NOx Treatment

by Selective Catalytic Reduction

with Catalytic Ceramic Filter Elements

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Technology Director
Ceramic Catalyst Filters for Multi-Pollutant Control

Also Treats
- CO
- VOC
- Hg
- Pb
- Se
- Other Metals
- Dioxin

Tri-Mer is the Largest Supplier of Ceramic Filter Systems in the World
Presentation Outline

- Technology Basis (SCR)
- System Design
- NOx Control
- Multi Pollutant Performance
- Project Delivery

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## Technology Basis

### UltraCat Ceramic Filter Elements

<table>
<thead>
<tr>
<th>CHARACTERISTICS OF (LOW-DENSITY) CERAMIC ELEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Form</strong></td>
</tr>
<tr>
<td><strong>Composition</strong></td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
</tr>
<tr>
<td><strong>Density</strong></td>
</tr>
<tr>
<td><strong>Support</strong></td>
</tr>
<tr>
<td><strong>Geometry</strong></td>
</tr>
</tbody>
</table>

![Diagram showing a ceramic filter element with dimensions 3m in length and 150mm in diameter.](image)
Technology Basis

UltraCat Ceramic Filter Construction

Ceramic Filter Element Outer Surface

Inner Fibers with Imbedded Catalyst
Technology Basis

Filtration Mechanism

- Dust cake builds upon the residual layer, does not penetrate into filter body
- Cake is periodically removed with a reverse pulse of air, a brief low volume shockwave
- Can handle variable loading conditions
- Tube does not flex like a Fabric Filter bag, No mechanical wear = long filter life
Technology Basis
Protection from Catalyst PM Blinding and Poisoning

Particulate captured on the filter surface
Nano-Catalyst embedded in the walls of the filter

PM does not penetrate walls of the filter
Process PM + SO2 Sorbent PM + NOx + Ammonia

CLEAN AIR
AIRFLOW
DIRTY AIR

Meets EPA Regulations
Technology Basis
Filter Elements - Basic Operations

Diagram:
- Jet Pipe
- Manifold
- Filter Tubes
- PLENUM
- Clean Air Exits
- Valve
- Particles Captured on Outside of Tubes
- Dirty Air Enters
Technology Basis

Filter Elements - Operating Temperatures

- PM + Acids + NO\textsubscript{x}  
  280 → 750 °F

- PM + Acids  
  200 → 1200 °F

- PM only  
  200 → 1,650 °F

- 200 °F Temperature Scale 1,650 °F

Acids Include: SO\textsubscript{2}, HCl, HF, SO\textsubscript{3}

Low temp applications might require second stage of catalyst
Technology Basis
UltraCat by Clear Edge vs. Other Filter Brands

Test phase after Ageing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UltraCat by Clear Edge</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>80% (dense outer wall)</td>
<td>90% (open outer wall, dense inner wall, gradient)</td>
</tr>
<tr>
<td>Filtration</td>
<td>Mainly on the conditioned outer surface</td>
<td>First dust penetration and then filtration</td>
</tr>
<tr>
<td>Dust penetration</td>
<td>0.63 mg</td>
<td>5.03 mg</td>
</tr>
<tr>
<td>Pressure drop rise</td>
<td>Gradual</td>
<td>Quick</td>
</tr>
<tr>
<td>Cleaning cycle interval</td>
<td>Long</td>
<td>Short</td>
</tr>
</tbody>
</table>
Technology Basis

Pressure Drop and Filter Life

- Initial pressure drop dP approximately 4 to 6 “H2O.
- Very gradually ultrafine and condensable penetrate filter.
- Less than 3% differential pressure increase per year.
- Performance is not affected by increase in pressure drop.
- Extra fan power is built into the system.
- Filters must be changed when the system runs out of fan.
- Filter change is not triggered by catalyst deactivation or change in PM performance.

7 - 10 years filter life
Presentation Outline

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1. If necessary, condition incoming gas to <750°F
2. Add sorbent to control acid gases and Hg.
3. Add aqua ammonia for NOx reaction.
4. Remove solid waste.
System Design

Single Housing Configuration

1. Maximum of 500 filters per housing.
2. No limit to housings operating in parallel
3. Single Housing Height 34’
4. Single Housing Width 11’
5. Single Housing Length 11’ to 38’ depending on filter count
6. Fully Insulated
7. Indoor/Outdoor
System Design

Constructed in Four Sections

1. Walk-in plenum
2. Tube Sheet
3. Hopper
4. Support Frame

Shipped in four pieces

Simple installation with a crane

Filter elements installed in the field by Tri-Mer personnel.
System Design

Filter Element Installation

Filter Gasket, Stud, Spacer, and Hold Down Plate

Completed Assembly with Blow Tubes in Place

Broken Filter Element
System Design

System Inspection Camera - Results

- Filters fail at a rate of less than 1 per 500 annually
- Changing a filter requires 4 to 6 hours, most of that is cool down time
- After service gradual heat-up is unnecessary

