

Oxidation Technologies for Stationary Rich and Lean Burn Engines

**Advances in Emission Control and
Monitoring Technology for Industrial
Sources**

Exton, PA

July 9-10, 2008

Oxidation Catalyst Technology



- An oxidation catalyst controls emissions from combustion sources (e.g. stationary engines)
 - CO (carbon monoxide)
 - HCs (hydrocarbon)
 - VOCs (volatile organic compounds)
 - HAPs (hazardous air pollutant)
- Oxidation is completed across the catalyst to form products: CO₂ (carbon dioxide) and H₂O (water)
- An oxidation catalyst is a “passive” emissions control device
 - No moving parts
 - No chemical reagents
 - Virtually maintenance free

Commercialization of Oxidation Catalyst Technology



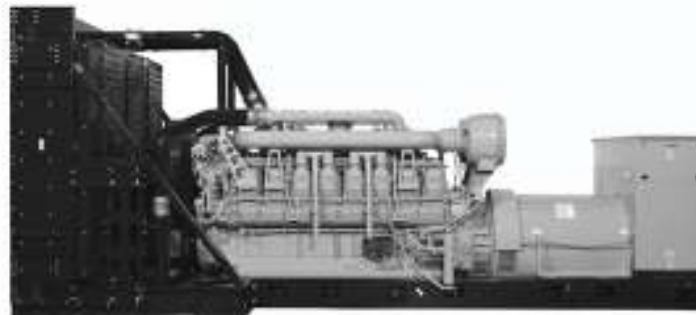
Application	Fuel	Emissions	Timeframe	Installations
Fork Lift Trucks	LP, Gasoline	CO, HC	Mid-1960s	1,000s
Mining Equipment	Diesel	CO, HC, Odor	Mid-1960s	1,000s
Automobiles	Gasoline, Diesel	CO, HC	1975	100,000,000s
Formaldehyde Plants	-	CO, VOC	Mid-1970s	100s
Process Plants	-	CO, VOC	Mid-1970s	1,000s
Engine Gen Sets	Various	CO, HC, Odor, VOC	1970s	1,000s
Turbines	Various	CO	Mid-1980s	100s
Boilers	Various	CO	Late-1980s	10s
Trucks	Diesel	CO, HC, PM	Mid-1990s	1,000,000s
Buses	Diesel	CO, HC, PM	Late-1990s	10,000s

- Oxidation catalyst technologies
 - NSCR (Three-way catalyst)
 - Diesel Oxidation Catalyst (DOC)
 - Oxidation Catalyst
- Advances in emission control
 - Substrates
 - Systems
 - Selections
- Applications on stationary engines
 - Case studies

Stationary Engine Profile Drives Oxidation Technology Selection



Fuel: Natural Gas
Combustion: Fuel-Rich
Emissions:
CO, HC, VOC
Technology: NSCR



Fuel: Natural Gas
Combustion: Fuel-Lean
Emissions:
CO, HC, VOC
Technology: Ox Cat

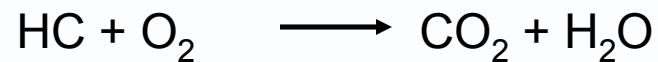
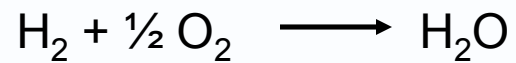
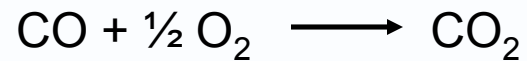
Fuel: Diesel (500 ppm S max)
Emissions: CO, HC, VOC, PM
Technology: DOC

NSCR Chemical Reactions



Chemical Reactions:

