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Design Principles of Diesel Emission Control Technologies

MVPC – October 2026

Canada

Introduction

- The underground mining industry saw rapid dieselization in the period from 1970 to 1990.
- Advances in mining techniques enabled accelerated development and extraction, such that the time and cost for fixed rail or conveyor-based ore haulage infrastructure was no longer acceptable.



Malartic Mine



Trackless diesel equipment

- Trackless diesel equipment was more flexible and could be rapidly repositioned without the need for significant infrastructure to be developed in advance or abandoned later.
- Diesel loaders and haul trucks were faster and had more payload suitable to the requirements of block caving and other rapid bulk extraction processes.



Wagner ST5 LHD



Diesel exhaust exposure

- Despite the benefits, diesel equipment brought a new problem to the underground mine in the form of toxic emissions.
- Early direct-injected (DI) diesels could have carbon monoxide emissions of 3,000 – 10,000 ppm and particulate emissions of 300 – 1,000 mg/m³.
- In addition, unburned hydrocarbon emissions caused lung irritation and a strong diesel odour.
- Mine ventilation was increased to help but something else was required to lower emissions at the source.



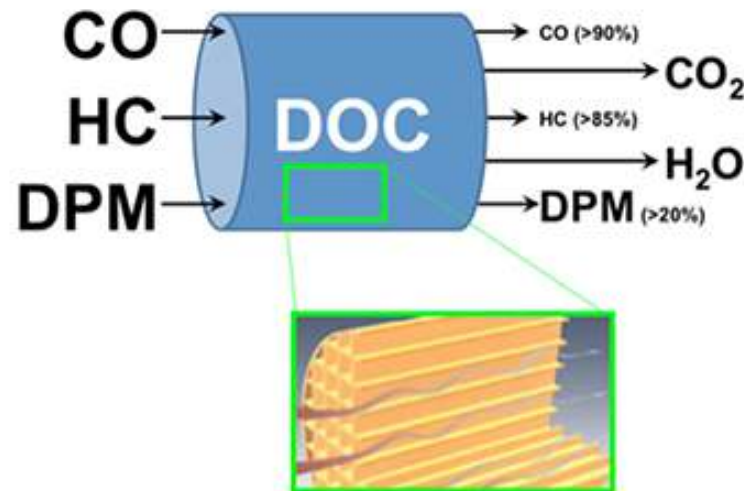
Emissions control

- Gasoline engines in passenger cars became subject to emissions regulation in the 1970s, however, diesel equipment was generally unregulated until the 1990s.
- The problem of emissions from mining equipment needed to be addressed immediately for occupational health so the industry adapted the oxidation catalyst and began using them in the late 1970s to reduce CO and HC emissions.
- For particulate matter, Corning's development of the diesel particulate filter was supported by the mining industry and first used underground at the Brunswick Mine in 1983.

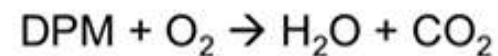
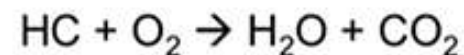
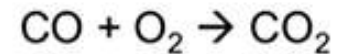


Diesel Oxidation Catalysts (DOC)

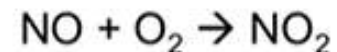
- The DOC uses excess oxygen found in diesel engine exhaust to oxidize CO, PM and HC. The catalytic material lowers the activation energy of these chemical reactions to allow them to take place at an exhaust temperature achievable in normal vehicle operation.



Desired Reactions



Undesired Reactions



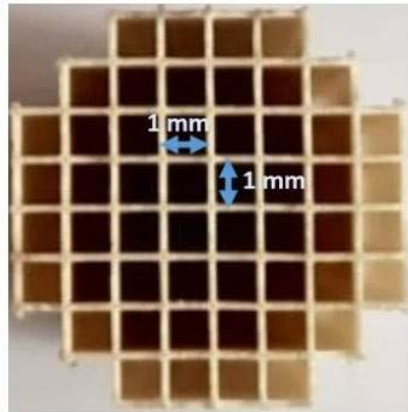
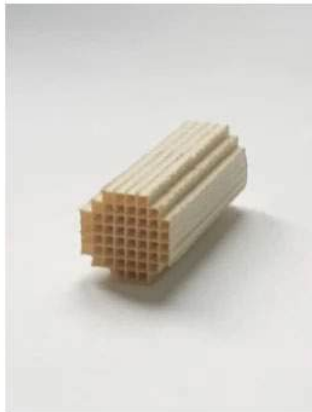
DOC Design Fundamentals

