Porous Metal Filters for Gas and Liquid Applications in the Nuclear Industry - 9556

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ABSTRACT

Sintered metal media are ideally suited for use in the most demanding industrial applications where long life is required and often other media are not cost-effective solution. As examples, filtration technology utilizing sintered metal media provides excellent performance in numerous liquid/solids and gas/solid separation applications found in the handling and processing of fluids containing radioactive materials. Many types of filter media, ranging from single use (disposable) to semi-permanent, are utilized today for separation of particulate matter. However, semi-permanent media are usually cleanable, either on or off-line, and are intended for sustainable, often multi-year, operating life in harsh environments. These harsh environments, which may involve corrosive fluids, high temperatures, high pressures or pressure spikes, often requiring continuous filtration service, are ideally suited for all-metal filtration systems employing semi-permanent sintered metal media. Sintered metal media, usually fabricated into tubular metal elements, have proven high particle removal efficiency and demonstrated reliability that uniquely afford excellent performance for demanding liquid/solids and gas/solids separation processes. The filter element and, in certain cases, the entire filter are weldable; therefore, the inherent sealing eliminates the need for potentially problematic seals. These media provide a positive barrier to ensure particulate removal to protect downstream equipment, for product separation, and/or to meet health, safety and environmental regulations. Typical applications for sintered metal media include: 1) gas and liquid filter systems used in various nuclear and radioactive waste processing applications, 2) an all-metal High Efficiency Particulate Air (HEPA) filter developed under Department of Energy (DOE) funding as an alternative to traditional HEPA filters fabricated with conventional glass fibers used on High Level Waste (HLW) tank ventilation systems at various nuclear sites in the US, and 3) smaller flow rate in-line gas filters utilized in compressed gas lines, utility lines, vent lines and gas sampling lines typically found in laboratory and small pilot test systems using radioactive materials. These filter examples employ a wide range of filtration technology, e.g., large scale cross-flow filtration system for the concentrating of liquid waste, in-situ back-pulse cleanable gas filtration system primarily utilizing surface particle filtration, and smaller in-line gas filter utilizing particle removal via depth filtration.

INTRODUCTION

A myriad of filtration technologies are used in the nuclear industries and in the processing of radioactive wastes. These technologies are employed on both liquid and gas streams, which comprise a wide range of non-corrosive to highly corrosive (either caustic or acidic) chemical constituents, containing a wide array of particulate matter, and a wide range of system temperatures and pressures. Filters are employed to provide a positive barrier to ensure particulate removal to protect downstream equipment, for product separation, and/or to meet health, safety and environmental regulations.

Many types of filter media, ranging from single use (disposable) to semi-permanent, are utilized today for separation of particulate matter. These media include fiber (cellulosic, glass and polymeric), fabric, ceramic, polymeric membrane, metal mesh, and sintered metal media (powder and fiber). However, semi-permanent media are usually cleanable, either on or off-line, and are intended for sustainable, often multi-year, operating life in harsh environments. For example, HEPA filters, traditionally comprised of glass fiber media which is a single-use disposal media, are widely used in air and gas filtration systems. These HEPA filters usually employ a highly pleated thin sheet of media in a compact filter element and are intended as single-use disposable filters. By definition, a HEPA filter has a minimum particle collection efficiency of 99.97% for 0.3 micrometer (μm) thermally generated di-octyl phthalate (DOP) particles.

The selection of an appropriate particle separation technology for a given application is driven by a number of criteria with often seemingly conflicting requirements (e.g., low pressure drop, highest filtration performance and long life versus lowest cost). Selection criteria associated with system operating conditions include temperature, pressure, gas composition, particle composition, corrosive nature of gas and/or particulate matter, particle size distribution, and suitable differential pressure drop. Selection criteria associated with filtration requirements include the degree of particle separation, downstream particle emissions requirements, continuous versus intermittent usage, length of service (e.g., days, months, year +), disposable or cleanable media, on-line versus off-line cleaning, and demonstrated robustness of the filtration technology. Economic criteria include system capital costs, operating costs, disposal costs and life cycle costs.

This paper addresses the attributes of sintered metal media and their use in industrial filtration systems. Topics include methods of manufacture, physical characteristics of the media, filtration fundaments, and system design. The fundamental processes of particle capture on or within the filter media, methods of operation, and on-line cleaning of deposited particulate matter will be discussed. Illustrative examples are presented of representative filtration applications for sintered metal filters in the nuclear industry and for radioactive waste processing.

SINTERED POROUS METAL FILTER MEDIA

Sintered metal media have been used in a myriad of separation applications over the past 50 years. Sintered porous metal media, fabricated from either metal powder or metal fiber, are widely used for industrial gas and liquid filtration processes found in the chemical, petrochemical, power generation, pharmaceutical/medical, food and beverage, and semiconductor industries where filtration is required to protect downstream equipment, for process separation, or to meet health, safely, and 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, allow their use in extreme conditions: high temperature, high pressure and corrosive atmospheres. Operating temperature can be as high as 1000^{o} C, depending on the selection of metal alloy. 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 have demonstrated high particle efficiency removal, reliable filtration performance, effective backwash capability, and long on-stream service. These filters can provide particulate capture efficiencies of 99.9% (often greater than 99.97% and as high as 99.9999999%) using either surface or depth media. 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. These issues are critical to achieving successful, cost effective operations. The life of such filter media (filter operating life) will depend on its particulate holding capacity and corresponding pressure drop. This accumulating cake can be periodically removed using a blowback cycle. The effectiveness of the blowback cycle and filter pressure drop recovery is a critical function of the properties of the accumulating particles in the cake and the filter media.