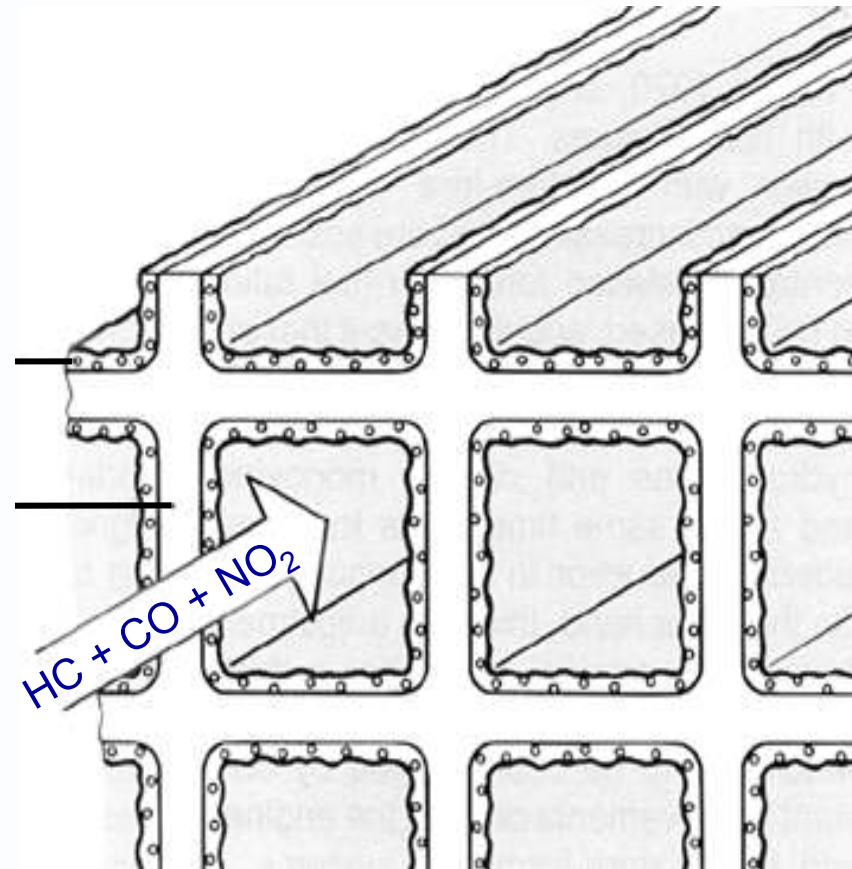
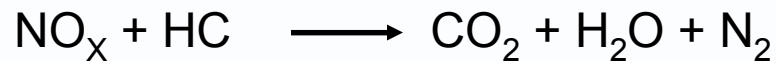
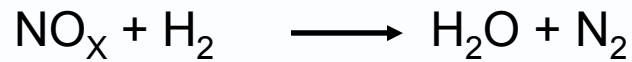
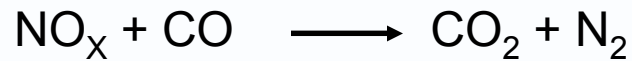
Step 1: Deplete O₂