- The DOC is a reactor placed in the engine exhaust stream. It must have the following characteristics:
 - *Be large enough to allow sufficient time for the oxidation reaction to take place.*
 - *Have enough surface area to host sufficient catalytic sites for the mass of pollutants to be converted.*
 - *Have a large open area to limit back pressure increase on the engine.*
 - *Have adequate durability to retain the catalytic material under vibration, temperature cycling and contaminants in the exhaust.*
- These requirements define the choice of catalyst support geometry and materials.



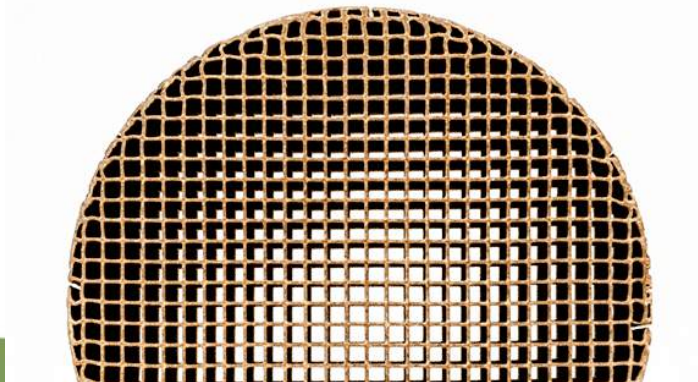
Support Geometry

- Early DOCs used pellets to support the catalyst material because many chemists were familiar with pellets as a research tool.
- But pellet-packed reactors had high resistance to flow and were not suitable for engines.
- Monolithic supports or “substrates” can be built with open cross sectional areas which improve flow and provide more surface area.



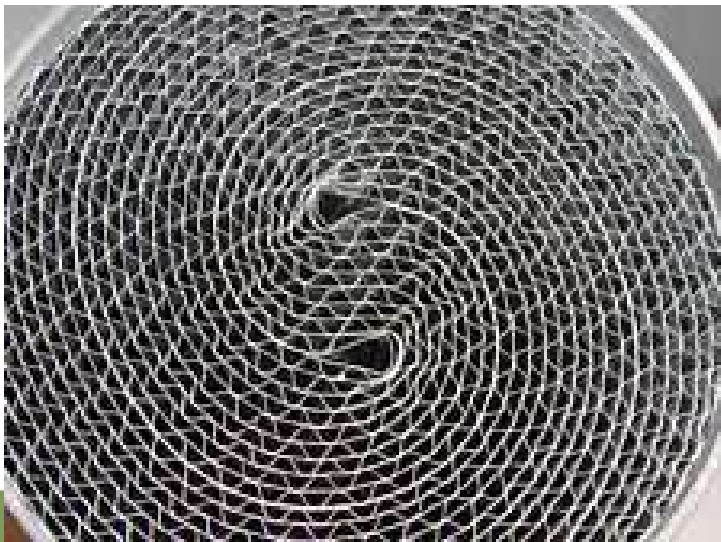
Substrate materials - Ceramic

- Monoliths are most often ceramic or metal.
- Ceramic can be extruded into many shapes and cell wall thicknesses and the extrusion process requires little finish work and is thus very low cost.
- They are light and inexpensive but are fragile and require careful packaging to prevent damage.



Substrate materials - metal

- Metal substrates are fabricated from thin stainless-steel sheets, crimped cut and rolled into a monolith.
- The steel sheets require additional finishing of either mechanical pinning or vacuum brazing to retain the sheets in the shell.