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.

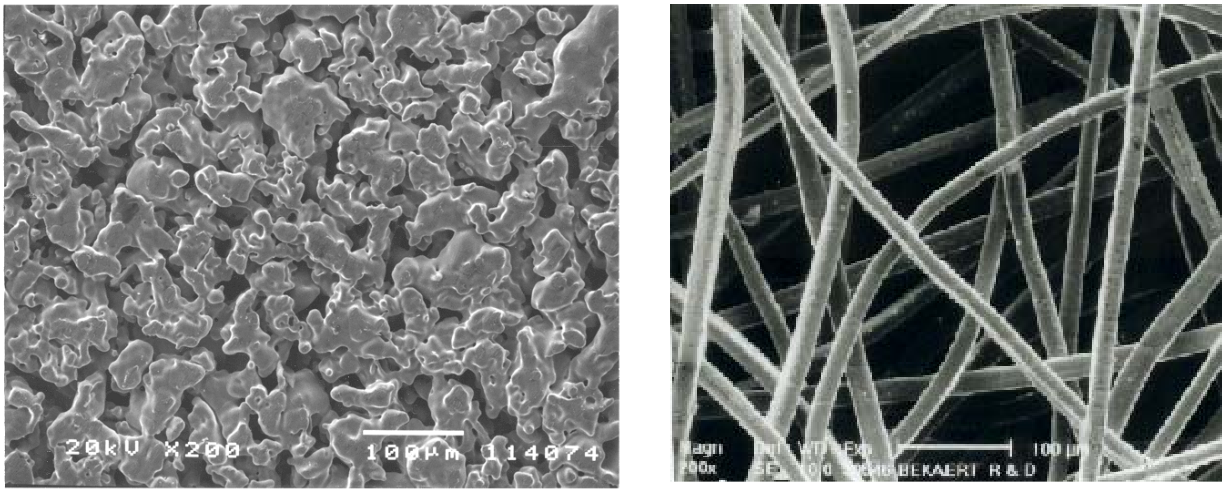

Figure 1. Photomicrographs of sintered metal powder media and sintered fiber metal media.

Sintered Powder Metal Media

Sintered metal media are manufactured by pressing metal powder into porous sheet or tubes, followed by high temperature sintering. A scanning electron photomicrograph of a typical sintered metal powder media is shown in Figure 1. The combination of powder size, pressing and sintering operation defines the pore size and distribution, strength and permeability of the porous media. Maximum pore size of sintered metal media is determined via the bublepoint method using ASTM standard E-128. The media grade designation is equivalent to the mean flow pore, or average pore size of the filter. Sintered metal powder media are offered in grades 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 40 and 100. The filtration rating in liquid service for media grades 0.2 to 20 is between 1.4 and 35 μm absolute. The filtration rating in gas service ranges from 0.1 to 100 μm absolute.

Filter cartridges, as shown in Figure 2, are either fabricated from sheet or iso-pressed tubes and have all welded construction. These cartridges can then be assembled into filter bundles, as show in Figure 2. 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. These well-controlled pores are essential to ensure effective particulate removal from process streams, coupled with subsequent particle removal during a backwash process.

The permanent structure of sintered metal media allows filter cartridges to be cleaned in several ways with no media migration. The appropriate selection of alloy type for corrosion resistance and media grade for particle removal assures liquid purity or gas during separation. In-situ cleaning in process filters is by liquid or gas backwash. Chemical cleaning with compatible materials or ultrasonic cleaning in a detergent solution will remove insoluble contaminants from within the filter media. Sintered metal media are available in a wide variety of corrosion resistant alloys including: Stainless Steel 316L, 304L, 310, 347, and 430; Hastelloy® B, B-2, C-22, C276, N and X; Inconel® 600, 625, and 690; Monel® 400; Nickel 200; Alloy 20; and Titanium.

Sintered porous metal offers a temperature range of 400 to 950° C depending on alloy material and atmospheric conditions. Table I shows elevated service temperatures of several sintered metal alloys.

Sintered metal filter elements can be supplied to withstand differential pressures over 210 bar (3000 psi). Sintered metal is permanent media with an all welded construction. The media can withstand pressure spikes with no media migration.

Figure 2. Photographs of sintered porous metal cartridges and filter bundle.

Table I. Elevated Temperature Service for Selected Sintered Metal Alloys

	Maximum Temperature			
Material	**Oxidizing**	**Atmosphere**	**Reducing**	**Atmosphere**
	°C	°F	°C	°F
316 L Stainless Steel	400	750	482	900
Inconel 600	593	1100	815	1500
Hastelloy X	788	1450	927	1700

Filtration properties are dependent on the media characteristics, the surface area available, and the process conditions of the application. Particle retention, media uniformity, absence of particle shedding, and cleanability are critical to the filter operating system. Laboratory feasibility assessment provides a suitable basis for determining filter design specifications. Pilot scale testing ensures the filter meets operational specifications under process conditions.

Sintered Metal Fiber 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 1. 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 a very higher permeability and hence a low pressure drop.

The properties of metal fiber 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.

Fiber metal media have a higher porosity than the powder metal media, thereby resulting in lower pressure drop. For high temperature or corrosive applications, Bekaert has developed fibres in other alloys besides AISI 316L stainless steel. 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 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.

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 liquid service is between 2 and 35 μm absolute. The filtration rating in gas service ranges from 0.1 to 10 μm absolute.