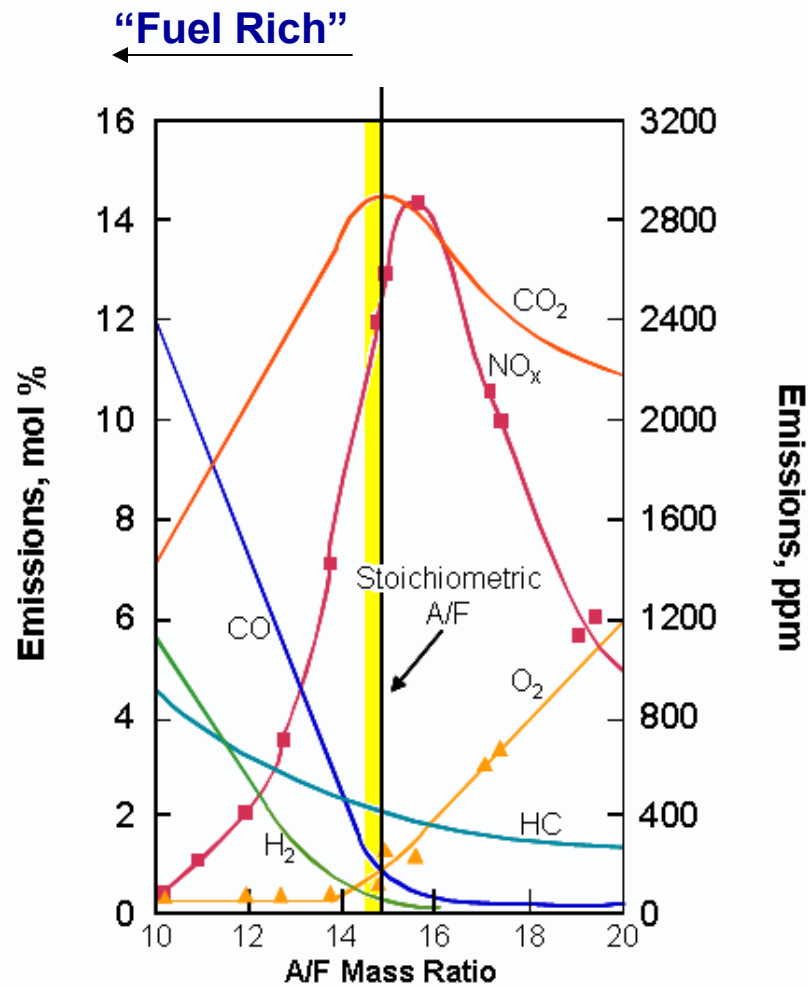
*Catalytic Surface
(Precious Metal)*

Substrate

Step 2: Reduce NO_x



NSCR on Rich Burn Engines



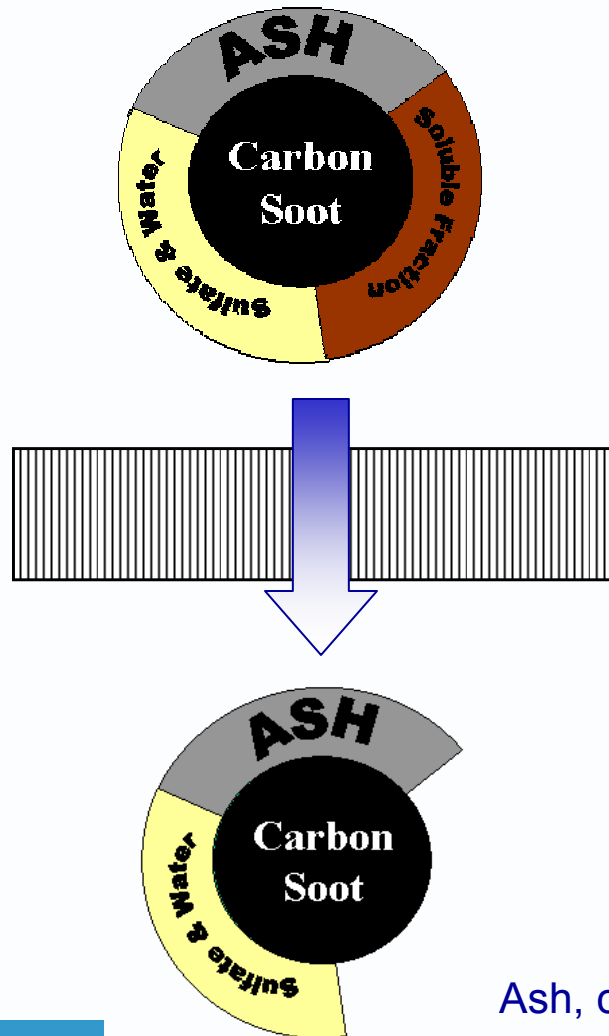
Engine operates slightly “fuel rich”

Air-fuel ratio controller required to maintain balanced engine emissions (NO_x, CO, HC) for stable catalyst performance

Typical reductions:

- 90% - 99% NO_x
- 90% - 99% CO
- 50% - 90% HC
- 80% - 95% CH₂O
- 80% - 95% HAPs

Diesel Oxidation Catalyst



Diesel particulate matter – What is it?

- Carbon soot
- Soluble organic fraction
- Sulfate and water
- Ash

Diesel Oxidation Catalyst (DOC)

