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Sintered Fiber Metal Media

Metal fiber filter media consists of very thin (1.5 to 80 µm) metal filaments uniformly laid to form a three-dimensional non-woven structure sintered at the contact points. A scanning electron photomicrograph of a typical sintered metal filter media is shown in Figure 2. These media are explicitly designed for either surface or depth filters. Either single or multi-layered construction are utilized with each layer comprised of potentially different diameter fibers to achieve optimal performance, e.g., pressure drop, filtration efficiency, particle loading capacity, and media strength. The multi-layered material has a graduated design, so the dirt holding capacity is much higher and consequently the life expectancy is longer. The final filter rating is determined by the weight per used layer, the fiber composition of the layer and the combination of several layers. The availability of a high porous structure (up to 85%) offers higher permeability and hence a low pressure drop.

Fiber metal media have a higher porosity than the powder metal media, thereby resulting in lower pressure drop. These fiber media are often manufactured from 316L stainless steel fibers, which are suitable for a wide range of process operating conditions. For higher temperature or more corrosive applications, Inconel® 601 and Fecralloy® are used for high temperatures (up to 560°C and 1000°C respectively) whereas Alloy HR can withstand temperatures up to 600°C and wet corrosive environments.

The proper selection of filter media with appropriate pore size, strength and corrosion resistance enables long-term filter operation with high efficiency particle retention. The filtration rating in gas ranges from 0.1 to 10 μm absolute.

FILTRATION FUNDAMENTALS AND MEDIA DESIGN

Understanding of the fundamental processes of particle removal as a gas stream passes through a filter is critical to optimum selection of appropriate media and to successful filter design and operation. For gases with low levels of particulate contamination, filtration by capturing the particles within the depth of a porous media is key to achieving high levels of particle efficiency. The structure of sintered metal provides a tortuous path in which particles are captured. Continued particle capture can lead to formation of cake of deposited particles on the media surface, as particles are now captured on previously deposited particles, first by filling (blocking) the surface pores and subsequently collecting on the media surface. The life of such filters will depend on its dirt-holding capacity and the corresponding pressure drop.

For gases with high dust loading, the operative filtration mechanism becomes cake filtration as the media is specifically engineered to ensure surface filtration and the possibility of cake particulate removal via pulse blowback cleaning. A particle cake is developed on the surface of the filter media, as illustrated in Figure 3 and shown in Figure 4, that becomes the filtration layer and causes additional pressure drop. The pressure drop increases as the particle loading increases, as shown in Figure 5. Once a terminal pressure is reached during the filtration cycle, the filter element is blown back with a pulse of clean gas to dislodge the filter cake. If the pore size in the filter media is chosen correctly, the pressure drop of the media can be recovered to the initial pressure drop. However, if particles become lodged within the porous media during forward flow, and progressively load the media, the pressure drop may not be completely recovered after the cleaning cycle. This increase in clean “recovery” pressure drop is shown in Figure 5. The optimal design application results in minimal increase in the clean (recovery) pressure drop after a blowback cleaning cycle, and more importantly, ensures an equilibrium operating condition after an initial series of blowback cycles.

The effectiveness of the cleaning cycle and the pressure drop recovery is a critical function of the properties of the cake and media pore size. The cake strength depends upon the dust particle morphology and size distribution, electrostatic and chemical interactions, and cake moisture levels.

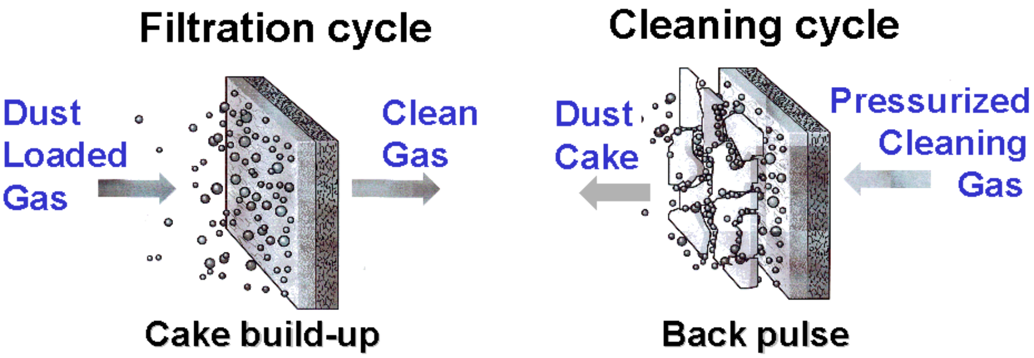

Figure 3. Particle loading during surface filtration and subsequent cake release during pulse blowback.