Elements Intact

Pulse Valve Inoperable

Broken Element
System Design
Multiple Filter Housings to Match the Flow

With 3 or More Housings…

- Modules are serviced individually
- Remaining modules treat 100% of the gas flow
- No loss of performance while servicing
- Minimal pressure drop increase while servicing
System Design

12 Housings – Kiln Exhaust

- Ceramic Proppants (Fracking)
- 650 F
- NO$_x$, SO$_2$, HCl, HF, and PM
- Operational Q1 2013
- Compliance Verified
System Design

Diesel Exhaust (PM, SOx, NOx)

Systems for treating diesel exhaust from ships at berth are comprised of 2 principal components.

1 Capture System
Stack adaptor and exhaust shuttle connected to stack of auxiliary engine

2 Treatment System
Catalytic ceramic filter system configured for treating PM, SO\textsubscript{x}, NO\textsubscript{x}
System Design

9 Housings – Glass Furnace, Tableware

- 3 Housings per Furnace, 3 Furnaces
- 600 °F
- PM, NO$_x$, SO$_x$, HCl, and Metals
- Operational Since Jan 2011
- Compliance Verified
System Design

6 Housings – Glass Furnace, Containers

- 3 Furnaces
- 600 °F
- PM, NO\textsubscript{x}, SO\textsubscript{x}, and Metals
- Operational Since Sept 2014
- Compliance Verified
System Design
5 Housings – Glass Furnace, Flat Glass

• 1 Furnace
• 725 °F
• PM, NOₓ, SOₓ, and Metals
• Operational Since April 2015
• Compliance Verified
### System Design

**Experience Counts: 25 Ceramic Filter Projects - Selected List**

<table>
<thead>
<tr>
<th>Project</th>
<th>Type</th>
<th>ACFM</th>
<th>Emissions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kohler Glass, WI</td>
<td>Glass Furnace</td>
<td>12,000</td>
<td>PM, NOx, HF</td>
<td>Specialty glass</td>
</tr>
<tr>
<td>Illumina, CA</td>
<td>RTO Exhaust</td>
<td>13,500</td>
<td>PM, HCl, NOx</td>
<td>Biotech company</td>
</tr>
<tr>
<td>U of Iowa, IA</td>
<td>Biomass Boiler</td>
<td>15,600</td>
<td>PM, NOx, CO</td>
<td>Boiler MACT</td>
</tr>
<tr>
<td>Gallo Glass, CA</td>
<td>Glass Furnace</td>
<td>23,125</td>
<td>PM, SO2</td>
<td>First module of 6</td>
</tr>
<tr>
<td>Military/Siemens, CA</td>
<td>Boiler Exhaust</td>
<td>24,000</td>
<td>PM, NOx, HCl, SO2</td>
<td>Boiler MACT</td>
</tr>
<tr>
<td>3M, MN</td>
<td>Production</td>
<td>25,000</td>
<td>PM, NOx</td>
<td>Two projects</td>
</tr>
<tr>
<td>Calgon Carbon, AZ</td>
<td>Reactivation Furnace</td>
<td>25,400</td>
<td>PM, SO2, HCl</td>
<td>First industry application</td>
</tr>
<tr>
<td>CAEM, Port of LA</td>
<td>Diesel Engine Exhaust</td>
<td>25,900</td>
<td>PM, NOx</td>
<td>Ships at dock</td>
</tr>
<tr>
<td>EveryWare Glass, PA</td>
<td>Glass Furnace</td>
<td>29,300</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>Durand Glass, NJ</td>
<td>Glass Furnace</td>
<td>106,000</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>Ardagh Glass, IL</td>
<td>Glass Furnace</td>
<td>144,000</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>AGC Glass, KS</td>
<td>Glass Furnace</td>
<td>150,000</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>AGC Glass, TN</td>
<td>Glass Furnace</td>
<td>165,000</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>Guardian Glass, MI</td>
<td>Glass Furnace</td>
<td>175,000</td>
<td>PM, NOx, SO2, Metals</td>
<td>EPA ruling</td>
</tr>
<tr>
<td>Imerys, GA</td>
<td>Ceramic kiln</td>
<td>324,000</td>
<td>PM, NOx, SOx, HCl, HF</td>
<td>First industry application</td>
</tr>
<tr>
<td>Confidential</td>
<td>Kiln Exhaust</td>
<td>450,000</td>
<td>PM</td>
<td>Design, industry first</td>
</tr>
</tbody>
</table>
## System Design