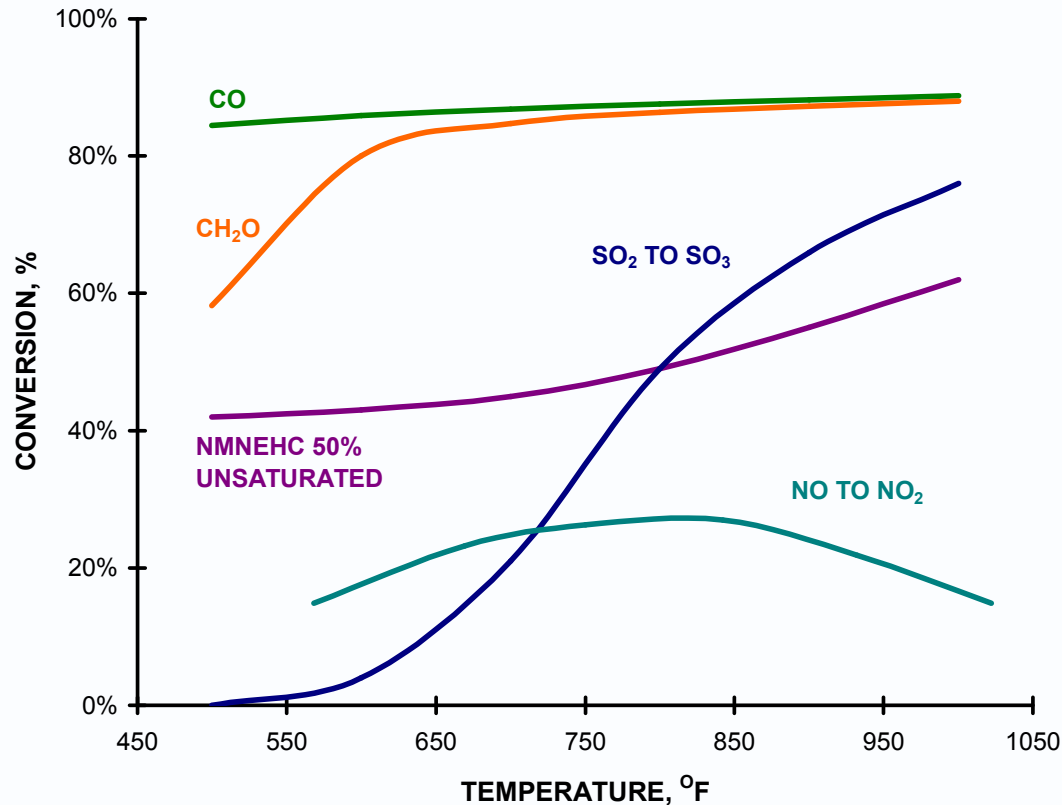
Applicable for diesel fuel < 500 ppm S

Soluble organic fraction	20% - 50% PM reduction
CO & hydrocarbons	> 90%
Aldehydes	> 70%
SO ₂	Some oxidation to SO ₃
Ash, carbon soot, sulfate & water	No impact

Oxidation Catalyst



CO... HC... VOCs... HAPs... SO₂... NO...



“Passive” technology will oxidize, to some degree, everything that it contacts.

The catalyst performance for each compound typically determined by residence time (i.e. catalyst volume) & operating temperature.

90% CO conversion case shown... 99% CO conversion possible with additional catalyst volume



Oxidation Catalyst Maintenance and Lifespan



- If applied properly, an oxidation catalyst technology does not need regular maintenance
- However, certain engine “upset” conditions can affect the performance and lifespan of oxidation catalyst technology
 - Thermal deactivation
 - Very high temperatures $> 700^{\circ}\text{C}$ (1300°F)
 - Catalyst poisoning from
 - Use of high sulfur diesel fuel (e.g. 2,000 ppm S)
 - Certain lube oil and lube oil additives (e.g. Zn, P)
 - In some cases, catalyst may be regenerated with proper cleaning to extend its useful life

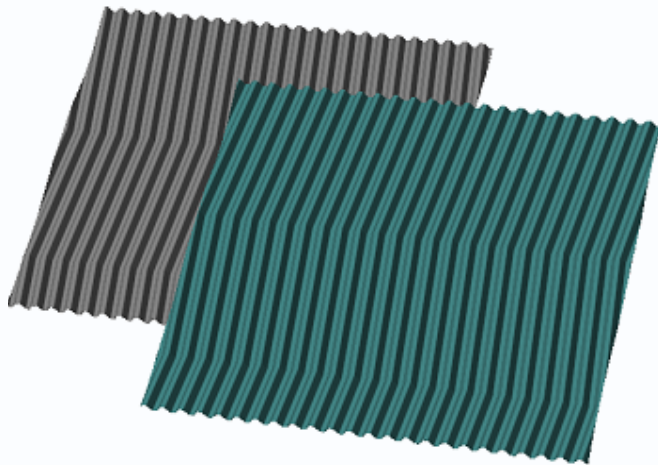
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Substrates – Versatility in Applications



- Metal substrate

- Low pressure drop
- High surface area
- Design flexibility to address application specific constraints on space