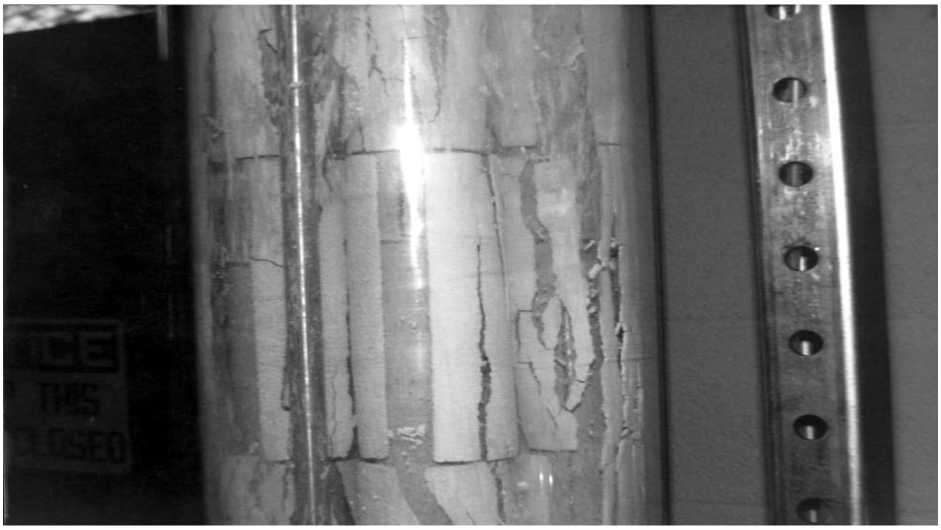

Figure 4. Photograph of cake release during pulse blowback.

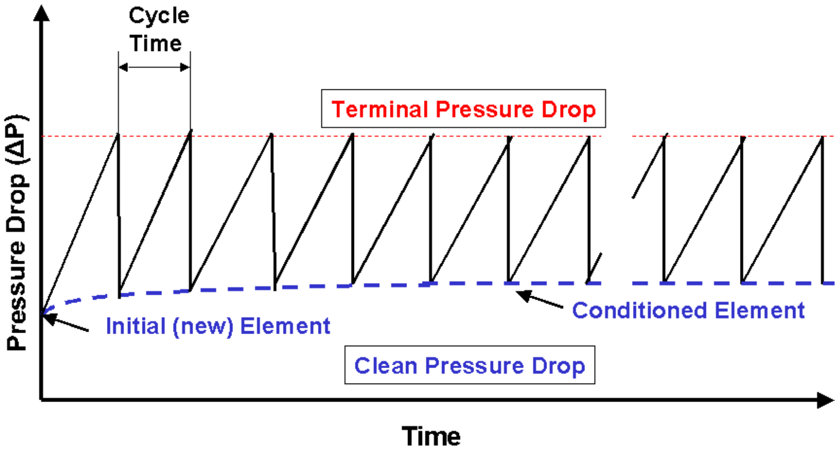

Figure 5. Typical pressure drop profiles during cake formation and periodic removal by pulse blowback cleaning.

As discussed above, the two main dynamic modes of particle filtration are depth filtration and surface filtration. In the case of depth filtration, the particles are captured inside the media; while in surface filtration they are retained, as the terms explain, at the surface where subsequently a cake of particles is formed. These two modes must be considered for the appropriate media design and selection for a given industrial application.

