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## **SINTERED METAL HOT GAS FILTERS**

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# SINTERED METAL HOT GAS FILTERS

## ABSTRACT

Sintered metal filters have been used for hot gas filtration in various plants in the chemical process, petrochemical and power generation industries. These filters can provide particulate capture efficiencies of 99.9% or better. The temperature for filtration has been as high as 900°C. Along with filtration efficiency consideration, more important criteria such as corrosion resistance, mechanical strength at service temperature and cake release issues are being addressed. These issues are critical to operating the hot gas filter successfully and cost effectively. Concerns related to hot corrosion and strength at high temperatures lead the technical community towards using ceramic filters. While ceramics are mostly inert to hot corrosion environments, they are brittle, and are prone to failure during thermal cycling or under rapidly changing loads, such as during process upset or filter blowback. Metal filters can be designed with required strength at elevated temperatures, hot corrosion resistance and toughness to withstand the thermal and mechanical stresses. This paper will describe the benefits of using sintered metal filters in corrosive environments at high temperatures and relevant industrial experience in using such filters. Filter operation and performance in selected applications will be discussed.

## INTRODUCTION

There are many applications in the chemical, petrochemical and power industries, where filtration of hot gas is required to protect downstream equipment, for process separation, or to meet environmental regulations. Filtering the gas emanating from a reactor at high temperature is important, since cooling will either require a heat exchange or mixing with cold air, at an added cost. When mixing with cold air, the dew point should be controlled to prevent condensation. Hot gas particulate filtration has been identified as a key component for the successful implementation of coal-based combined cycle power systems such as Pressurized Fluidized Bed Combustion (PFBC), Integrated Gasification Combined Cycle (IGCC) and hybrid cycles (Thambimuthu, 1993). While cyclones and electrostatic precipitators are often used for separating particles from a gaseous stream, fabric bag house filters, barrier or cross flow filters provide separation efficiency of 99.9% or higher. Fabric bag houses (made of polymeric or Fiberglass materials) are typically used at temperatures ranging from 90°C to 250°C (Croom, 1993). Operation of cyclones and precipitators require additional energy input. Back-pulsed filters are static in operation and are sized for the available pressure drop and gas flow conditions. Filters with permanent media become 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.

Understanding of the operative filtration mechanism is key to successful filter design and operation. For gases with low levels of particulate contamination, filtration by trapping the particles in the depth of a porous material is satisfactory. The life of such a filter will depend on its dirt holding capacity and corresponding pressure drop. For gases with high dust loading, the operative filtration mechanism is cake filtration. A particle cake is developed over the filter element, which becomes the filtration layer and causes additional pressure drop. The pressure drop increases as the particle loading increases. Once a terminal pressure is reached during filtration cycle, the filter element is blown back with clean gas to dislodge the filter cake. If the pore size in filter media is chosen correctly, the pressure drop of the filter can be recovered to the initial pressure drop. However, if particles become lodged within the porous media during forward flow, and progressively load the filter media, the pressure drop may not be completely recovered after the blowback cycle.

The effectiveness of the blowback cycle and pressure drop recovery is a critical function of the properties of the cake. The cake strength depends upon the dust particle morphology and distribution, electrostatic and chemical interactions, as well as the level of moisture and other vapors present in the cake. If high temperatures are involved, then the fine particles may bond, begin to sinter, or chemically react with the filter element, making the cake release difficult. Successful filter design will consider the factors discussed above and other factors relevant to the particular process.

## **SINTERED POWDER METAL FILTERS**

Sintered metal filter elements have been commercially available for more than forty years. They have been made in various alloys to meet various corrosion and strength requirements. The primary benefits of sintered metal filters are (1) strength, toughness and pressure capability, (2) corrosion resistance, (3) cleanability and (4) long service life. While strength, pressure capability, cleanability etc., are also available in ceramic filters, ceramic filters are brittle and lack toughness. Therefore, ceramic filters can not be used reliably as back-pulsed filter or in services where large temperature swings may occur (Wagner, 1998). The inherent toughness of the metal filters provides the ability for continuous, back pulsed operation for extended periods. For high temperature applications, additional criteria such as creep-fatigue interactions and high temperature corrosion mechanism in sintered metal filters need to be addressed.