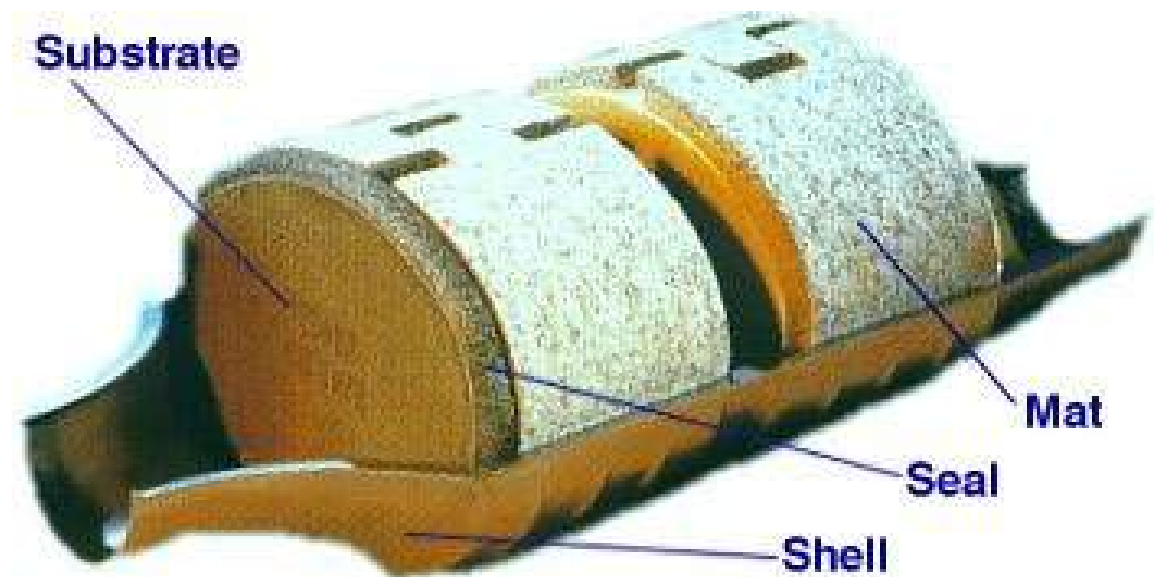
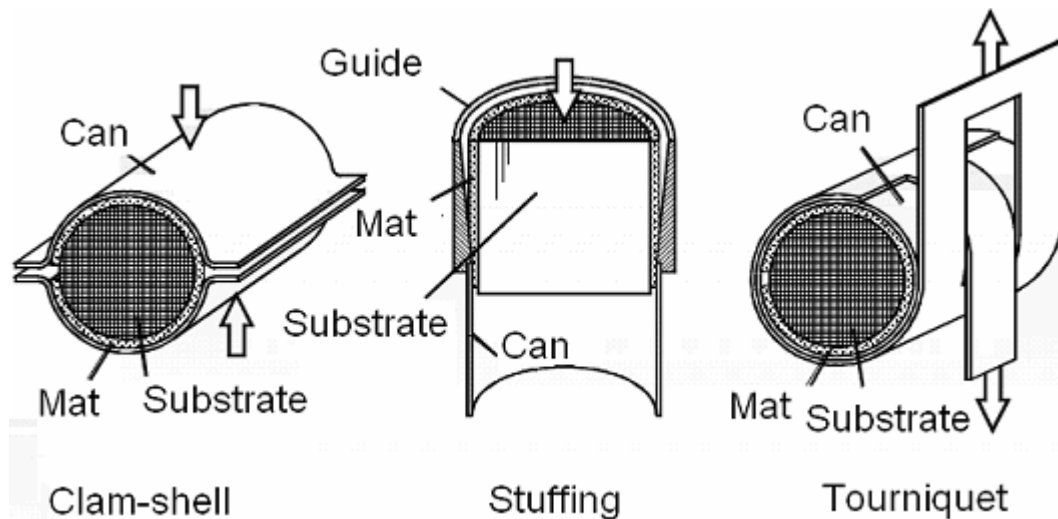
Material selection

- Metal substrates are very durable and can be welded directly to fabricated exhaust system components without additional packaging
- They are expensive and heavier than ceramic where weight is important.
- Ceramics like cordierite is cheaper to manufacture but needs engineered packaging including core support to protect the monolith and provide sufficient durability.