Surface filtration is primarily a straining (sieving) mechanism where particles larger than the pore size of the filter media are separated at the upstream surface of the filter; their size prevents them from entering or passing through the pore openings. Subsequent particles accumulate as a cake that increases in thickness as more particle-laden fluid is forced into the filter media. The cake, due to its potentially finer pore structure, may aid in the separation of finer particles than can be achieved by the filter media. However, the cake must exhibit sufficient porosity to permit continued flow through it as filtration proceeds. Because most surface filters are not perfectly smooth or have perfectly uniform pore structure, some depth filtration of finer particles may take place that will affect the life of the filter. Thus selection of the optimal media grade and knowledge of the particle size distribution, especially the finer particles, is essential to achieving long filter operating life.

Depth filtration is mainly used in applications where low particle levels must be separated such as in the protection of downstream equipment against fouling or erosion, protection of catalysts from poisoning and in product purification. The particles penetrate into the media and are subsequently captured within its multiple layer structure. This multiple layer structure prevents premature blocking of the media and increases the capacity to hold dirt and on-stream lifetime. Because the particles are captured within the depth of the media, off-line cleaning will be required. This off-line cleaning can be accomplished with solvents, ultrasonic vibration, pyrolysis, steam cleaning or water back flushing.

Face velocity and particle size are influencing factors on the degree and location of particle capture on or within the filter media. Face velocity is defined as the filter system gas flow rate per unit filter area.

Optimal design of filtration systems requires proper selection of face velocity to achieve long on-stream life operation and prevent particle intrusion into the media. A filter design, which exceeds the maximum face velocity, can lead to premature blinding of the filter element(s). Gas filtration performance is enhanced when a surface or cake is formed providing additional long-term filtration. Optimal face velocities typically are in the range of 6-8 ft/min (3-4 cm/s) to ensure adequate cake removal during pulse blowback cleaning cycles.

FILTER SYSTEM DESIGN AND OPERATION

Gas/solids filtration systems for chemical process applications operate in one of two basic process designs, namely as continuous process filters or final (or trap filters). Both designs are well suited for sintered porous metal elements. In their typical operating mode, both designs function in a similar fashion, gas flows through the media whereas particulates are retained and accumulate on it. The fundamental difference between the two is the frequency and method of solids removal and element regeneration. The decision on which type of filter to employ depends on individual process parameters, primarily the solids loading in the feedstream.

Final or trap filters are used on basically clean streams where the objective is either polishing or protection of downstream processes and equipment. These filters are not intended for in-situ cleaning and solids removal requires disassembly. Elements are normally cleaned externally using chemical or ultrasonic methods. The interval between cleaning varies with the solids load and the feed gas.

A continuous process filter is ideally suited for heavily particulate laden streams or in processes containing hazardous materials. Again, the cleaning or blowback interval depends on the solids loading. Typical periods range from 1 to 2 minutes up to many hours. The blowback cycle can be initiated either manually or automatically based on time lapse or differential pressure. Figure 5 illustrates two sequential series of filter cleaning cycles during the initial and subsequent equilibrium portion of the filter operating life.

Mott Corporation offers two different continuous process filter designs, the HyPulse GSP (Gas-Solids-Plenum) and the HyPulse GSV (Gas-Solids-Venturi). Both systems are well suited for automated process control and include in-situ cleaning for the elements but in somewhat different ways.

Particulate loading on the filter elements is similar for both filter configurations. During the filter cycle, the gas/solids mixture enters the unit and flows toward the outside of the sintered metal filter elements, where solids are retained. The “cleaned” gas passes through the element wall, into the plenum chamber, and is discharged from the filter system.

The forward flow (filtration cycle) and reverse flow (blowback cleaning) for the HyPulse GSP filter system is illustrated in Figure 6. Upon reaching a given differential pressure or cycle time, the feed is discontinued and the backflow cycle begins. The filter is isolated and gas enters the gas inlet. Reverse flowing through the plenum chamber and elements discharges the cake from the element wall.

The forward flow (filtration cycle) and reverse flow (blowback cleaning) for the HyPulse GSV filter system is shown in Figure 7. This system delivers high throughput with minimum backpulse gas requirements. Sintered metal cartridge filters are manifolded together and backpulsed sequentially while the unit remains on-line. When a predetermined differential pressure or cycle time is realized, the elements are backpulsed to remove the cake. While on-line, a burst of high pressure gas enters the nozzle manifold through the upstream solenoid valves. The blowback gas exits the nozzles and enters the venturis entraining the gas from the plenum chamber. The resulting gas flow creates a high-energy backpulse on the elements that lifts off the filter cake. The cake falls into a discharge hopper and is removed. The reverse pulse of blowback gas typically lasts from 2 to 3 sec. Only a portion of the elements are pulse cleaned at any one time while the remainder continue to operate in the filtration mode, thereby ensuring continuous flow of the process gas stream.