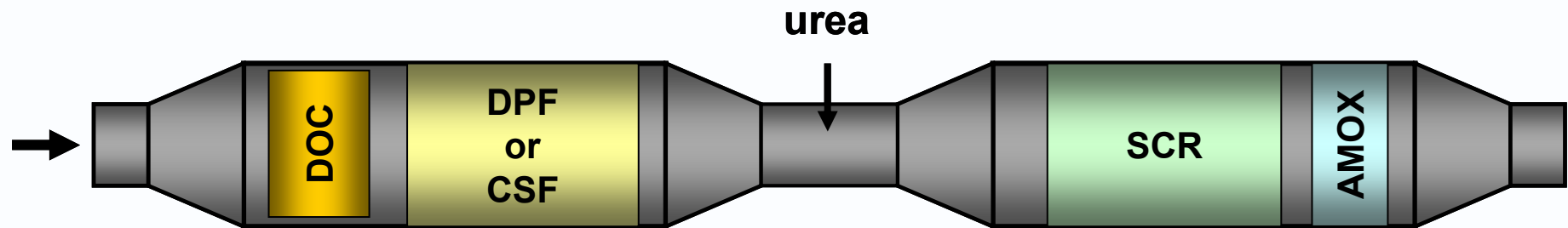
- Ceramic substrate

- Well-suited for washing to extend useful life
- Resistant to acid gas environments



Systems – Optimizing the Catalyst Technology

- Each component in an integrated catalyst technology system is considered for:
 - Its contributions toward the overall required performance
 - Its impact on other installed technologies



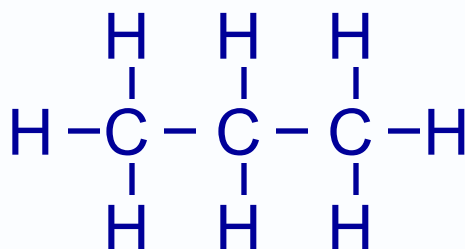
- A DOC installed upstream of the particulate collection element may be optimized for high VOC conversion at high temperatures.
- An ammonia destruction (AMOX) catalyst installed downstream of the SCR may be optimized for high NH_3 slip conversion to N_2 at low temperatures.

Selections – Perspectives on VOCs & Catalyst



- “Organic compounds that evaporate readily into the atmosphere at normal temperatures. VOCs contribute significantly to photochemical smog production and certain health problems.” (www.epa.gov/trs/)
- EPA website identifies 231 unique VOCs, including propane and propylene...