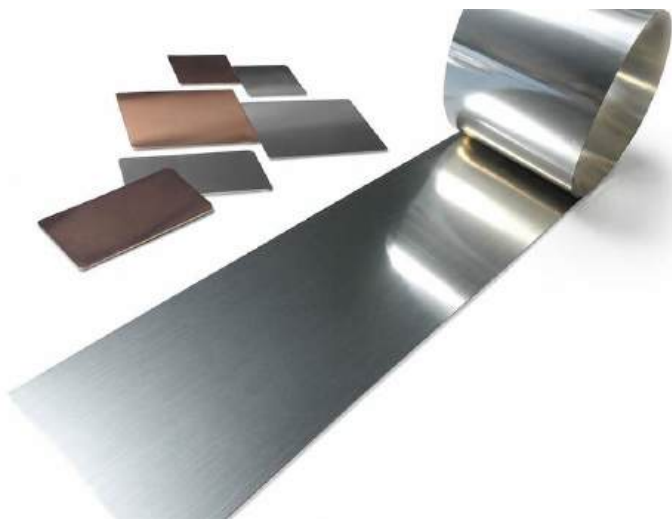
Manufacture and packaging - Ceramic

- Ceramics are extruded in the optimal shape to the required length.
- The monolith is wrapped in an intumescent mat for retention and pressed or welded into a metal shell.



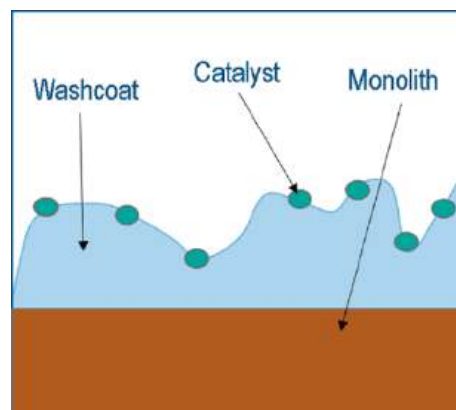
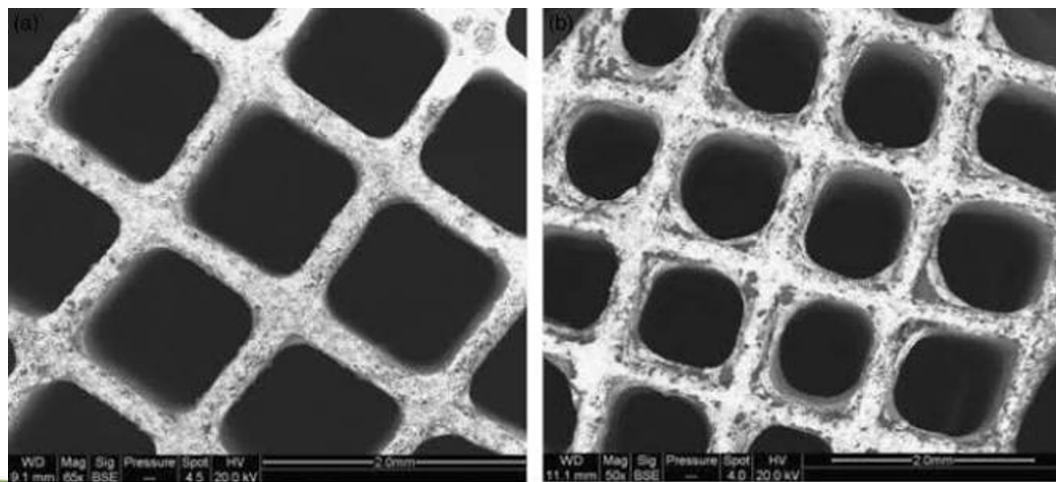
Manufacture and packaging - Metal

- Metal substrates are crimped and cut and commonly brazed into a metal shell.
- The shell requires no additional protection.