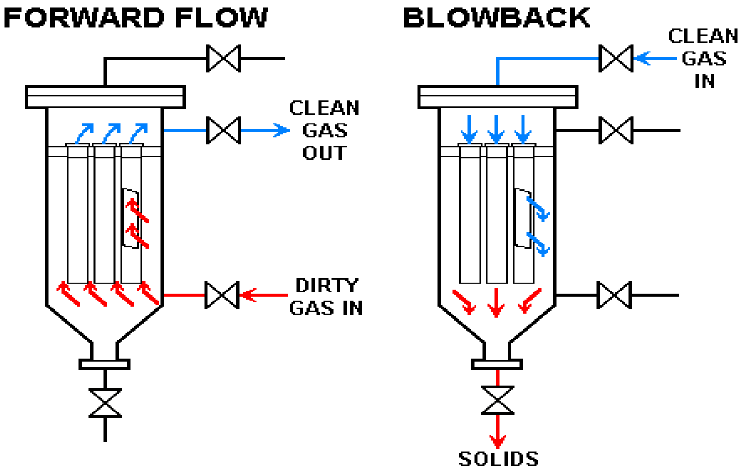

Figure 6. Schematic diagram Mott GSP filter showing gas flow during filtration (forward) flow and blowback (reverse) flow.

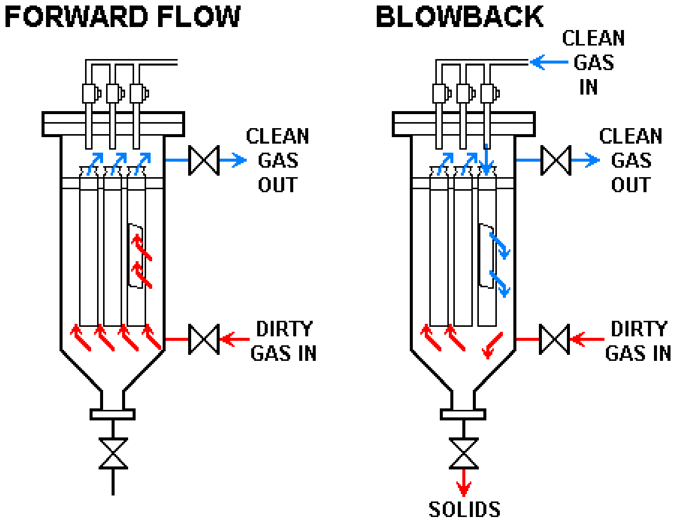

Figure 7. Schematic diagram Mott GSV filter showing gas flow during filtration (forward) flow and pulse blowback (reverse) flow on a segment of filter elements.