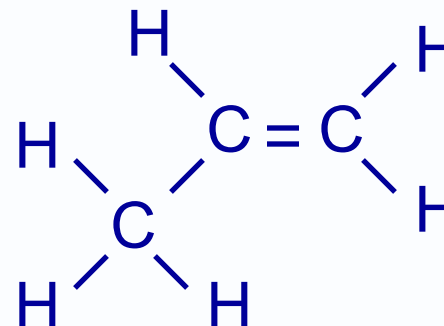
Propane



Saturated compound

Ignition temp ~ 770F

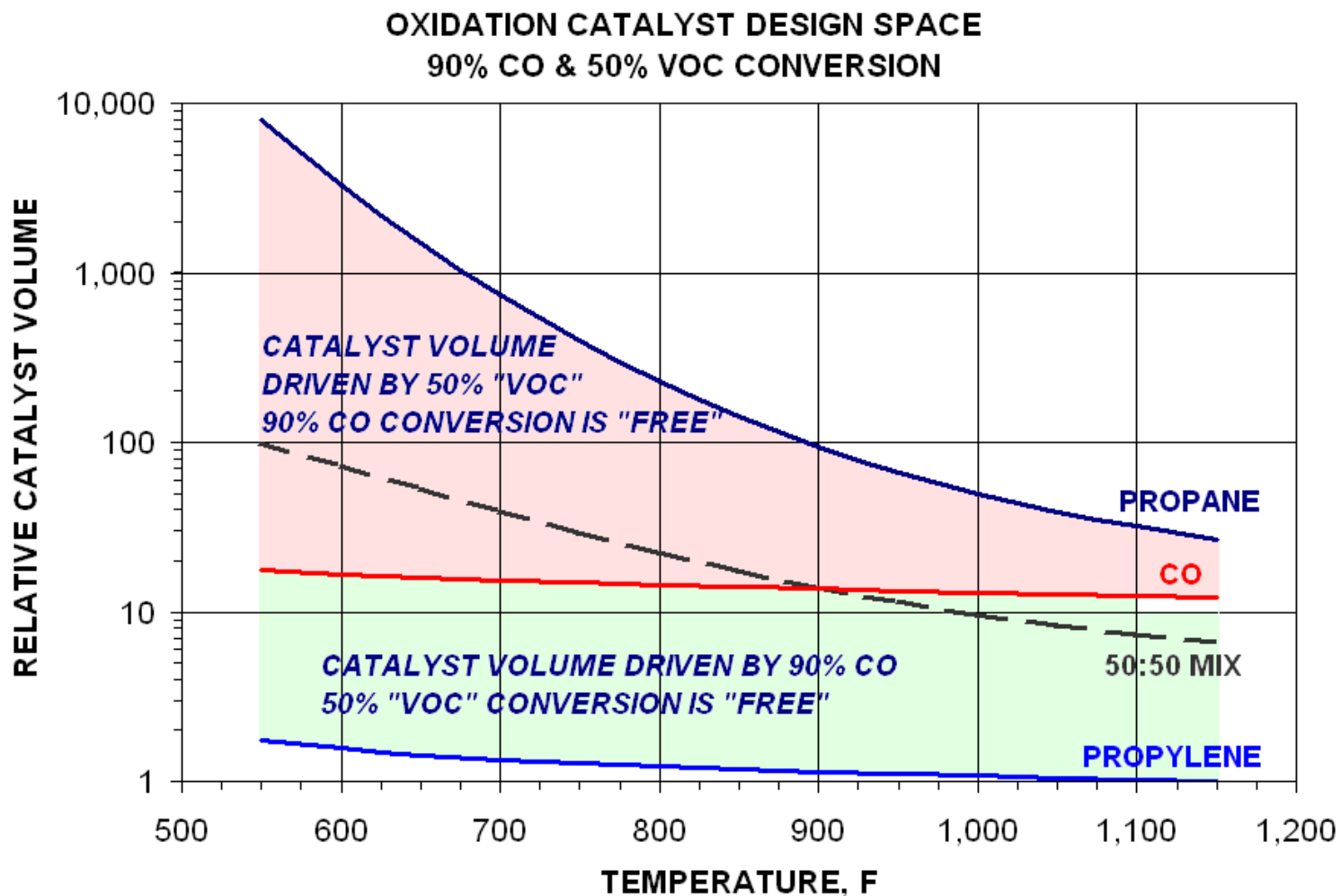
Propylene



Unsaturated compound

Ignition temp ~ 500F

Identification of VOC Compounds is Critical in Catalyst Volume Sizing



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Case Study #1

Emission Control - NSCR



- The problem...emission control at a natural gas compressor station in northern Alberta, Canada, powered by Waukesha 7042 GSI engines.
- The solution...NSCR (three-way) catalyst to meet emission targets for NO_x , CO, NMHC. Catalyst housings supplied in two configurations.
 - Separate catalyst housing and muffler
 - Integrated single unit containing catalyst and muffler elements
- The result...emission reduction targets achieved and housing designs allowed for easy servicing to prolong the useful life of the catalyst.



Case Study #2

Emission Control - DOC



- The problem...after a Boston, MA hospital completed a new addition, complaints of strong, nauseous diesel odors were reported during monthly generator testing.
- The solution...a DOC mounted at the manifold of the generators was the preferred solution over dilution fans or an activated carbon adsorption bed on the hospital outside air intakes.
 - Lowest first cost
 - Easiest installation
 - No scheduled maintenance
 - No additional demands on control systems or electricity usage.
- The result...diesel odor abated, 90%+ CO conversion, 80%+ HC conversion, and 40%-50% PM reduction.