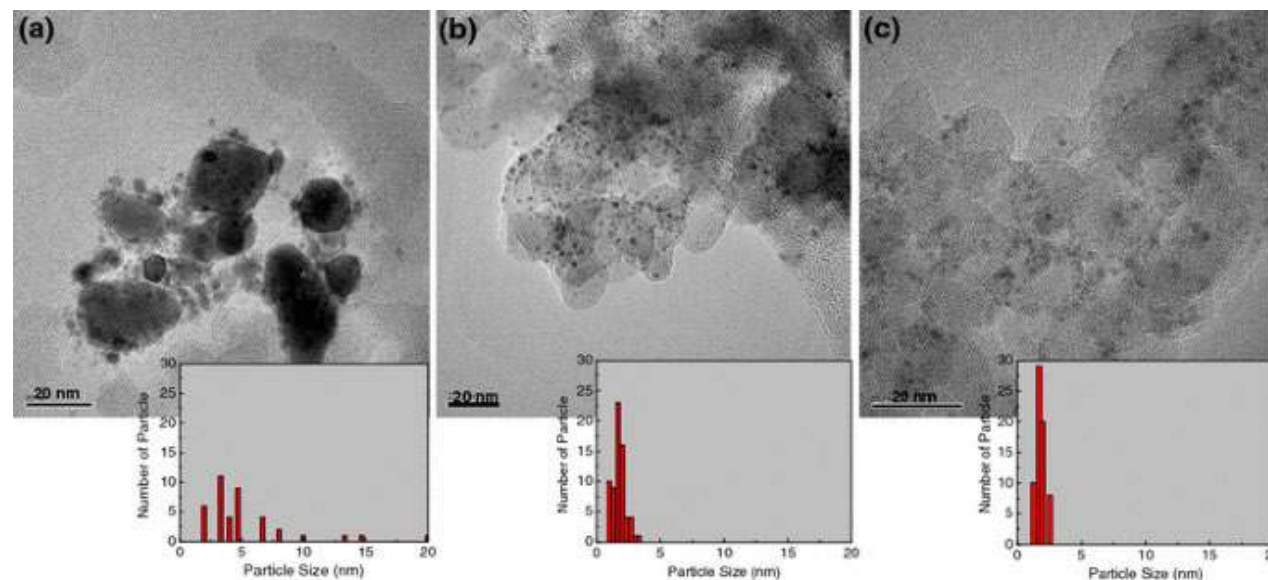
Washcoat material coating

- Washcoat is used for all DOCs to increase the surface area of the substrate and provide site to retain catalytic materials for reaction.
- The most common type is alumina and it's used for both metal and ceramic substrates.



Catalyst material coating

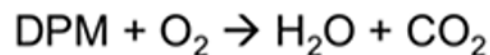
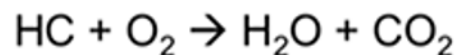
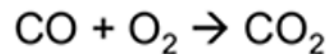
- The catalytic material is prepared and applied to the washcoat.
- The finished coated catalyst is calcined in an oven.
- Note that ceramic DOCs are coated prior to core assembly while metal DOCs are coated after.



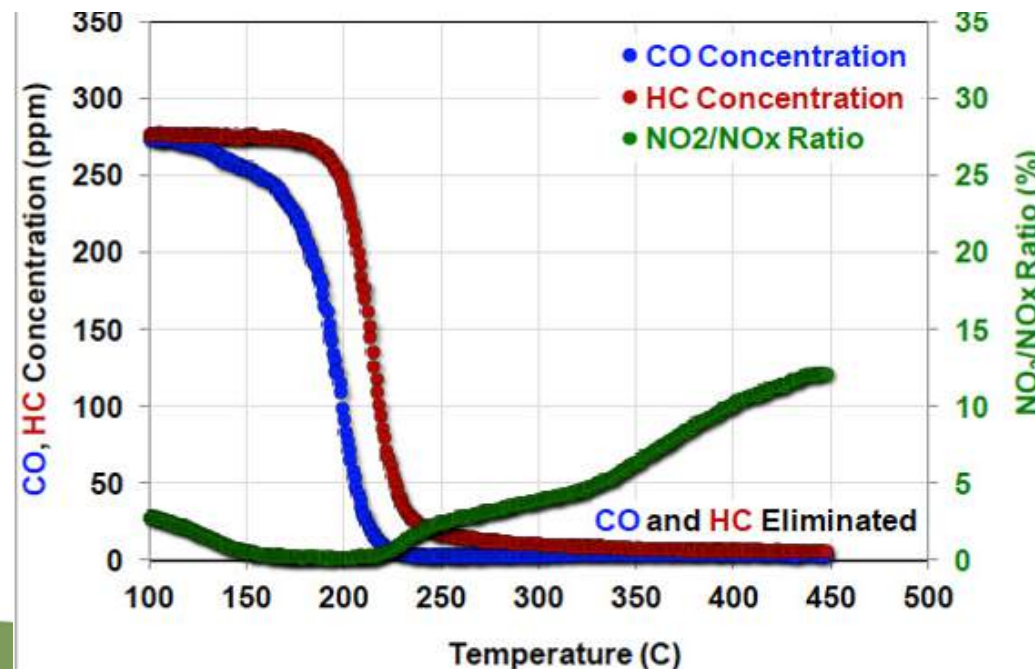
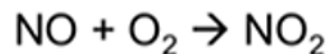
Catalyst performance

- DOC performance varies with many factors; catalyst material, washcoat material, geometry, size, exhaust gas characteristics.
- For now we will look at a basic platinum (Pt) based DOC.

