Catalyst-embedded ceramic filters offer a new technological capability of removing NO\textsubscript{X} at lower temperatures, while simultaneously removing PM, SO\textsubscript{X} and HCl. The technology also removes organic hazardous air pollutants (O-HAPS) THC, dioxins and mercury, all in a single compact system.

Applications for the technology include: the Cement NESHAP; Boiler MACT for coal; incinerator CISWI MACT; Hazardous Waste MACT; regulations on glass furnaces; ceramics manufacturing, including fracking proppants, kilns of all varieties; and thermal oxidizer clean up.

As regulations proliferate and become more stringent, the filters offer a powerful straightforward approach compared to a long train of stand-alone equipment. The advantages are not in performance alone, but in capital cost and operating expense.

Typically, PM is removed to ultralow levels (less than 2 mg per Nm\textsuperscript{3}, 0.001 grains per dscf), while other pollutants can be eliminated at levels greater than 90 percent.

**European Successes Jump the Pond**

Low-density ceramic filters, often called “candles” because of their solid tube shape, have been used in pollution control to remove PM and acid gases since the late 1980s. The additional capability to reduce NO\textsubscript{X}, dioxins and O-HAP THC became available in 2005 with the innovation of embedding filter walls with micronized catalyst.

With the success of the first systems in Europe, Japan and Australia, the United States now has regulations that require use of this advanced technology. There has been a sharp up-swing of projects as the capability of these systems has become more widely known.
Filter Types: Standard and Catalyst
Two types of filters are currently available from Tri-Mer Corporation. Standard UltraTemp filters remove PM or PM plus acid gases and metals, including mercury; UltraCat catalyst filters remove those pollutants while also destroying O-HAPS, dioxins and NOX.

Catalyst filters feature the same fibrous construction as the standard version, but have nanobits of catalyst embedded throughout the filter walls. Distribution across the entire wall thickness, as opposed to just having a catalyst layer, creates a very large catalytic surface area accessible from all directions. The walls that contain the catalyst are about 3/4 inches thick. Ammonia is injected upstream of the filters and reacts with the NOX at the surface of the micronized catalyst to destroy the compound. (Figure 1)

An analysis comparing the effectiveness of this nanocatalyst with that of conventional catalysts was summarized in a paper by Schoubye and Jensen of Haldor Topsoe A/S:

“The catalyst particles are micro-porous, and, due to their small size, they catalyze the gas-phase reactions without diffusion restriction (i.e., almost 100 percent utilization of the catalyst’s intrinsic activity), as opposed to usual pellet or monolithic catalysts. In industrial plants, the conventional catalyst types typically operate with 5-15 percent catalyst effectiveness in the SCR of NOX by NH3 and with even lower catalyst utilization in dioxin destruction.”

Another remarkable feature is low temperature activation. Substantial NOX removal is initiated as low as 350°F, with over 90 percent removal as the temperature approaches 450°F.

System Design Criteria
Filter elements have been manufactured in numerous lengths, and the latest generation of 10-foot filters makes even very large-scale applications practical.

Filters are placed in a housing module configured identically to a reverse pulse jet baghouse. The polluted airstream enters the bottom of the housing. Process PM and reacted acid gas sorbent PM are captured on the filter surfaces, while the NOX and the injected aqua ammonia are transformed to harmless nitrogen gas and water vapor as the airstream passes through the filters. O-HAPS (Cement NESHAP) and dioxins (CISWI and HW MACTS) are broken down without the addition of ammonia. Cleaned air passes up through the center of the filter tubes and out of the space above. (Figures 1, 2 and 3) Single housings with multiple filters are manufac-
tured in custom sizes to accommodate individual project airflows. Multiple housings are operated in parallel for correspondingly larger flow volumes.

Notably, the modular design of the housing units allows filters to be configured for even the largest gas flow volumes. The modular nature of the system also provides redundancy so that a single module can be taken offline while the other modules receive the flow. The system temporarily operates at a slightly higher pressure drop, which the fan design takes into account.

Placing multiple plenums in parallel provides built-in redundancy to maximize uptime. The system is designed so that if one plenum needs to be taken offline for service, others treat the entire flow at a temporarily higher pressure with no change in performance. Thus, the pollution control system does not compromise the uptime of the facility.

Particulate is captured on the face of the filter and does not penetrate deeply into the filter body, thus facilitating repetitive, complete cleaning. At start-up, the pressure drop is 4 or 5 inches w.g. Over the life of the filter, the pressure undergoes a very gradual increase, which averages 3 to 5 percent per year.

After many years of continuous operation, pressure drop will have increased several inches and companies will elect to replace the filters when it makes sense in terms of energy cost, rather than because of decline in performance. Even if the filters have the embedded catalyst, the need for replacement is usually due to an increase in pressure drop, rather than any significant change in catalyst effectiveness. In general, filter life is five to 10 years on a range of applications.

Conventional reverse pulse jet methods are used for filter cleaning. Compressed air is pulsed down the center of the tubes to clean the accumulated PM from the outer surfaces. PM falls to the bottom of the hopper and is removed. Filters are cleaned on-line, staggered within each housing module to prevent dust re-entrainment, but with no need to isolate individual modules. The amount of compressed air required is minimal.

**Standard Filter: Typical Pollutant Control**

Particulate: The typical level of particulate material at the outlet of the ceramic filters is less than 0.001 grains/dscf (2 mg/Nm³) based on a spectrum of different applications. With the exception of mercury, heavy metals are captured at the same rates as other particulate (greater than 99 percent). There is no selective lack of capture as is sometimes reported in other devices.