Case Study #3

Emission Control - Oxidation



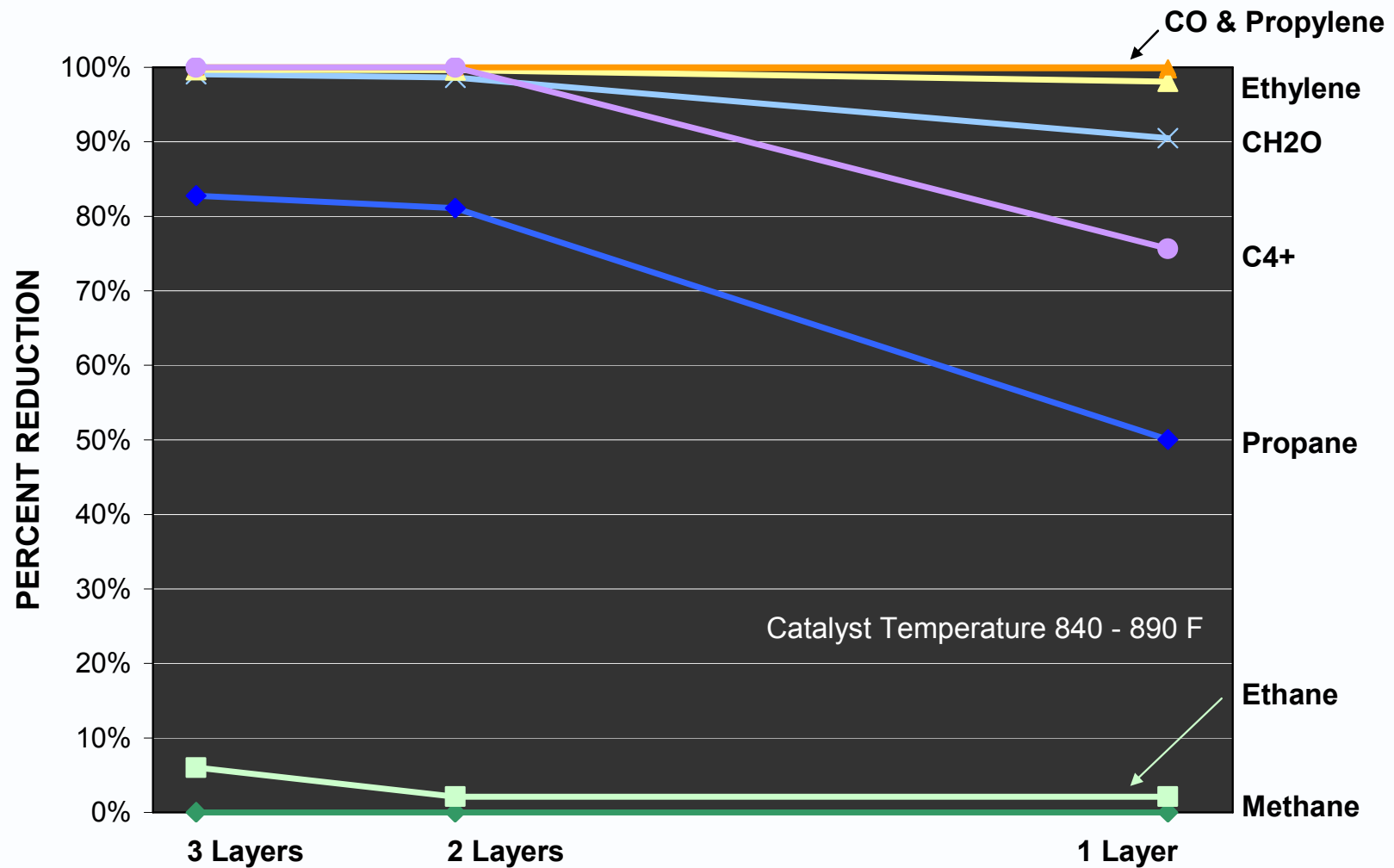
- The problem...a 1,000 hp, four stroke, stationary engine operating in Southern California is required to meet an acrolein (HAPs) stack emission requirement of 40 ppbv(wet).
- The solution...Oxidation catalyst selected and subjected to slipstream reactor testing to prove its performance:
 - 3000 ppbv(wet) acrolein inlet concentration
 - 40 ppbv(wet) acrolein outlet concentration
 - 98.6% acrolein conversion efficiency
 - 1000°F engine stack temperature
 - Acrolein measurements by GC/MS