Desired Reactions



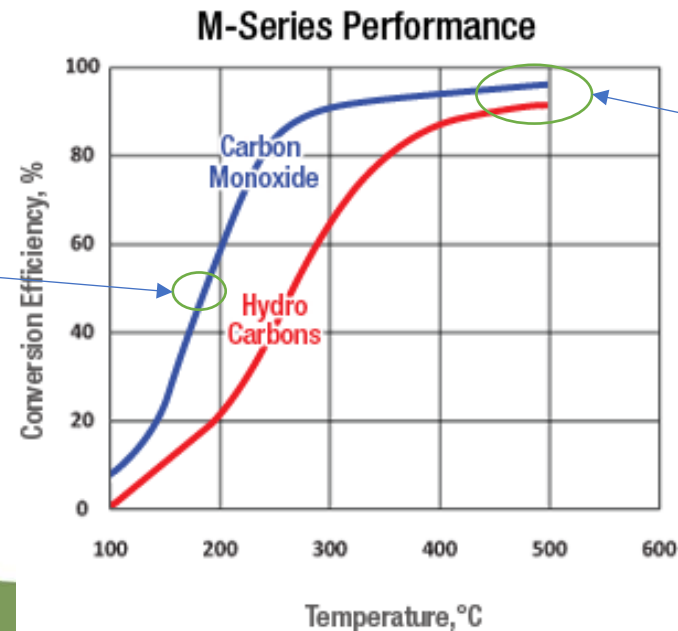
Undesired Reactions



Catalyst conversion efficiency

- Conversion efficiency is a function of temperature and reactant exchange. (Kinetics and mass transfer)
- Light off temperature is a function of catalyst activity, but high temperature conversion efficiency is a function of residence time.

Light Off temperature
T50 when 50%
conversion is achieved.



Maximum conversion
efficiency limited by
DOC size (and cost).

Sizing considerations

- A larger catalyst will have a higher ultimate conversion efficiency because of a long residence time for mass transfer.
- But a larger catalyst may take longer to heat up thus lowering efficiency in the kinetic-controlled range.
- How to we define “size”? – with the concept of space velocity.
- Volumetric hourly space velocity (VHSV) or (GHSV)

GHSV = Volumetric exhaust gas flow rate / Monolith volume

Units = $(\text{m}^3/\text{h}) / \text{m}^3 = \text{h}^{-1}$



GHSV Guidance for DOC

- GHSV values of around $100,000\text{h}^{-1}$ or less are often used where regulatory compliance of tailpipe emissions are required.
- Higher values can be used where fast performance and low temperature activity is more important.
- *Why such a strange unit? The inverse of GHSV the residence time and dividing 3600s/h by $100,000\text{h}^{-1}$ gives a time of 0.036s so it's easy to compare residence times for mass transfer.*



