Advanced multipollutant control with lightweight ceramic filters

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Advanced, low-density ceramic filter systems are now capable of removing PM, SO_2, HCl, dioxins, and mercury in a single system. Particulate matter (PM) is removed to ultralow levels (<2 mg/ Nm^3, 0.001 grains/dscf); other pollutants are removable at percentages greater than 90 percent. These ceramic filters have been used for the last decade by the U.S. military at munitions-destruction facilities and at hundreds of sites worldwide. Complete systems using this filter technology are now widely available to industry.

Advanced, low-density ceramic filter systems are now capable of removing particulate matter (PM), SO_2, HCl, dioxins, and even mercury in a single system. Particulate matter is removed to ultralow levels (<2 mg/Nm^3, 0.001 grains/dscf), while other pollutants can be removed at percentages greater than 90 percent.

Ceramic filters

Ceramic filters, often called *candles* because of their solid tube shape, have been used in pollution control for decades.

The original high-density candle filters were manufactured from refractory grains such as alumina or silicon carbide and pressed into the basic candle shape—a tube with a closed, rounded bottom and a flange at the top. The newer, low-density filters start as a slurry of refractory fibers and are vacuum-formed into shape. The contrast between types of ceramic filter elements is shown in Table 1.

Table I

Contrast between types of ceramic filter elements

Characteristics of high- and low-density ceramic-filter elements

	High density	Low density
Structure	Granular	Fibrous
Density	High	Low
Filter drag	High	Low
Porosity, % (Inverse of resistance to flow)	0.3 - 0.4	0.8 - 0.9
Tensile strength	High	Low
Fracture mechanism	Brittle	Ductile
Thermal shock resistance	Low	High
Cost	High	Low

There are hundreds of applications of these types of filters in Europe, Japan, and Australia. The filter elements are made in various lengths, but it is the latest generation of 3-meter (10-ft)-long filters that make industrial applications practical. The filters are placed in a housing module similar to a baghouse (Fig. 1).

Figure 1

Many filters placed in a single module. Multiple modules are operated in parallel to handle large volumetric flow rates.

These lightweight ceramic filters solve many of the problems associated with "candle filters." While effective, the latter were brittle and prone to cracking and breakage from thermal shock and vibration.

As shown in Figure 2, the fibers maintain a very high, open area for low resistance to airflow, minimizing pressure drop and the number of elements required for a given flow rate. This high, open area also makes elements easy to clean, using the standard reverse pulse-jet techniques associated with fabric filter baghouses (see Table 2).

Figure 2

Micrograph of filter elements composition

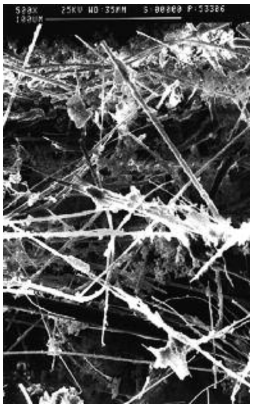


Table 2

Characteristics of low-density fibrous ceramic filter elements

Form	Monolithic rigid tube
Composition	Refractory fibers plus organic and inorganic binding agents
Porosity	About 80-90%
Density	About 0.3 - 0.4 g/cc
Support	Self-supporting from integral flange
Geometry	Outer diameter up to 150 mm (6 in.) Length up to 3 m (10 ft.)

Operating characteristics

Ceramic filters must operate above the condensation temperature of the pollutants, or the particulate will not release from the filter surface unless the temperature is raised and the material volatilizes, thus cleaning the filter. Table 3 shows typical operating temperatures for the ceramic filters. The filters are chemically inert and highly corrosion resistant, as would be expected from ceramic materials. Filters are manufactured in two varieties: standard and catalyst. The catalyst filter is identical to the standard filter, except that it has nanobits of SCR catalyst embedded in the filter walls for NO_x removal and dioxin destruction.