Case Study #3

Field Data by FTIR



FTIR FIELD MEASUREMENTS in ENGINE SLIPSTREAM



Note: acetaldehyde emissions (not shown) were below instrument detection limit

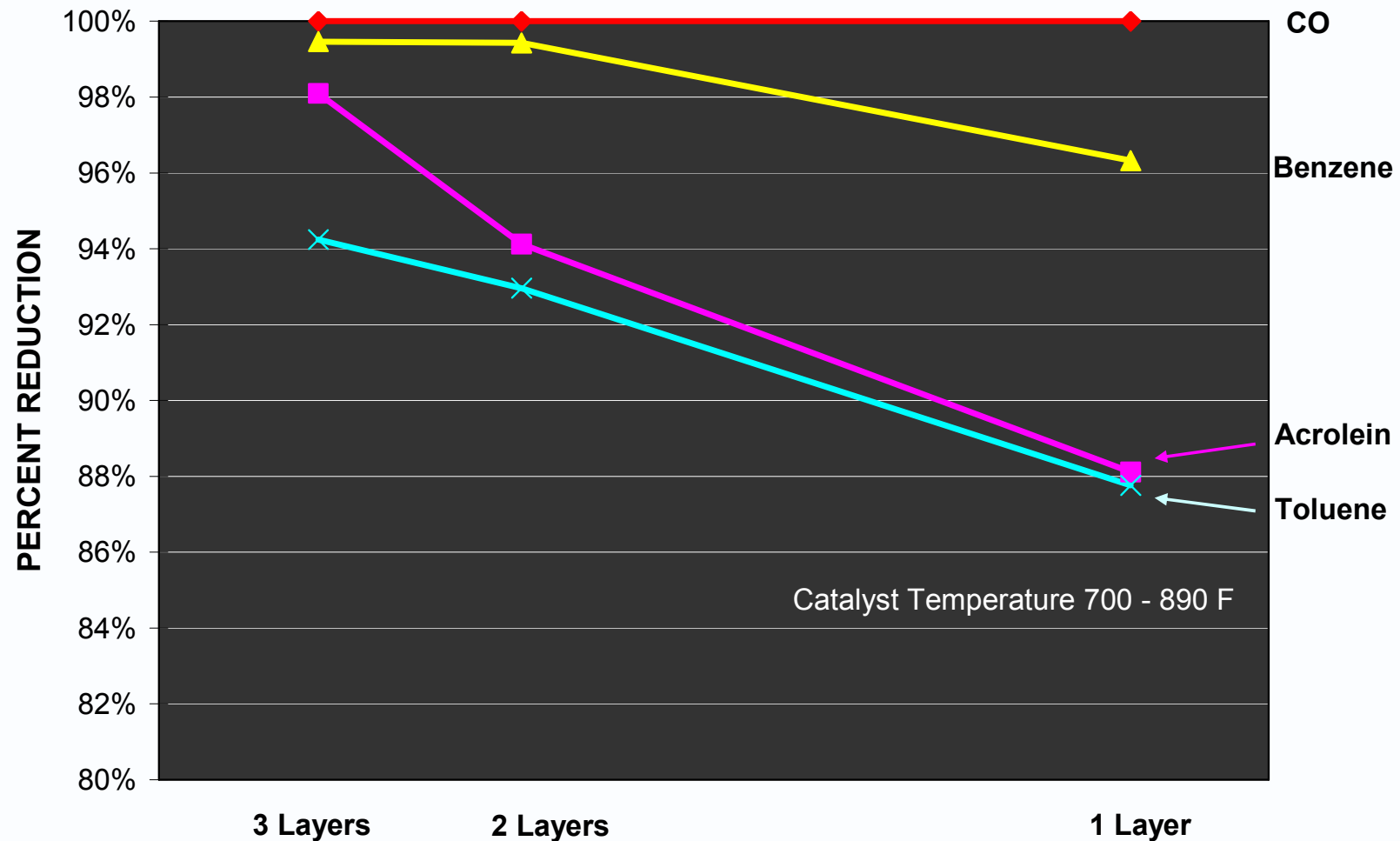


Case Study #3

Field Data by GC/MS



GC/MS FIELD MEASUREMENTS in ENGINE SLIPSTREAM



Case Study #3

Emission Control - Oxidation



- The result...based on slipstream testing at lower operating temperatures, three layers of oxidation catalyst were installed on the stationary engine.
 - Stack permit testing showed the acrolein emission to be 3 ppbv(wet), well below the 40 ppbv(wet) emission limit
 - Meaningful measurements below the nominal instrument detection limit of 10 ppbv(wet) were possible due to significant hydrocarbon conversion that allowed for very clean chromatogram peaks.
 - Engine stack temperature measured 1,000°F, a 20-40°F increase above nominal associated with catalyst backpressure

Summary



- Oxidation catalyst technologies, including diesel oxidation catalyst (DOC) and NSCR (three-way catalyst) offer:
 - Historically proven success of controlling emissions from a wide variety of combustion sources, including stationary engines
 - Robust and mature technology capable of significant emissions reductions of CO, HCs, VOCs, and HAPs (and NO_x for rich burn engines)
 - Cost of technology is directly related to the level of performance required and the identity of those compounds whose emissions are to be controlled
 - A future of continued innovation for optimum performance.

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