Sintered metal filters are manufactured by pressing pre-alloyed powder either as tubes or as a porous sheet, followed by high temperature sintering. The combination of powder size, pressing and sintering operations defines the pore size and distribution, strength and permeability of the porous element. An advantage of metal filters is that they are welded to metal hardware to obtain strong sealed joints. Sintered metal filters are available in gas filtration ratings from 0.05  $\mu\text{m}$  to 20  $\mu\text{m}$  (Khalaf and Rubow, 1998).

## **TEMPERATURE AND CORROSION RESISTANCE**

Table 1 lists the recommended maximum temperature of use for commercially available sintered metal filters in oxidizing and reducing or neutral environments. The temperature limits have been placed due to deterioration in strength at elevated temperature. The reduction in strength at elevated temperature is primarily due to intrinsic softening of the alloy and further due to progressive corrosion attack. A few successful application case histories will be discussed in another section of this paper.

In molybdenum bearing heat resistant alloys, such as Hastelloy-X, the formation of  $\text{MoO}_3$  at 796°C in highly oxidizing environment starts to degrade and plug the media. This limits the application temperature of Hastelloy-X in oxidizing environments to 650°C. Heat resistant alloys will usually withstand exposures to higher temperatures in reducing or carburizing atmospheres. Nickel based alloys are susceptible to intergranular attack by sulfur and sulfur-bearing compounds. Presence of chromium, iron and silicon in Nickel alloys reduces the tendency for sulfidation attack.

**Table 1 : Maximum Recommended Temperature of Use For Porous Metals in Different Environments**

Porous Alloy	Maximum Use Temperature, (°C) in Various Environments			
	Neutral	Oxidizing	Reducing	Sulfidizing
316L Stainless Steel	500	400	500	350
310 Stainless Steel	500	500	500	500
Hastelloy® C276	550	450	550	250
Inconel® 600	800	800	800	250
Hastelloy® X	925	650	925	250

**FILTRATION CONSIDERATIONS AT HIGH TEMPERATURE**

The filtration parameters that are important for designing hot gas sintered metal filter include:

- Type of solids, reactive or inert, whether dry or sticky
- Gas composition and dew point
- Solid loading, particle density, particle cake density and permeability
- Solid particle size distribution, shape and morphology
- Operating pressure
- Operating temperature
- Allowable pressure drop
- Gas flow rate
- Desired filtration efficiency, by particle size, or by total solids weight

For gas filtration at temperatures less than 200°C, all above parameters are equally important for designing a successful filtration unit. At temperatures higher than 200°C, the likelihood of reaction and bonding amongst the dust particles, and reaction with the sintered metal filter increases. This can lead to difficulties in dislodging the cake during blowback cycles. Prior separation using demisters to remove tar or oil vapor components from the hot gas would provide significant assistance in operating the hot gas filter efficiently. The composition of gas and chemistry of the particulate matter should be determined and compatible alloys should be chosen to minimize the risk of cake sticking or reaction with the sintered metal filter elements.

**SINTERED METAL HOT GAS FILTER DESIGNS**

Mott Corporation offers two designs of sintered metal gas filters, namely Gas/Solids plenum blowback filter (GSP) and Gas/Solids venturi blowback filters (GSV).