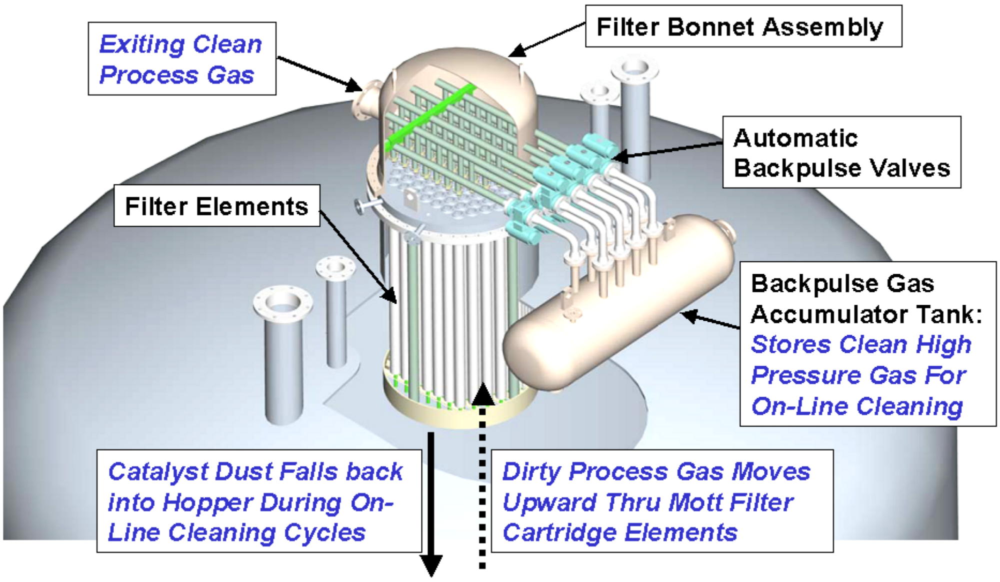

Figure 8. Cutaway illustration of GSV filter system as installed on catalyst hopper.

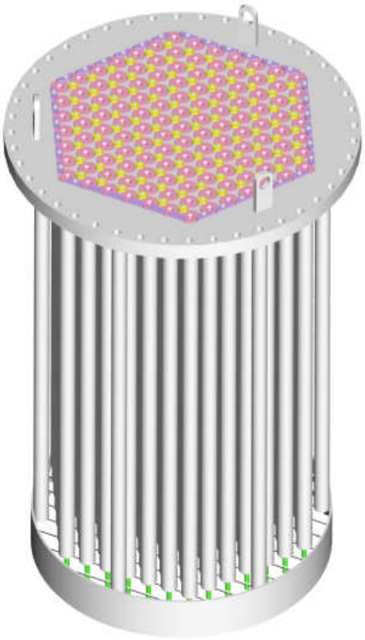

Figure 9. Tubesheet bundle frame assembly.

A cutaway illustration of a GSV filter system, as installed on catalyst hopper, is presented in Figure 8. The figure shows the flanged filter top head bonnet assembly, accumulator tank (for the blowback gas) and backpulse valves. Figure 9 illustrates a tubesheet bundle frame assembly. The filter is designed such that the filter can be easily disassembled for service and/or replacement of filter elements.

Media Selection and System Performance

Extended testing provides data relevant to the trends of performance efficiency and indicated desirable rates of operation. Recovery pressure drop after blowback can be determined to ensure long-term trends. Optimum operating conditions are criteria for long operating life.

Proper particle loading and pulse blowback cleaning are critically important to the selection of the optimum operating system conditions. For example, a study with flyash particles was conducted to determine the appropriate operating conditions. The filter housing was fabricated from transparent acrylic plastic, to allow direct visual observation of filtration and blowback, and accommodated a maximum of 6 filter elements with an associated verturis, solenoid valve manifold, and blowback control system. Figure 4 shows the cake release of the flyash at the inception of the pulse blowback cycle. Equilibrium recovery differential pressure, as graphically shown in Figure 5, typical occur within 25 blowback cycles, but are dependent on media selection, face velocity and particle characteristics (namely size, shape and composition).

COMMERCIAL APPLICATIONS: CASE STUDIES

Gas filters are typically used on catalyst hoppers and duct vents employed in the fluid catalytic cracking (FCC) and continuous catalytic reforming/regeneration (CCR) process operations used in crude oil refining and petrochemical industries. Process flow schemes for typical operations are shown in Figures 10 and 11. The filters efficiently remove catalyst particles from the vent gas streams, thereby minimizing particulate air pollutants while allowing for these materials to be either reused or deposed in an environmental appropriated manner. Sintered metal filters are ideal for these applications, as the metallic media are well suited to provide long-term life. These filters offer lower capital cost for the filter system, lower installed cost, and lower annual operating costs, while providing high levels of particle removal efficiency.

Figure 10 shows a process flow scheme for a typical FCC process operation at a crude oil refinery. There are typically three types of catalyst storage hoppers in FCC process, namely: “fresh”, “equilibrium” and “spent” catalyst storage hoppers. Fresh catalyst storage hoppers are for storage of fresh catalyst at the plant site. Equilibrium catalyst storage hoppers are used for in-process storage as the catalyst is transferred between the reactor and regenerator. The spent catalyst storage hoppers are for temporary storage prior to off-site disposal of spent catalyst.