Table 3

Typical operating temperatures for the ceramic filters

Temperature range of operation		
Filter name	**Pollutants removed**	**Temperature range**
Standard	Particulate matter (PM)	300˚F to 1650˚F
Standard	PM + SO_2, HCl, or other acid gases	300˚F to 1200˚F
Catalyst	PM + NO_x - Dioxins also destroyed	350˚F to 700˚F
Catalyst	PM + NO_x (+Dioxins) + SO_2, acid gases	350˚F to 700˚F

Pollutant control

The typical level of PM at the outlet of the ceramic filters is less than 0.001 grains/dscf (2.0 mg/Nm^3). This is true even with very heavy inlet loadings of several thousand milligrams per cubic meter. PM is captured on the face of the filter and does not penetrate deeply into the filter body, thus allowing for repetitive and complete cleaning. This is an engineered feature of the filter surface. The filter does not "blind" or "fill up" with particulate as ordinary filters will. As a result, over the life of the filter, there is very little increase in pressure drop, which averages about 6 in. water gauge, depending on the application. Pressure drop can be lowered by adding more filter elements or footprint, and capital cost can be reduced by decreasing the filter count at the expense of fan horsepower.

The filter construction also means that standard reverse pulse jet methods, which send a pulse of compressed air down the center of the tube, can thoroughly clean the accumulated PM from the outer surface of the tube. Filters are cleaned on-line, with no need to isolate each housing module.

Typical filter life is 5 to 10 years. The filters are effective across the range of particle sizes, but are most often used when there is a large fraction of PM2.5 and submicron particulate. (See Table 4.)

SO_2 and acid gas control

Both standard and catalyst filter systems feature an option for dry injection of calcium or sodium-based

Table 4

Ceramic filters are most effective where there is a large fraction of PM 2.5 and submicron particulate

Efficiency of fibrous ceramics filter elements in various applications

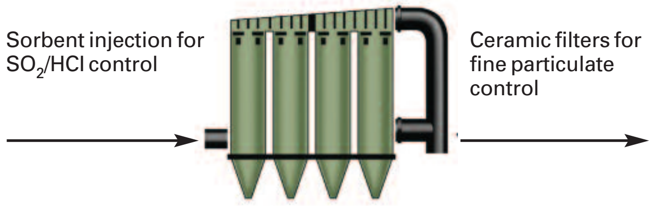
Process	Particle size	Inlet PM loading		Outlet PM loading		Inferred efficiency
	d_{50}[1], µm	mg/Nm³	gr/dscf	mg/Nm³	gr/dscf	%
Aluminum powder production	<50	550	0.24	<1	<0.0004	99.9
Nickel refining	<10	11,800	5.16	<1	<0.0004	>99.8
Smokeless fuel production	4.8	1000	0.44	1.5	0.0007	99.9
Zirconia production	1.2	8000	3.5	0.8	0.0003	99.85
Secondary aluminum	<1.0	870	0.38	0.5	0.0002	>99.99

[1] Diameter of median size particle

sorbents for the capture of acid gases (see Fig. 3). Sodium bicarbonate (baking soda) and trona are typical sodium-based sorbents. Trona is the naturally occurring ore from which soda ash and sodium bicarbonate are produced and is mined exclusively in Wyoming. When properly milled, Trona can be used as a dry sorbent, with no other processing required, and it is available throughout North America.

Figure 3

Standard filter system for control of particulate, SO_2, HCl, and other gases



Injected in the duct, upstream of the filter modules, the additional sorbent particulate is easily captured along with its pollutant gas. The sorbent must be milled to small particle size to maximize surface area for maximum reactivity. The reaction occurs within the duct prior to the filter and on the filter cake that builds up on the surface of the filters. The chemical reaction of the sorbent with the acid gas creates a solid particle that is also captured on the filters alongside the unreacted sorbent and other particulate in the pollutant stream.