FILTRATION FUNDAMENTALS AND MEDIA DESIGN

Understanding of the fundamental dynamics of particle separation as a fluid stream passes through a filter media and then the subsequent cake removal (if applicable in particular applications) is critical to optimum selection of appropriate media and to successful filter design and operation. From the standpoint of filtration processes, the two fundamental modes of filtration are dead-end (conventional) and cross-flow. In addition, the location of particle capture further complicated filter media design and selection for a given application, i.e., are particles primarily captured within the depth of the media (depth filtration) or on the media surface (surface filtration).

Filtration processes are divided into two distinct modes of filtration: dead-end (conventional) and cross-flow, as illustrated in Figure 3. The more common of the two is dead-end or conventional filtration where all of the fluid flows through the media and particle separation occurs on or within the media. Whereas in cross-flow filtration, only a small portion (typically 5-10%) of the incoming fluid passes through the media. This flow is commonly called filtrate or permeate. Particle separation occurs at the surface of the media and then accumulating particle matter is subsequently re-entrained back into the primary flow, where it exits though the far end of the filter element as a more concentrated stream.

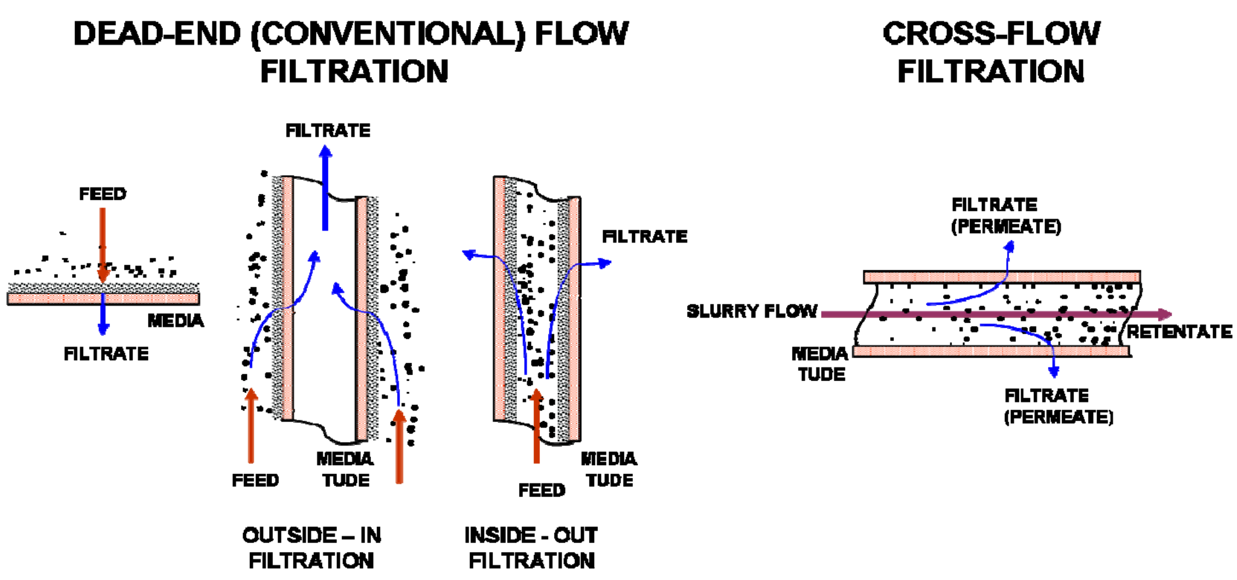

Figure 3. Illustrations of particle loading in dead-end (conventional) and cross-flow filtration.

The two types of particle filtration utilized in dead-end filtration are depth filtration and surface filtration. In the case of depth filtration, the particles are captured within 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 types must be considered to ensure the appropriate media design and selection for a given industrial application.

Depth filtration in both gas and liquid service is mainly used in applications where low particle levels must be separated, for example, to protect downstream equipment, for product purification, or to meet health, safety and environment requirements. 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 for particle holding and on-stream lifetime. Because the particles are captured within the depth of the media, the filters are either meant to be used only once or cleaned off-line. This off-line cleaning can be accomplished with solvents, ultrasonic vibration, pyrolysis, steam cleaning or water back flushing.

Surface filtration in most liquid applications primarily utilizes particle capture via 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. In gas service, particles are captured on or near the filter surface via additional capture mechanisms, i.e., primarily impaction, interception and diffusion. For both liquid and gas service, 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.

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 particle holding capacity and the corresponding pressure drop.

Filters used in high particle loading applications found in both gas and liquid service are often on-line back-pulsed cleaned to increase filter life. Here 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 4, which becomes the filtration layer and causes additional pressure drop. The pressure drop increases as the particle loading increases, as shown in Figure 4. 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 4. 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.