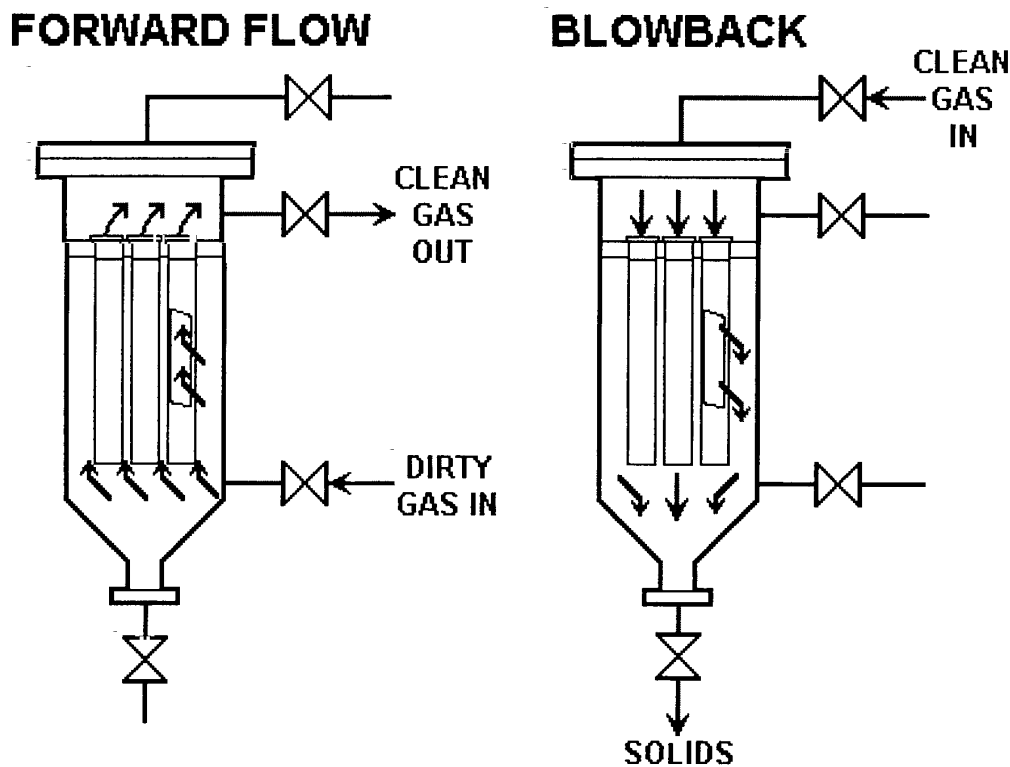
**Gas/Solids Plenum Blowback (GSP) Filter**

GSP is a semi-continuous use gas filter and features a plenum blowback. Figure 1 shows a schematic design of the GSP filter. GSP filters, when used on relatively clean gas to polish the gas stream for protection of downstream process and equipment may work as depth as well as surface filter. If used on clean gas stream, the elements are cleaned externally using chemicals and ultrasonic cleaning methods. The GSP filter is also used as a blowback filter in gas with higher dirt loading, such that a dense cake is formed on the element wall. Once the pressure drop reaches a terminal value, the forward gas flow is interrupted. Gas is then blown through the filter in the reverse direction at a velocity approaching twice the forward flow velocity to dislodge the surface cake. The duration of the reverse blow may range from 15 to 60 seconds, as required, to recover the pressure drop. This design is adequate for batch processing, or when a second GSP filter is available. The flow can be diverted to the second filter, when the first filter is being blown back. The solids are collected in the heel and discharged from the bottom into a collection vessel.