### Tri-Mer Catalytic Ceramic Filters - Applications

<table>
<thead>
<tr>
<th>Combust/ Incinerate</th>
<th>Chemicals &amp; Minerals</th>
<th>Metallurgical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass furnaces</td>
<td>Alumina refining</td>
<td>Secondary aluminium smelting</td>
</tr>
<tr>
<td>Solid fuel boilers</td>
<td>Calcium carbide production</td>
<td>Precious metal recovery</td>
</tr>
<tr>
<td>Syngas cleaning</td>
<td>Activated carbon production</td>
<td>Swarf drying</td>
</tr>
<tr>
<td>Chemical waste</td>
<td>Catalyst production</td>
<td>Tin smelting</td>
</tr>
<tr>
<td>Medical waste</td>
<td>Silica production</td>
<td>Lead smelting</td>
</tr>
<tr>
<td>Radioactive waste</td>
<td>Fine chemicals production</td>
<td>Nickel refining</td>
</tr>
<tr>
<td>Munitions destruct</td>
<td>Sulphuric acid plant</td>
<td>Foundries</td>
</tr>
<tr>
<td>Petrochemical sludge</td>
<td></td>
<td>Copper smelting</td>
</tr>
<tr>
<td>MSW, scrap tires</td>
<td></td>
<td>Steel making</td>
</tr>
<tr>
<td>Animal waste</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Presentation Outline

• Technology Basis (SCR)
• System Design

• **NOx Control**
• Multi Pollutant Performance
• Project Delivery
1. Dry powdered sorbent – bicarb, trona, or lime – is injected into the duct. It immediately starts to react with the SO₂, SO₃, and HCl to form solid particles that will be captured by the ceramic filter.

2. Non-hazardous 19% aqueous ammonia is atomized and sprayed into the duct. It immediately turns into a gas and mixes with NOₓ. This mixing is not affected by the process PM or sorbent PM.

3. The gas stream goes into the filter housing, and the particulate from the process and sorbent is captured on the outside surface of the filters. Filters are periodically cleaned (about twice a day for many applications) with a burst of compressed air while filter housings remain on-line.

4. The NOₓ and ammonia mixture react on the enormous surface area of the nano-catalysts embedded in the filter walls. The mixture is free from particulate that can blind or poison the catalyst, so the reaction can occur more efficiently and across a much wider temperature range. NOₓ is broken down into harmless N₂ and water vapor. There is minimal ammonia slip.

5. Treated air exits the ceramic filter system, drawn by an induction fan to the stack.
Selecting Catalytic Reduction (SCR)

\[ 2\text{NO}_{\text{gas}} + 2\text{NH}_3_{\text{gas}} + \frac{1}{2}\text{O}_2_{\text{gas}} \rightarrow 2\text{N}_2_{\text{gas}} + 3\text{H}_2\text{O}_{\text{gas}} \]

NOx is converted to the harmless basic constituents of our atmosphere, nitrogen and water vapor.
NOX Control

Conventional SCR Catalyst Support Systems

High Removal at >650 F

Blinding and poisoning the catalyst are the greatest drawbacks.

“Hot side”
Reactors placed before any PM or other pollutant removal

“Cold side”
Reactors placed after electrostatic precipitator or fabric baghouse for PM control.
In industrial plants the conventional catalyst types typically operate with 5-15% catalyst effectiveness in the SCR (Selective Catalytic Reduction of NOx by NH3) – Haldor Topsoe, P. Schoubye paper 2006

Typical temperature range
600 F – 1,100 F
NOx Control
Catalytic Filter Technology for NOx

The combination of two well established technologies

Standard filter tube + SCR catalyst (in micronized form Infused in filter walls)
Utilization is virtually 100%, compared to 15% for traditional SCR
Haldor Topsoe, P. Schoubye paper 2006

- Lower temperatures achieve higher removal efficiency.
- 60-70% starting at 350 °F, and over 90% approaching 450 °F.
- Traditional block SCR usually requires 650 °F to reach 90%.
NOₓ Control
Float Glass Furnace

- Compliance Requirement is 80% Reduction
- Average Reduction = 80.5%
- Ammonia Slip <5 ppmv as Measured by In situ IR
- Precise Control Minimizes Ammonia Consumption
- Filter Operating Temp = 690°F

![Graph showing NOₓ Concentration and Removal Efficiency over time](image)

Average Inlet NOₓ [ppm] 915.2
Average Outlet NOₓ [ppm] 176.6
Average NOₓ Percent Removal [%] 80.5%
NO\textsubscript{x} Performance
Multiple Stationary Diesel Generators