Face velocity and particle size are influencing factors on the degree and location of particle capture on or within the filter media. Face velocity (flux) is defined as the filter system fluid 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 to 8 ft/min (3 to 4 cm/s) to

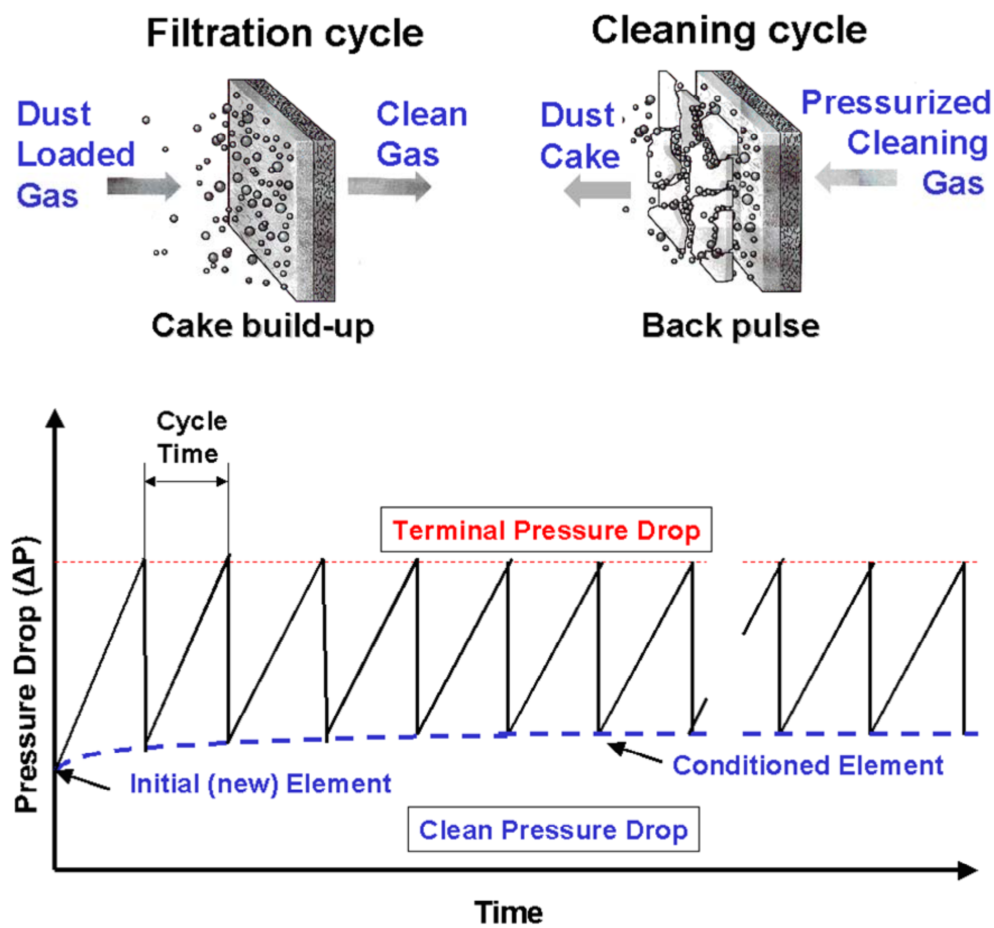

Figure 4. Particle loading during surface filtration and subsequent cake release during pulse blowback and typical pressure drop profiles during cake formation and periodic removal by pulse blowback cleaning. Similar cycles are for both gas and liquid systems.

ensure adequate cake removal during pulse blowback cleaning cycles. In liquid service the optimal flux rates are typically 10 to 20 $l/min/m^2$ (0.3 to 0.5 gpm/ft^2).

FILTER SYSTEM DESIGN AND OPERATION

The proper selection of filter media with appropriate pore size, strength and corrosion resistance enables long-term operating life. The filter design for liquid/solids and gas/solid separation is selected which produces the required filtrate, minimizes backwash or blowdown and maximizes throughput.

Liquid Service

Four types of filter configurations, is illustrated in Figure 5, are commonly used in liquid service for process applications. These are described as follows:

1.) Outside-in filtration: traditional liquid/solids barrier separation occurs on the outer perimeter of a closed-end tubular filter element (LSP). A gas assisted pneumatic hydro-pulse backwash has proven to be the most effective cleaning method for sintered porous metal filters.