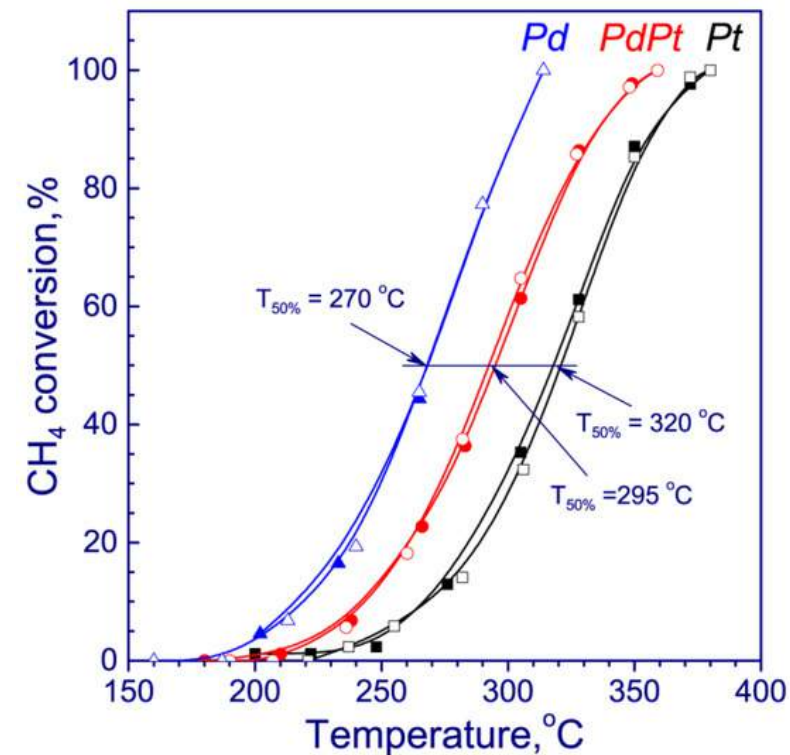
Comparison of catalytic formulations

- Platinum (Pt) catalysts were used extensively in early DOCs and they were very effective in reducing CO/HC at low temperatures even at high space velocities.
- Unfortunately, they also tended to oxidize NO to NO₂ and form sulphates.
- Sulphate production became less important when sulphur was removed from diesel fuel by regulation.
- NO₂ formation is still an issue for underground mining where the higher toxicity of NO₂ vs NO is reflected in occupational health exposure limits.



Platinum (Pt) vs Palladium (Pd) DOCs

- Palladium and other catalysts have been found to oxidize less NO_2 .
- The trade-off is usually less activity (higher light off temperature).
- Often bimetallic Pt:Pd formulas used



Conclusions - DOC

- DOCs are a very effective tool for diesel emissions control by themselves or as part of an integrated T4/Stage 5 aftertreatment package.
- Careful consideration is required for catalytic formulation selection.
- WP6 will review practical aspects of DOC selection criteria.



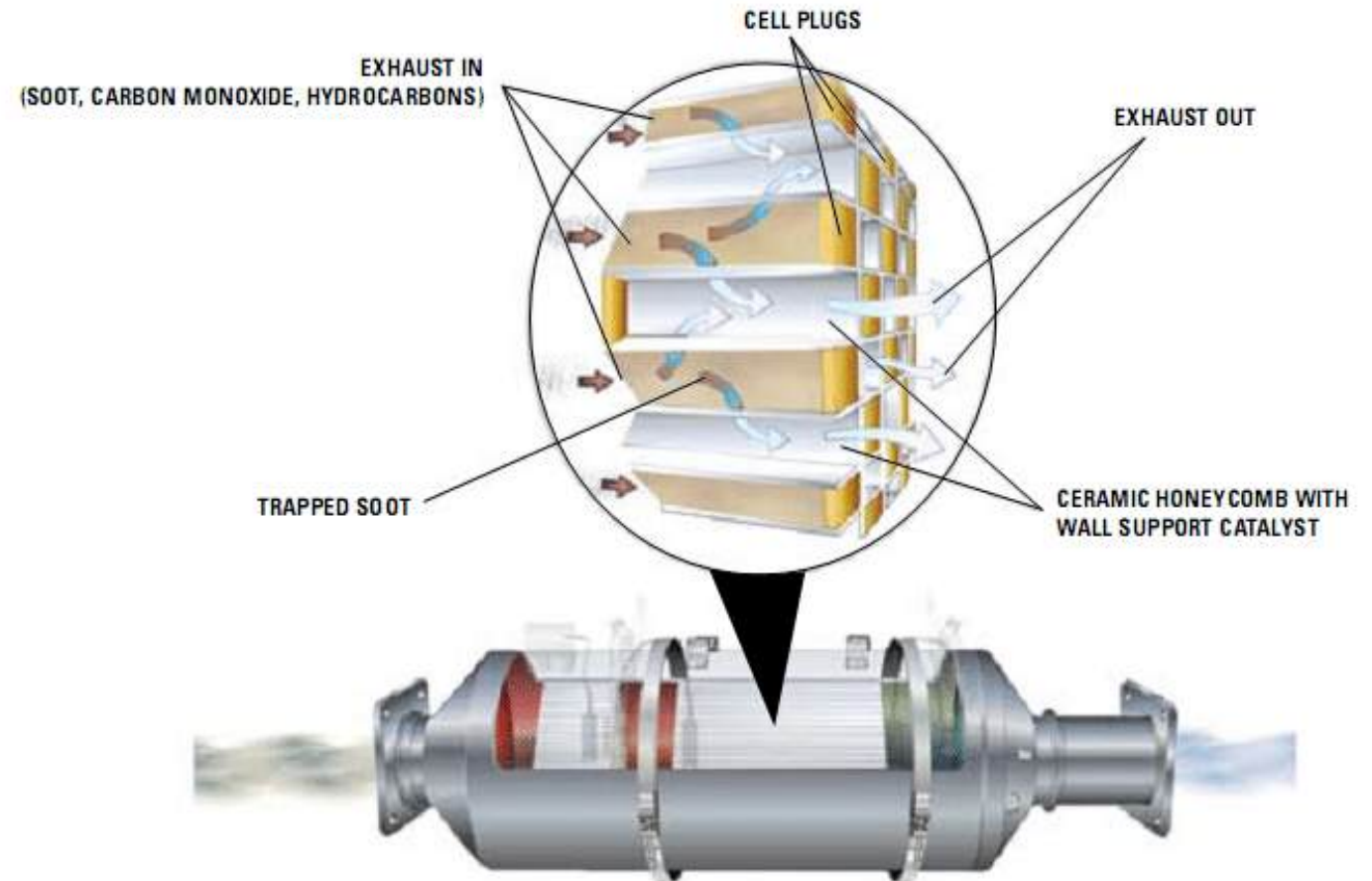
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Diesel Particulate Filters (DPF)