- Compliance Requirement is 90% Reduction
- Average Reduction = 91.0%
- Filter Operating Temp = 450\textdegree}F
- Ammonia Slip <5 ppmv as Measured by Insitu IR
- Precise Control Minimizes Ammonia Consumption

<table>
<thead>
<tr>
<th>Test Number (average duration is 44 hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[NO\textsubscript{x} Concentration (ppmv @ 7% O\textsubscript{2})]</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>[Removal Efficiency (%)]</td>
</tr>
</tbody>
</table>

Average Inlet NO\textsubscript{x} [ppm] 519.4
Average Outlet NO\textsubscript{x} [ppm] 34.6
Average NO\textsubscript{x} Percent Removal [%] 91.0%
Average Ammonia Slip [ppm] 3.5
NO$_x$ Performance
Lignite Coal

Average Inlet NOx [ppm] 433.7
Average Outlet NOx [ppm] 85.3
Average NOx Percent Removal [%] 80.1%
Average Ammonia Slip [ppm] 0.9
Presentation Outline

- Technology Basis (SCR)
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- NOx Control
- Multi Pollutant Performance
- Project Delivery
## Multi Pollutant Performance

### Typical Ceramic Filter PM Results

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>PARTICLE SIZE</th>
<th>INLET PM LOADING</th>
<th>OUTLET PM LOADING</th>
<th>INFERRED EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum powder production</td>
<td>d$_{50}^1$, µm</td>
<td>550, mg/Nm$^3$</td>
<td>0.24, gr/dscf</td>
<td>&lt;1, mg/Nm$^3$</td>
</tr>
<tr>
<td>Nickel refining</td>
<td>&lt;10</td>
<td>11,800, mg/Nm$^3$</td>
<td>5.16, gr/dscf</td>
<td>&lt;1, mg/Nm$^3$</td>
</tr>
<tr>
<td>Smokeless fuel production</td>
<td>4.8</td>
<td>1000, mg/Nm$^3$</td>
<td>0.44, gr/dscf</td>
<td>1.5, mg/Nm$^3$</td>
</tr>
<tr>
<td>Zirconia production</td>
<td>1.2</td>
<td>8000, mg/Nm$^3$</td>
<td>3.5, gr/dscf</td>
<td>0.8, mg/Nm$^3$</td>
</tr>
<tr>
<td>Secondary aluminum</td>
<td>&lt;1.0</td>
<td>870, mg/Nm$^3$</td>
<td>0.38, gr/dscf</td>
<td>0.5, mg/Nm$^3$</td>
</tr>
</tbody>
</table>

1. Diameter of median size particle  
2. 1 mg/Nm$^3$ equals 2288 grains/dry standard cubic foot.

Meets all EPA and state requirements across the spectrum of applications.
Multi Pollutant Performance

In-Duct Reaction PLUS Sorbent Cake on the Filter

Sorbent Injection Chemistry

\[
Ca(OH)_2 \text{ (powder)} + SO_2 \text{ (gas)} + \frac{1}{2}O_2 \text{ (gas)} \rightarrow CaSO_4 \text{ (powder)} + H_2O \text{ (gas)}
\]
Multi Pollutant Performance

Lhoist Sorbacal SP Surface Area

Product development highly reactive hydrate (Ca(OH)₂):

Reaction of Ca(OH)₂ and acid flue gas components:
- Acid – base reaction by gas – solid contact
- Surface area of the solid is important

**Sorbacal® A:**
- 35 - 38 m²/g; 0.13 cm³/g
- d₅₀: 2 - 3 µm

**Sorbacal® SP:**
- 42 - 45 m²/g; 0.25 cm³/g
- d₅₀: 6 - 8 µm

At the moment developing
(Sorbacal® SPS for > 160°C)

(1): spec. surface area/pore volume
Multi Pollutant Performance

SO$_2$ Reduction on Various Glass Furnace Applications
Presentation Outline

- Technology Basis (SCR)
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- Project Delivery
Established 1960
12 Acre Site Near Detroit, Michigan
Project Delivery

In-House Manufacturing, U.S. based

- Air pollution control (APC) specialists
- Engineer, design, fab, and install
- Wet and dry systems
- In-house equipment fabrication
- Steel and thermo-plastic fab facilities
Project Delivery

200,000 Sq Ft of Engineering Offices and Manufacturing
Tri-Mer offers turnkey systems and services:

- Pollution control system design
- Engineering (mechanical, electrical, civil, structural)
- Site work such as demolition
- Site work up-front construction
- Regulatory agency support
- Controls and integration
- Continuous Emission Monitors
- In-house equipment fabrication
- Installation and start-up
- Aftermarket support services
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