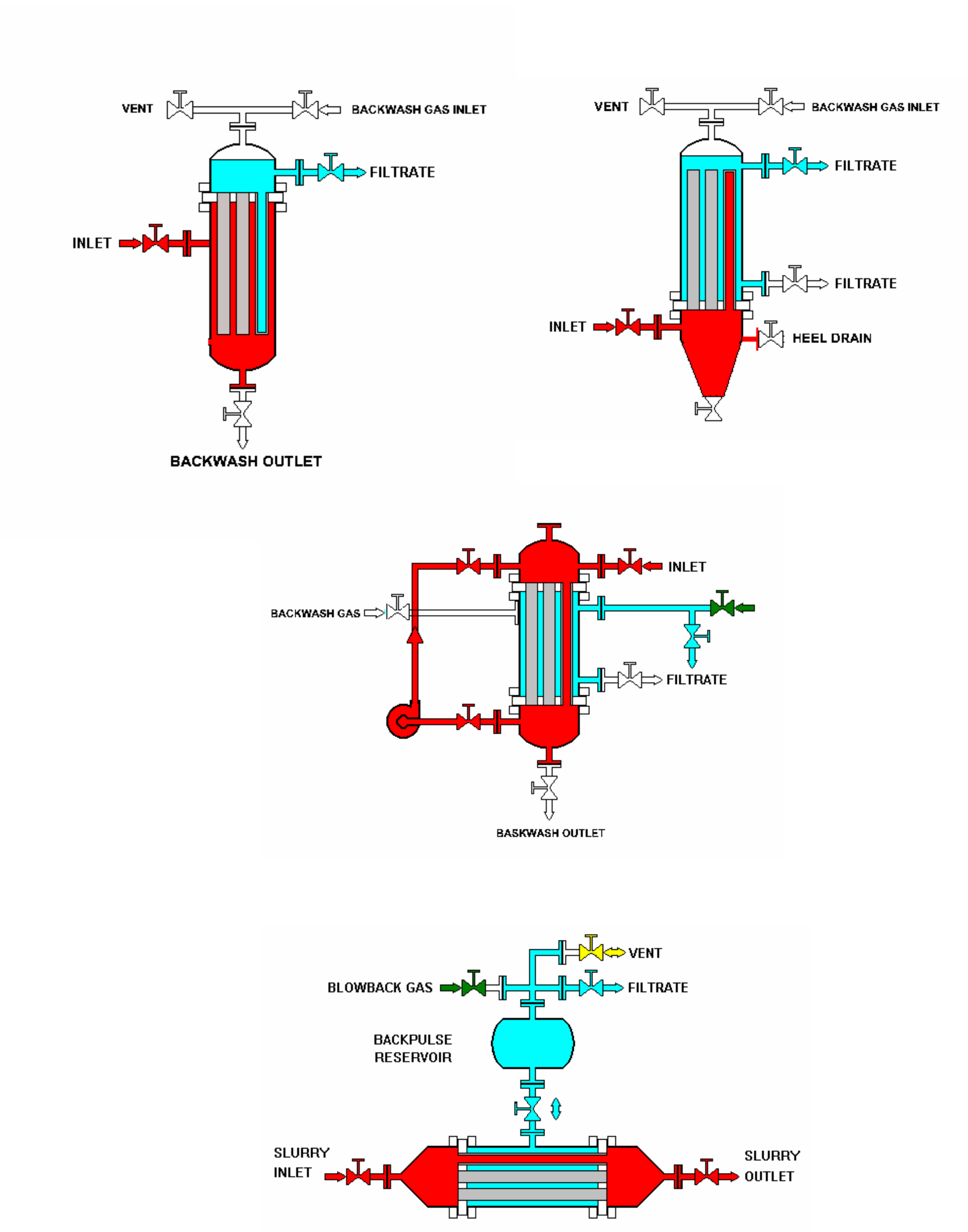

Figure 5. Schematic diagrams of filter configurations for liquid process system applications: Outside- in filtration - LSP (top left), inside-out filtration - LSI (top right), multi-mode flow - LSM (middle) and cross-flow - LSX (bottom).

2.) Inside-out filtration: solid/liquid barrier separation occurs on the inside of a closed-end tubular filter element (LSI). LSI backwash modes include: a.) Full shell slurry backwash, b.) Empty shell slurry backwash, c.) Empty shell and empty element wet cake backwash and d.) Empty housing wet cake discharge.
3.) Inside-out Multimode filtration: liquid/solids (barrier or cross-flow) separation occurs on the inside of open-ended tubular filter element (LSM and LSX). Elements are sealed within two tube sheets, as shown in Figure 2. Filtration with multi-option top or bottom feed inlet. The LSM filter, with a feed re-circulation feature, has proven itself in several continuous loop reactor systems. The downward velocity controls the cake thickness of the catalyst with the lower the velocity, the thicker the resulting cake. Filter backwash modes are similar to LSI backwash modes and also includes a bump-and-settle type backwash that allows concentration of solids without draining the filter element or housing. Continuous loop reactor systems may not require backwashing.

Porous metal cross-flow (LSX) filters are used primarily to concentrate or clarify liquid suspensions of particulate solids. An LSX filter system can be operated in once through or recirculation mode. Continuous liquid sampling of streams with suspended solids is the most common use of once through systems. Single pass concentrating of solid suspensions requires multiple filter modules in series and is economically attractive with high flux processes. The majority of LSX filter applications are set up in a recirculation loop with a holding tank. The pump head supplies the pressure for the solid/liquid separation. Axial flow rate is adjusted with a backpressure control valve at the slurry outlet of the filter. Filtrate flux and transmembrane pressure are controlled with the filtrate flow valve to stabilize the dynamic membrane. The filter is backpulsed either at preset intervals or when low filtrate flow is indicated.

Feed slurry is pumped in axial flow through the element, while clear filtrate is driven by transmembrane pressure radially outward into the shell, as shown in Figures 3 and 5. LSX filters typically operate at axial velocities of 1 to 6 m/s (3 to 20 ft/sec) to keep solids in suspension and to re-entrain accumulating solids from the filter surface. The axial fluid flow generates tangential shear forces that constantly sweep the media surface. Limiting factors for axial flow are pumping costs and particle attrition. Typical flux, i.e. filtrate flow rate per unit area, tends to range from 4 to 10 $l/min/m^3$ (0.1 to 0.25 gpm/ft^2) at transmembrane pressures of 70 to 410 kPa (10 to 60 psid). However, some applications have low fluxes of 1, while others can operate at high rates of 60 $l/min/m^3$ (1.5 gpm/ft^2). Testing is recommended to optimize flux for a given solid-liquid system as a function of media, axial velocity and transmembrane pressure.

Scaleability in both liquid and gas filtration systems allow for accommodating high flow rates and increased solids capacity. Filtration units are suitable for batch or continuous processes. Single housing filter systems are recommended where flow rates allow and flow can be stopped for a few minutes prior to backwash, or if off line periods can be tolerated for maintenance. Two filter dual systems are recommended where continuous flow is required and short periods of off line can be tolerated for maintenance. Three filter systems are recommended for continuous operation even during maintenance periods.