Dust control filters are typical required and installed on these catalyst hoppers for three reasons. The pneumatic transfer of catalyst creates dust during the transfer process. Dust must be controlled to minimize atmospheric emissions per governmental regulations. In-place recovery and reuse of costly catalyst during the unload/fill/transfer operations reduces operating costs.

A typical catalyst hopper, with an associated dust filter mounted on the top, is shown in Figure 12. These hoppers typical have a diameter of 8 to 17 ft (2.4 to 5.2 m) and height of 35 to 65 ft (10.7 to 20 m), with a resulting storage capacity of 50 to 270 tons (45 to 250 metric tons). Figure 8 shows in greater detail a GSV filter assembly mounted on top of catalyst hopper. The typical filter is 24 to 48 inch (0.60 to 1.20 m) outside diameter.

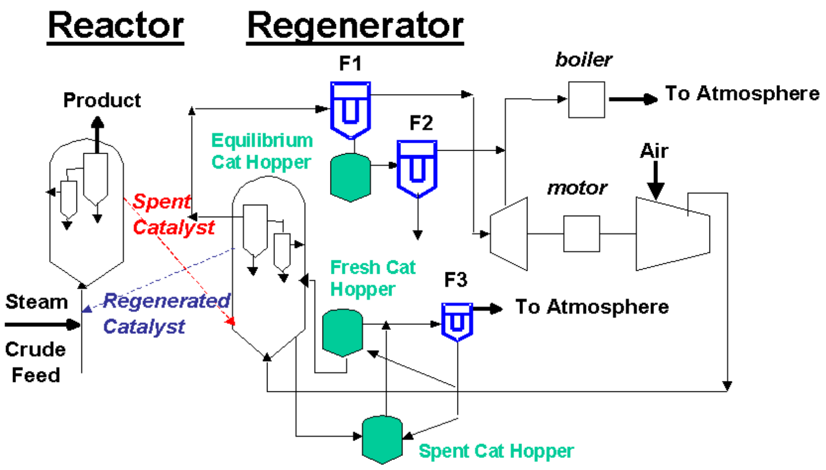

Figure 10. Process flow scheme of typical FCC process operation showing the location of 3 catalyst hoppers and filters (F1, F2 and F3).

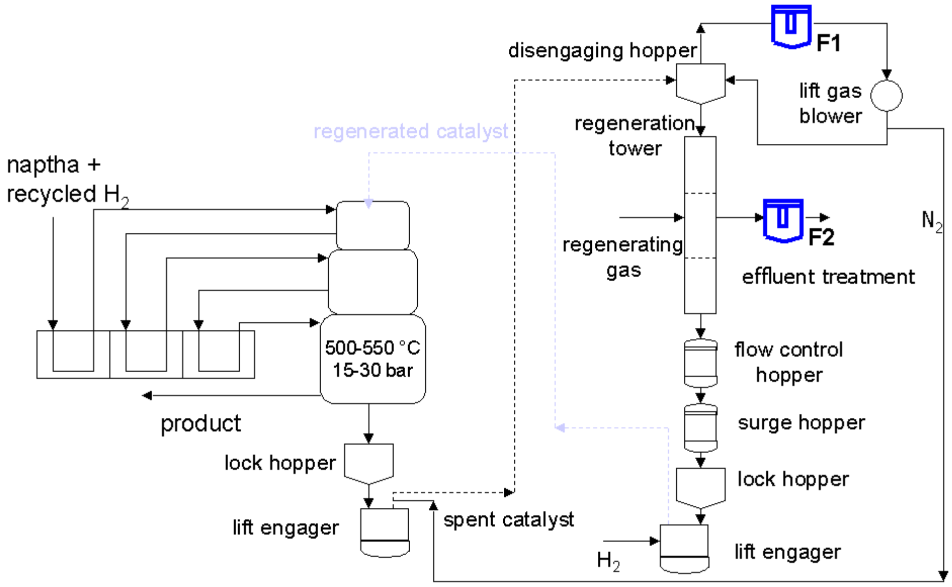

Figure 11. Process flow scheme of typical CCR process operation showing the location of 2 filters (F1 and F2).