SO₂, SO₃, HCl, other acid gases: Ceramic filters, like fabric filter baghouses, can use the dry injection of calcium or sodium-based sorbents for the removal of acid gases. Hydrated lime is the typical calcium-based sorbent. Sodium bicarbonate (baking soda) and trona are typical sodium-based sorbents.

Injected in the duct upstream of the filter modules, the additional sorbent particulate is easily captured along with its pollutant gas. The chemical reaction of the sorbent with the acid gas creates a solid particle that is captured on the filters alongside the unreacted sorbent and process particulate. The reaction occurs within the duct prior to the filter and on the cake that accumulates on the filter surface. The existence of a sorbent cake on the filters increases the exposure of the SO₂ or HCl, and increases the removal rate. For a given removal efficiency, filters require significantly less sorbent than electrostatic precipitators (ESPs), which can result in a large savings in sorbent costs. This is true for calcium and sodium sorbents.
With sorbent injection, SO\textsubscript{2} removal is in the range of 90 percent for most applications. Lesser permit requirements equate to less sorbent consumption and associated cost. SO\textsubscript{3} and HCl are preferentially removed at even higher rates than SO\textsubscript{2}. Sorbent injection of powdered activated carbon (PAC) is also an option for mercury control. The mercury chemistry and temperature of the application determine the formulation of PAC used and the resulting effectiveness. Mixtures of sorbent and PAC are commercially available. Sorbent costs, including storage and handling, are a major consideration in evaluating the total cost of ownership.

**Catalyst Filters for NO\textsubscript{X}, O-HAP THC, Dioxins**

Catalyst filters have the same composition and capabilities as the standard filters for PM, acid gases and Hg. The difference is the addition of micrionized catalyst.

NO\textsubscript{X}: All catalysts can be severely compromised by particulate blinding of the catalyst surface, chemical interactions with particulate on the surface, and gas-phase poisons. A common problem with traditional “big block” SCR is that the catalyst becomes blinded and poisoned, drastically reducing effectiveness and necessitating early replacement. Ceramic catalyst filters address these perennial issues. Particles, including solid-phase metals, are captured on the surface of the filters.

The filter catalyst is distributed throughout the filter walls in micrionized form and is almost completely protected inside the filter. This feature virtually eliminates the particulate-type interactions and extends catalyst life. Regarding gas phase, the proprietary catalyst formulation is engineered for extremely low conversion of SO\textsubscript{2} to SO\textsubscript{3} (some catalysts have over 10 times the rate) and is virtually immune to HCl.

The reaction of the ammonia and NO\textsubscript{X} at the micrionized catalyst surface is the same as conventional SCR but benefits from more contact time because the mixture of gases does not have to diffuse in and out of the big block catalyst pores, as previously mentioned by Schoubye and Jensen.

Eliminating the diffusion restriction helps reduce the slippage of untreated gases; NO\textsubscript{X} destruction greater than 90 percent has been reported. (Figure 6) Ammonia slip is well under 10 ppmv.

Cement O-HAP THC: The filters are very effective in destroying formaldehyde and other targeted O-HAPS. Efficiency is dependent on temperature. (Ammonia is not needed for O-HAP destruction.) The significant reduction
of O-HAPs results in an adjustment of total allowable THC according to the NESHAP formula. This direct approach for O-HAPS reduction is a very cost effective compared to PAC injection or thermal oxidation.

Catalyst filters virtually eliminate ammonia slip if SNCR is being used in the kiln. Excess ammonia slip, often a problem, is consumed by the filters while acting as a polishing step for NOX removal. This is an important secondary benefit when the filter system is used to collect PM, remove HCl, and/or destroy O-HAPS. Thus the need for a fabric filter baghouse or electrostatic precipitator is eliminated while gaining an important benefit.

Dioxins: These compounds are included in regulations for incinerators and hazardous waste facilities. Dioxins are destroyed in a similar fashion by the catalyst filter. Care must be given to the operating temperature range to avoid reformation of the dioxins.

**Operating Temperatures**

For PM control only, standard filters can operate at temperatures of 300 to 1,650°F. For PM plus SO2/HCl, the range is slightly narrowed by the chemistry of the sorbents to 300 to 1,500°F.

NOX control imposes different temperature constraints. One important feature of the NOX filters is an operating range that is lower in temperature compared to conventional big-block SCR. Conventional SCR requires at least 600°F for efficient removal, while the micronized catalyst becomes effective at 350°F. (Table 1)

O-HAP destruction becomes effective as temperatures approach 400°F and increases rapidly with relatively small increments of added temperature.

Occasionally, gas must be heated above the natural outlet temperature to reach minimum catalyst activation levels. This is done by insulating ducts against heat loss, adjusting process temps, going upstream of economizers, and on rare occasion adding inline heaters.

The need to cool the gas is much more common. Cooling the gas to the operating temperature range is required for some applications, and is accomplished with dilution air or water spray quenching. This illustrates another benefit of the effective lower temperature range for NOX of the catalyst filters: cooling to much lower temperatures does not affect removal efficiency. Certain heat recovery approaches also become more feasible.

**Proven Solution**

Ceramic filters have been used by the U.S. military at munitions destruction facilities in Indiana, Utah, and Oklahoma for 13 years, and hundreds of ceramic filter systems are operating worldwide, primarily in Europe and Japan. With the additional capability of NOX control, ceramic filter systems have become the technology of choice for an increasingly wide range of applications.

Since 2009, diverse industries in the United States have recognized the merits of the technology and responded with rapid adoption. Single housing and multi-housing systems treat a spectrum of pollutants across many industries throughout the United States.

Developments in ceramic filter technology offer a powerful, proven strategy for meeting today’s regulatory requirements, as well as those likely to be adopted in the future.

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