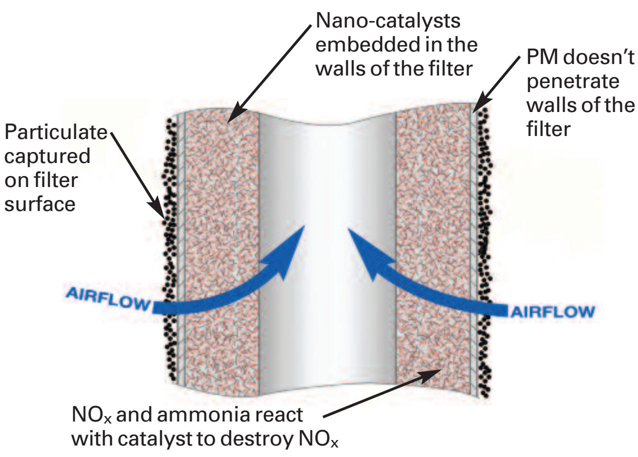
With sorbent injection, SO_2 removal is typically 90 percent or higher, with removal efficiencies as high as 97 percent. HCl removal is typically 95 percent, and often as high as 99 percent. The temperature range for effective removal is 300°F to 1200°F.

Catalyst filters: High NO_x control, effective on dioxin

For NO_x or dioxin removal, catalyst filter elements are available with nanobits of SCR catalyst embedded in the walls. The filter walls that contain the catalyst are about ¾ inch (20 mm), as represented in Figure 4. Urea or ammonia is injected upstream of the filters. The catalyst embedded in the filters destroys the NO_x with up to 95 percent removal efficiency. Note the lower operating temperature required for high NO_x destruction: 350°F to 400°F, compared to 600°F to 650°F for conventional SCR.

Figure 4

Ceramic fiber filter tube with embedded nano-catalysts



Besides the need for high temperature, a common problem with traditional SCR is that the catalyst becomes poisoned and ineffective, necessitating early replacement. Typical poisons are ordinary PM, metals, and HCl. The catalyst used in the filters has a proprietary formulation with a fraction of the conversion rate of SO_2 to SO_3 of traditional SCR catalysts. The catalyst is not poisoned by SO_2.

The increased reactivity at lower temperatures shown by the catalyst filters results, in part, from their micronized form. The diffusion restriction is very low, and, most significantly, the catalyst is almost completely protected from blinding by particulate matter, since it is inside the filter itself (see Fig. 5). With the catalyst filter PM removal, sorbent injection for SO_2 (and other acid gases) and catalytic reduction for can be incorporated in a single system.

Figure 5

Micrograph of nano-catalysts embedded in ceramic-coated fibers.

Dioxin removal is also exceptionally high, generally 97 to 99 percent. The dioxins are broken down by the catalyst. ***Note:*** Operating temperature for high NO_x removal must be kept at 350°F to 700°F to achieve NO_x removal up to 95 percent.

Multi-pollutant capability creates a powerful, all-in-one-solution that is superior, in both performance and economics, to having a separate pollution control device for each pollutant. Particularly with NO_x, in many circumstances there is insufficient temperature to operate traditional SCR. Low-temperature NO_x removal capability opens a new direction in NO_x control for operators of a wide range of boilers, and other industrial processes requiring NO_x control (see Fig. 6).

Mercury control

The ceramic filter systems are compatible with standard mercury removal techniques. Control of mercury is notoriously difficult: each instance is analyzed individually and customized solutions are engineered. A few general observations can be offered, however.