Gas Service

Gas/solids filtration systems 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 as to what type of filter to employ depends on individual process parameters and 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

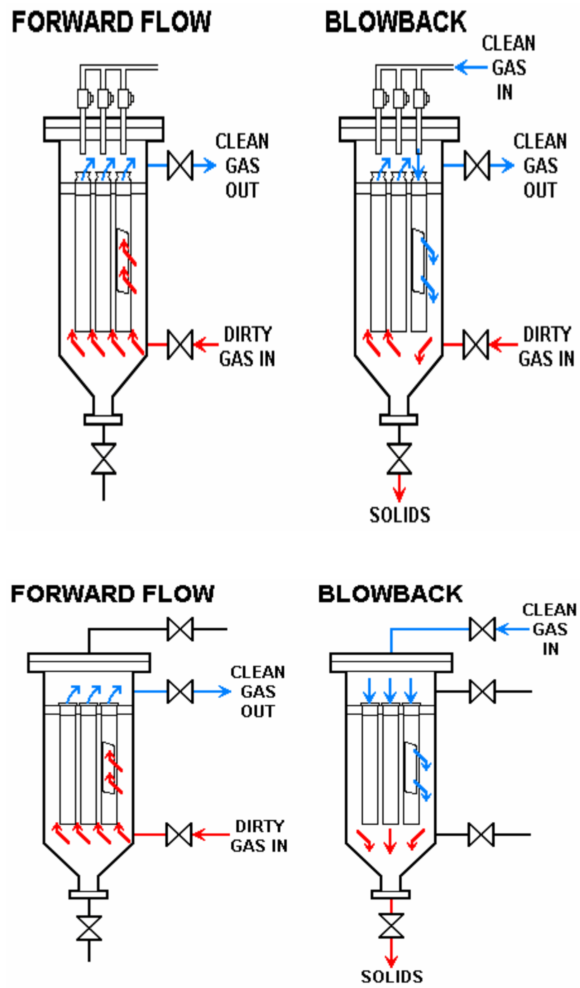

Figure 6. Schematic diagram of GSP filter (top) showing gas flow during filtration (forward) flow and blowback (reverse) flow and GSV filter showing gas flow during filtration (forward) flow and pulse blowback (reverse) flow on a segment of filter elements.

on time lapse or differential pressure. Figure 4 illustrates sequential series of filter cleaning cycles during the initial and subsequent equilibrium portion of the filter operating life.

For processes gas streams requiring on-line blowback cleaning, Mott offers two different continuous process filter designs, the HyPulse® GSP (Gas-Solids-Plenum) and the HyPulse® GSV (Gas-Solids-Venturi). Both types of filter systems are illustrated in Figure 6. These 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 cartridges 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 cartridges, where solids are retained. The “cleaned” gas passes through the cartridges 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 6. 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 continues to operate in the filtration mode, thereby ensuring continuous flow of the process gas stream.

The selection of the appropriate media and system operating conditions for both liquid and gas filtration systems is usually established through extended testing to obtain performance efficiency and 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. Equilibrium recovery differential pressure, as graphically shown in Figure 3, typically occur within 25 blowback cycles, but are dependent on media selection, face velocity and particle characteristics (namely size, shape and composition).

APPLICATION CASE STUDIES

Four broad applications for sintered porous media usage in the nuclear and radioactive waste processing are presented in this section. These were chosen to illustrate typical uses for sintered metal filters in both gas and liquid applications. The first case describes liquid cross-flow filter systems designed and employed in a number of nuclear and radioactive waste processing applications. The second case describes blowback gas filter systems designed and employed for a number of nuclear and radioactive waste processing applications. The third case is an all-metal HEPA filter developed under DOE funding as an alternative to traditional HEPA filters fabricated with conventional glass fibers. A specific application for the filter system is the potential for replacement of glass fiber HEPA filters currently used on High Level Waste (HLW) tank ventilation systems at various nuclear sites in the US. The fourth case describes in-line gas filters utilized on smaller flow compressed gas lines, vent lines and gas sampling lines.

The versatility of sintered metal media as a filter media is demonstrated by its applicability in a wide range of filtration technologies and applications in both gas and liquid applications in nuclear and radioactive waste processing applications. These filter examples employ a wide range of filtration technology, e.g., large scale cross-flow filtration system for the concentrating of particulate matter in liquid streams, in-situ back-pulse cleanable gas filtration system primarily utilizing surface particle filtration, and smaller in-line gas filter utilizing particle removal via depth filtration.

Case Study 1: Cross-flow Liquid Filter Applications

For more than 2 decades cross-flow filter system using metal powder filter media have been used in various size systems for nuclear fuels processing and the removal or concentrating of radioactive and stimulate particulate matter. Much of this work has been associated with DOE contracts at the Hanford and Savannah River Sites.

Example 1:
A manufacturer of nuclear fuels pre-concentrates uranium oxide fines suspended in ammonium diuranate (ADU) solution with LSX cross-flow filter for subsequent centrifuge separation. The fines occur at this processing step at very low concentrations where centrifugation would be inefficient. The ADU solution that is stored in slab tanks is concentrated batchwise to 4 weight % total suspended solids. Remote operation and high efficiency fines recovery returned the cost of the LSX filter system to the customer in a very short time.

Example 2:
A nuclear waste processor removes suspended solids from radioactive solutions that are fed to a cesium adsorption column with four (4) in-series operating LSX cross-flow filters. Objective is protection of the packed bed adsorber against plugging and fouling while providing continuous flow. The concentrate from the LSX filters is returned to the rad waste storage tanks on-site and mixed with fresh wash solutions. All welded design was required to prevent media bypass by radiation degraded seals.