### **Gas/Solids Venturi Blowback (GSV) Filter**

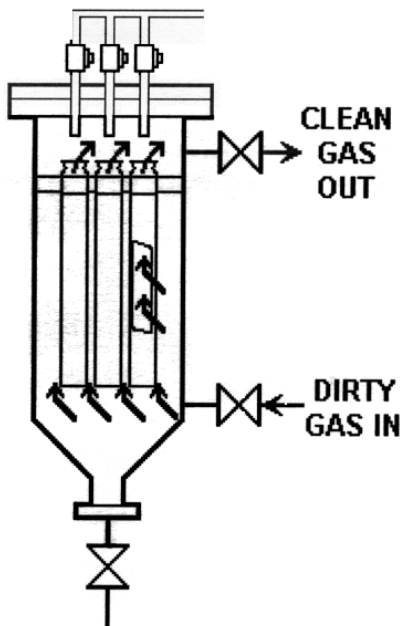
The disadvantage of the GSP design is that forward flow must be interrupted for solids removal or blowback. For continuous service, the GSV filter uses venturi/nozzle pulse blowback system. The blowback is performed on a single filter element, or banks of filter elements sequentially through a manifold. The blowback is accomplished without stopping the forward flow. The filter remains on-line, while some of the elements are blown back to remove deposited cake. The duration of the blowback pulse may vary from 0.1 to 1 second, depending on the process and operational requirements.

The advantage of venturi blowback system is that the blowback gas removes solids from the filter elements, which fall in the bottom for removal, while the blowback gas is filtered through the on-line elements. Some of the blowback gas is educted from the clean gas above the elements amplifying the pulse. The venturi system minimizes the amount of gas required for blowback.



**Figure 1: Schematic design of GSP filter**

## FORWARD FLOW



## BLOWBACK

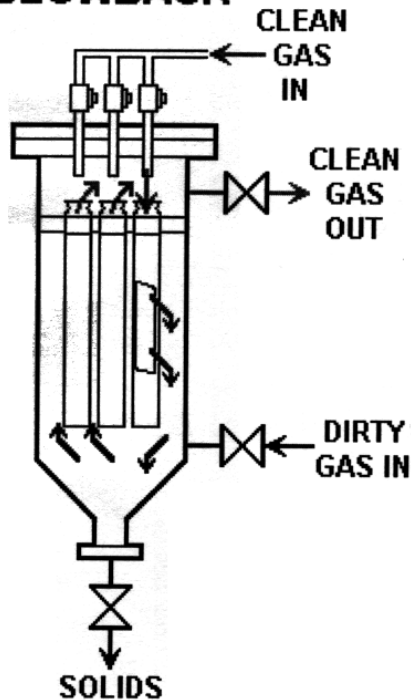


Figure 2: Schematic design of GSV filter

## INDUSTRIAL HOT GAS FILTER APPLICATIONS

### Case 1: GSP Particle Trap Filter

The objective for this project was to polish the hot air emanating from a heater at 800°C and remove particles down to 0.5  $\mu\text{m}$  size, to protect downstream equipment. The available space to locate the filter was small, and therefore the 42" long filter elements were placed horizontally. The system pressure was 1450 psi. Nineteen Hastelloy-X porous elements were used in this filter. The filter elements have lasted more than 7 years and have accumulated 15,000 hours of service. The filter elements were cleaned ultrasonically after 10,000 hours of service.

Eventual failure of these porous elements was due to gradual degradation of Hastelloy-X elements via oxidation. The filter elements were becoming plugged with Molybdenum oxide. Hastelloy-X contains 8 to 10 wt.% Molybdenum as an alloying constituent. Molybdenum oxide melts at 796°C. At an application temperature of 815°C, the Molybdenum from the alloy was slowly reacting with oxygen and forming Molybdenum oxide that would melt and plug the filter. Following this incident, the temperature rating of Hastelloy-X porous element in oxygen bearing environment was lowered to 650°C. Inconel 600 porous elements were recommended to replace the Hastelloy X elements.

### Case 2: GSP Catalyst Trap Filter

The objective for this project was (1) minimize the loss of expensive catalyst via the exit gas stream of a fluidized bed reactor, and (2) prevent the catalyst particles from entering the downstream product recovery system. Conventional cyclones normally used to retain solids in high temperature fluidized beds were not considered sufficiently efficient for this process.