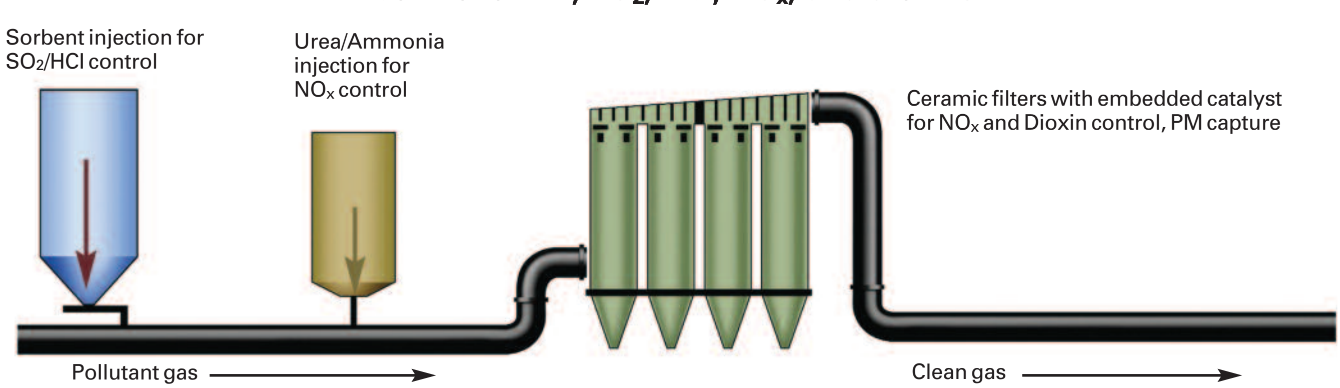
The filters can handle high particulate loads while maintaining exceptionally low outlet levels. Just as the addition of dry sorbents for the removal of acid gases is effective, so is the addition of powdered activated carbon (PAC) in the standard and catalyst systems. In general, regular PAC becomes less effective with temperature, topping out around 400°F. Under the right conditions, 70 to 80 percent control can be achieved. The chemical composition of the pollutant gas plays a major role; hence, the difficulty of blanket statements. At higher temperatures, brominated PAC is required. According to the manufacturers of brominated products, temperatures of 500°F to 800°F are acceptable. Significant levels of mercury capture have also been achieved in applications with injected powdered trona.

When would ceramic filters be the control technology of choice?

For particulate removal only, the standard lightweight ceramic filter can operate at temperatures up

Figure 6

Control of PM, SO_2, HCl, NO_x, and dioxins

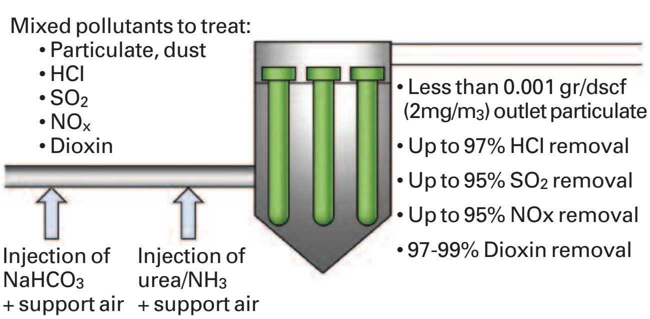


to 1650°F. This is far above the temperature range of fabric filters. For applications with temperatures below 400°F that do not have temperature excursions or hot materials that pose a fire hazard to the bags, the more advanced fabric filters are less costly than ceramic filters. In borderline cases, the ceramic filters have a much longer element life and often prove to be the most cost-effective solution. In applications that require NO_x removal, since fabric filters cannot control NO_x, the catalyst filters are preferable.

Ceramic filters also replace electrostatic precipitators (ESPs) when there is a need for very low PM levels, especially on applications with significant portions of PM2.5 and submicron particulate. The filters can handle much higher inlet loadings, are not subject to the selective removal constraints of ESPs, have lower maintenance requirements and fewer corrosion issues, and are roughly equivalent (or lower) in energy usage when regulations are strict. Because of the formation of filter cake on the filter surface (which provides more exposure to the acid gases), less sorbent is used and higher removal efficiency is achieved on acid gas removal. ESPs do not remove NO_x or dioxins, of course, so a second device (perhaps with temperature addition) would be needed. In contrast, the catalyst filter can handle all the pollutants in a single device at lower temperatures (see Fig. 7).

Figure 7

Catalytic element performance



The catalyst handles all the pollutants in a single device at lower temperatures.

Lightweight ceramic filters have been used for the last 10 years by the U.S. military at munitions-destruction facilities in Indiana, Utah, and Oklahoma. There are hundreds of operating filter applications throughout the world. Modular design of the housing units allows filters to be configured to handle even large gas-flow volumes. These developments offer a new approach that solves many of the difficult situations faced by owners, operators, and consultants in meeting the increasingly strict regulations regarding air pollution control. **APC**

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