Example 3:
Another radioactive liquid waste processing example uses a cross-flow filter in a salt waste processing facility, at the Salt Waste Processing Facility (SWPF) at the Savannah River Site, designed to treat caustic salt waste containing radioactive constituents. The objective is to concentrate the solids, using a batch process, from 0.07 weight % to 7 weight % solids, which will require multiple recirculation of the liquid slurry through the cross-flow filter. The operating conditions were at a temperature of 20 to 40^{o} C. The porous metal elements were 12.7 mm outside diameter by 3.0 m long with 0.90 mm media wall thickness. The material was 316L stainless steel. The cross-flow filter system contained 220 elements to handle a filtrate flow rate of 48 L/min.

Case Study 2: Gas Blowback Filters

The following examples illustrate the use of both metal powder and metal filter media in blowback gas filters systems.

Example 1:
A process for producing uranium dioxide utilizes a HyPulse® gas/solids venturi pulse (GSV) blowback sintered metal filters for the recovery of uranium oxide fines from a process kiln. The sintered metal filters must withstand kiln off-gas stream temperatures of 300° F (150° C) and be chemically resistant to the gaseous components. The primary risks associated with this conversion are chemical and radiological. The conversion process uses strong acids and alkalis that involve turning uranium oxide into soluble forms, leading to possible inhalation of uranium. In addition, the corrosive chemicals can cause fire or explosion hazards. Successful field applications and laboratory support provided performance data that resulted in the first commercial filter installation put in service in 1984 for a uranium conversion plant. The completely enclosed GSV filter operates with 99.999% efficiency with a very low solids load to the filter and infrequent backpulsing. Key operating parameters include controlled approach velocity to the filter, high efficiency, and use of venturi for blowback for continuous operation.

Example 2:
Several applications for radioactive waste processing utilize a gas/solids venturi pulse blowback sintered metal filters. The following are examples of typical applications for process gas filters on radioactive off-gas process streams:

System operating conditions were 350^{o} C, gas flow rate of 30 m^3/hr (17.5 ACFM), gas pressures at atmospheric to sub-atmospheric conditions, UO_3 particles primarily in the 1 to 50 μm size range. Filter media is 316L stainless steel.

System operating conditions were 600-700^{o} C, gas flow rate of 9100 m^3/hr (5360 ACFM), gas pressures of 13-55 kPa (2 to 8 psig). Filter media is Inconel 625.

System operating conditions were 120-250^{o} C, gas flow rate of 13,000 m^3/hr (7650 ACFM), and gas pressures near atmospheric. Filter media is Inconel 601.

System operating conditions were 16-200^{o} C, gas flow rate of 510 m^3/hr (300 ACFM), gas pressures near atmospheric. Filter media is 316L stainless steel.

Case Study 3: Gas Blowback Filters

An all-metal HEPA filter has been developed as an alternative to traditional HEPA filters fabricated with conventional glass fibers. This metal filter was developed utilizing sintered porous metal media fabricated from nickel metal powder. One specific application is the potential for replacement of glass fiber HEPA filters currently

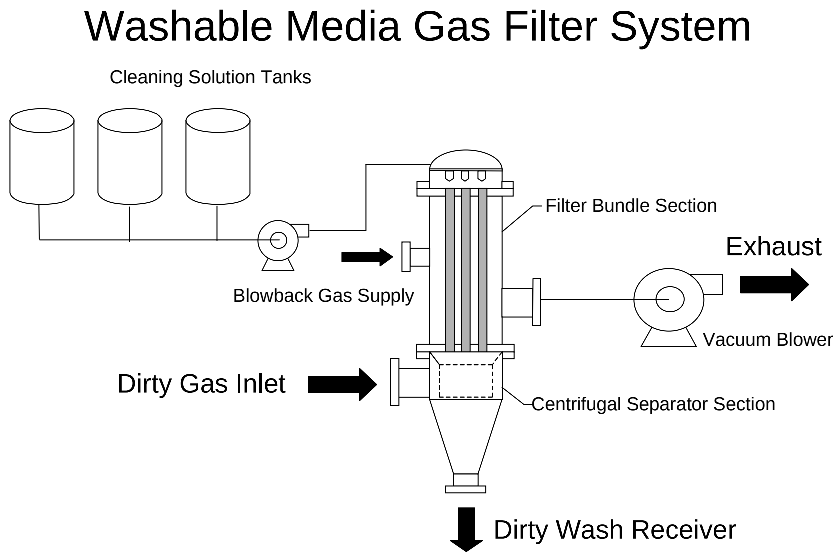

Figure 7. Schematic diagram of regenerable HEPA filter system.

used in High Level Waste (HLW) tank ventilation systems at various DOE nuclear waste storage sites in the US. The glass filters are subject to a shortened life span due to their deterioration from moisture condensation and therefore must be disposed of when spent. The disposal process is costly, creates solid waste, and is hazardous since the site personnel are at risk of exposure to radiation. Savannah River Technology Center (SRTC) began investigating the use of porous metal as a HEPA filter material in 1996. This effort subsequently lead to a DOE funded development.