The gas temperature was 540°C, and gas environment was highly oxidizing and carburizing. The gas consisted of 75 wt.% organic vapor, 10 wt.% H<sub>2</sub>O, 10 wt.% CO<sub>2</sub>, and 5 wt.% N<sub>2</sub>. The operating pressure was 20 psig, and face velocity was 4 ft/min. The mean particle size was 8 μm, with 2% of particles below 1 μm size.

Inconel 600 porous was chosen for filtration, and the filter element was reinforced with a perforated inner core to minimize the stress corrosion damage. A total filter area of 216 ft<sup>2</sup> was used in several GSP filters. These GSP filters provide one year of uninterrupted service, and then the filter elements are removed for chemical cleaning.

### **Case 3: GSV Dehydrator Vent Filter**

A sintered metal hot gas filter was installed over a fluidized bed dehydrator to separate silica particles from the effluent gas. Hot nitrogen gas at 900°C was used to dry silica particles in a fluidized bed. The required filtration efficiency was 98% at 1.3 μm particle size. The operating pressure was 10 psi. Since the atmosphere is mildly oxidizing, Hastelloy X porous was chosen for hot gas filtration due to its higher strength. The filter is operating per expectations. Since the process is not run continuously, the filter sees considerable thermal cycling. Due to its toughness, the sintered metal filter absorbs the thermal stresses. If hot corrosion damage will occur, Inconel 600 porous can replace the Hastelloy-X porous elements.

### **FUTURE WORK**

A Mott 310 Stainless Steel filter has been installed as a police filter downstream of a ceramic hot gas filter in an IGCC power plant (Ståhl and Neergaard, 1998). It is planned to monitor the performance of this filter over an extended period from a hot corrosion standpoint. The operational temperature range is from 280 to 450°C. The gas contains small amounts of hydrogen sulfide, which can cause sulfidation attack.

To predict reliability for prolonged service at elevated temperatures and corrosive environments, further work needs to be performed to assess the structural properties of sintered metal filters at elevated temperatures over a long period of time. An expanded database of high temperature properties of porous metals in oxidizing, reducing and sulfidizing gaseous environments is needed. Extensive mechanical testing should be conducted as a function of temperature, environment and thermal cycle.

Sulfur bearing environments are most aggressive. Most conventional iron and nickel based alloys will not function adequately as sintered metal filters in sulfidizing environments at elevated temperatures. Iron aluminide alloys have been identified as potential candidates for elevated temperature service in sulfidizing environment (Judkins, Tortorelli and Wright, 1996). Welding of iron aluminide alloys has been a problem, but solutions have been discovered (Mitchell, 1997). More work needs to be performed to assess the strength and reliability of the weld joints in iron aluminide alloys.

### **CONCLUSIONS**

Sintered metal hot gas filters have been successfully deployed in the chemical process, petrochemical and the power industries for many years. A variety of alloys are available that have the required mechanical strength and the corrosion resistance to withstand the service conditions. More work needs to be performed to develop sintered porous materials that will withstand the sulfidizing environment at elevated temperatures. This development will be crucial to the successful use of sintered metal hot gas filters in the coal combustion plants.

In addition to the development of appropriate metallurgy for various corrosive conditions at elevated temperature, the cake discharge behavior at elevated temperature is also key to successful filter operation. The nature of particles at elevated temperatures, their reactivity with the sintered metal filter surface, and the inter-particle bonding will define the nature of the cake. Appropriate solutions will need to be developed to obtain a cake that is readily dislodged during blowback. A robust mechanical design of the filter system to operate at elevated temperatures and handle the thermal as well as pressure loads during filter operating cycle will be required.

Finally, while ceramic filters possess the required corrosion resistance and mechanical strength for withstanding the high temperature environment, the ceramic filters lack toughness and fail in a brittle manner. Ceramic filters also lack the ability to withstand sudden temperature changes and thermal shock. Sintered metal filters due to their intrinsic toughness overcome such limitations, and if designed appropriately, should provide long service without failure.

## ACKNOWLEDGEMENTS

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