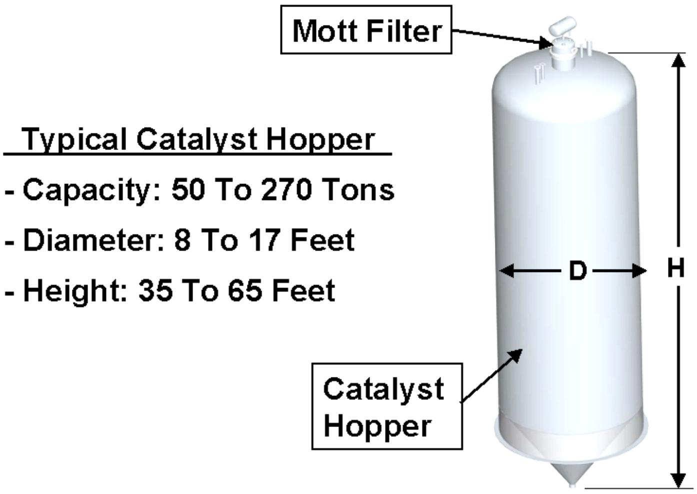

Figure 12. GSV filter system mounted on top of catalyst hopper.

Typical operating conditions of the catalyst hoppers are as follows. Catalyst is moved in and out of storage hoppers by pneumatic transfer using compressed gas. This gas is constantly vented from the top of each hopper during catalyst transfer operations. The vent hopper gas must be filtered for dust suppression. The catalyst dust particles in the vent gas can range in size from 1 to 100 μm in diameter. The hopper vent gas operating pressures range from partial vacuum to 25 psig (1.7 bar). The operating temperatures range from 60 °F to 650 °F (15 °C to 340 °C). The required filtration efficiency is usually 99% solids removal or a dust emissions concentration level less than 50 mg/Nm^3.

Porous metal media is robust and is very well suited for catalyst hopper vent filter applications as the filters must be capable of operating over a very wide range of flow, temperature and pressure conditions. Many of these applications are ideally suited to 316L stainless steel media, which can handle service temperatures up to 750° to 1000° F (400 °C to 540 °C). Filters are capable of ensuring that the particle emission standards, which may be as low as 30 to 50 mg/Nm^3, can be met.

One primary function of the filter in CCR processes is to prevent fine catalyst particle from re-entering the reactor where they can deposits on the inner reactor surfaces, thereby adversely affecting the reaction rate. These fines are generated by attrition of the original catalyst particles. The operating pressures in some systems range from 170 to 350 psig (12 to 25 kg/cm^2) while in others processes, the pressure can be as low as 50 psig (3.5 kg/cm^2). The operating temperatures typically range from 210 °F to 400 °F (100 °C to 200 °C).

SUMMARY

Sintered metal media provides an effective means of filtering to remove particulate whether they are impurities, valuable by-product, or catalyst within a chemical process stream. Sintered metal media is semi-permanent and is well suited for dust removal and gas treatment, particularly where pressure spikes, high temperatures, corrosive atmospheres, hot gasses and sparks are present. Filtration systems utilizing sintered metal media have been used successfully in place of bag houses, cyclones, electrostatic precipitators and scrubbers.

Filter operating conditions affect its useful life and impact the efficiency of blowback solids removal. Media grade selection coupled with particle characteristics, and filter design operating flowrate, are important parameters to ensure optimal filter media operating life. Sintered metal filters should be operated within the design parameters to prevent premature blinding of the media due to fluctuations in process operations. The cake becomes the filter media and the porous media acts as a septum to retain the filter cake. Filter cakes can be effectively removed via pulse blowback cleaning from the filter elements and removed as bulk powders from the bottom of the filter housing or fall directly into the catalyst hopper.

Both plenum blowback and venturi pulse blowback process systems are effective and can be designed to accommodate a wide range of applications and performance requirements. Recovery pressure equilibrium depends on both filter rating and face velocity. Extended testing provided data relevant to the trends of performance efficiency and indicated desirable rates of operation. Recovery pressure drop after blowback was examined for long-term trends at different flow velocities. Optimum operating conditions were determined for long operating life.

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