HEPA filters are employed in the inlet and outlet ventilation systems used with HLW liquid radioactive waste storage tanks found at DOE nuclear processing sites. There are about 300 underground tanks, each approximately 3800 m^3 (1 million gallons) in size, and equipped with a ventilation system designed to maintain the gas within the tank at a slight negative pressure of approximately 250 Pa (1 inch water), to prevent leakage of radioactive contamination and avoid hydrogen buildup in the tank head space. The ventilation air, which is continuously passing through the tank headspace at a flow rate of approximately 850 m^3/hr (500 CFM), is intended to entrain any hydrogen before it accumulates to dangerous levels.

This project, under DOE funding, developed novel technology to replace the glass fiber HEPA filters with a regenerable and more durable filter. A cylindrical nickel sintered porous metal filter element was developed for this application. The nickel filter is cleaned by washing the dirty surface with an in situ spray wash. Temperature, humidity, moisture, and other factors associated with the HLW tanks do not affect the metallic media; thereby resulting in an anticipated long service life of at least 15 years. The filter has multiple tubular elements welded to two tube sheets for reliable sealing and integrity. All materials of construction are stainless steel or nickel.

The nickel filters have achieved removal efficiencies, of a 0.3 micrometer di-octyl phthalate (DOP) aerosol, ranging from 99.975 to 99.999% when tested according to the standard ASTM DOP test for HEPA filters. One of the elements that achieved a 99.999% removal efficiency was subsequently plugged and cleaned in-situ 7 times with simulated sludge/salt particles and atmospheric dust. After these rigorous tests, subsequent DOP testing showed the filter still achieved 99.999% removal efficiency.

The media design flow specification is 9.1 $m^3/min/m^2$ (30 CFM/ft^2) at a maximum differential pressure of 0.24 bar (3.5 psi). All nickel metal filters have tested at or below that design pressure drop. While this is a higher pressure drop than traditional glass fiber HEPA filters, this system pressure is accommodated by a vacuum pump of appropriate capacity.

The full-scale design of the regenerable HEPA filter system (RHFS) incorporates several important features in its design and operation. The filter element bundle is an all welded assembly, which can be removed and replaced as a unit if the elements ever need replacement. Each element has a spray nozzle mounted above it for cleaning; it could also be cleaned by a soak and backwash technique. The inlet nozzle incorporates a cyclonic separator to initially remove large suspended material and droplets. Tests indicate a significant reduction in the dirt load passing to the filter elements, which would extend the operating time between cleanings. A high capacity blower was selected to overcome the higher pressure drop of the metallic elements. The blower is capable of operating the system at higher pressure drops than those currently used with the glass fiber HEPA filters. This additional capacity further increases the operating duration of the filter. The RHFS, at each stage of the development process, has met the design requirements for a suitable replacement system for the glass fiber HEPA filters, thereby enabling great cost savings. It remains to test a full-scale operating system on an actual high level waste tank to fully demonstrate the performance and anticipated cost savings of the RHFS. While the nickel HEPA media and filter were developed for the HLT application, they have applicability as a replacement media for glass fiber HEPA media in numerous demanding applications requiring not only the efficiency requirements of a HEPA filter, but the attributes of sintered metal.

Case Study 4: In-line Gas Filters

In-line gas filters are utilized in compressed gas lines, utility line, vent lines and gas sampling lines typically found in laboratory and small pilot small test systems using radioactive materials. Particle filtration requirements are HEPA grade or higher. In-line filters, originally designed for the semiconductor industry where the requirements for particle removal efficiencies is > 99.9999999%, are ideal for nuclear applications since the filters readily meet the efficiency and process requirements. These filters employ depth filtration media, made from either metal powder or metal fibers, that have high particle loading capability and are not meant to be cleaned and reused. These in-line filters are designed for a wide range of operating conditions. The filters can operate at pressures as high as 250 bar (3750 psig), temperature up to 450^o C and flow rates from 10 to 1500 SLM. Filters are available with media fabricated from 316L stainless steel, nickel and Hastelloy C-22 alloy materials; thus, these filters are suitable for a wide range of process gases and operating conditions. The filters range in length from 8.4 to 28.5 cm and diameters from19 to 76 cm and come in an array of standard end connections.

These in-line filters remove contaminates in the supply gas stream, remove process particulate matter caused by any back-streaming of process gases and prevent particle contaminates from entering process instrumentation and sampling systems. Depending on the process, pressures in these gas lines typically range from partial vacuum to atmospheric to as much as 700 kPa or higher, with temperatures typical ranging from ambient to 200^o C. Given the small scale of the test system, gas flow rates are typically low and range from 1 to 1500 SLM range depending on the scale of the test system.

SUMMARY

Sintered metal media provide an effective means of filtering fluids to remove radioactive particulate matter whether they are contaminants or product. These media are ideally suited for more demanding applications involving high temperatures, high pressures, and/or corrosive fluids, i.e., either gases or liquids. The versatility of sintered metal media is demonstrated by its applicability in a wide range of filtration technologies and applications. Filtration examples, as presented in this paper, include cross-flow filtration systems for the concentrating of radioactive liquid waste, in-situ back-pulse cleanable gas filtration system primarily utilizing surface particle filtration, and smaller in-line gas filters utilizing particle removal via depth filtration.

Sintered metal filters should be operated within the media design parameters so as not to limit filter life due to premature blinding of the media, fluctuations in process operating conditions, or media corrosion. The benefits of using a sintered metal filter element include their long life, low maintenance, and predictable behavior. Bench-scale and pilot-scale system coupled with subsequent successful full-scale filter installations have demonstrated that filter element designs have been successfully tested and evaluated, resulting in confidence that the filter design meets the performance criteria established. The design is rugged, reliable, and consistent with mechanical designs typically used in nuclear facilities.