- DPFs look similar to DOCs but differ greatly in construction performance of operation.
- Primarily designed to trap and burn off particulate matter (soot), they can also be catalysed for CO and HC conversion.



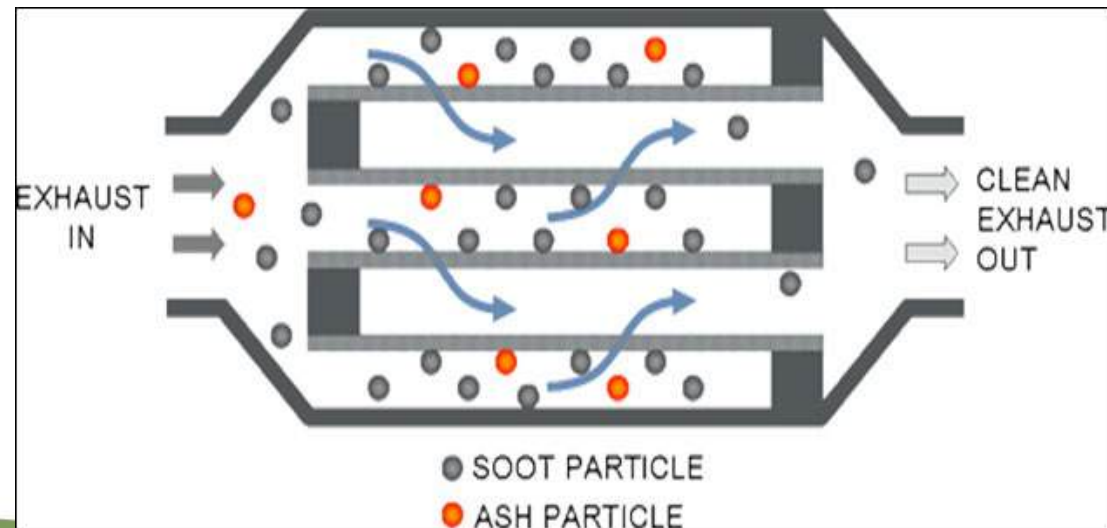
DPF Design Fundamentals

- The DPF is placed in the engine exhaust gas stream. It must have the following characteristics:
 - *Have sufficient volume to trap and retain enough soot to allow for reasonable periodic burn-off (regeneration) intervals.*
 - *Be made of a material with a porosity that will trap soot particles as a function of their size (which is related to engine characteristics).*
 - *Have a geometry to enable a good backpressure characteristic both when clean and during soot loading.*
 - *Have adequate durability to maintain structural integrity under engine/vehicle vibration and thermal gradients during regeneration events.*



DPF Geometry

- The most common DPF geometry is the wall-flow filter.
- Ceramic cordierite is extruded similar to a DOC except:
 - The ceramic DPF material is more porous than the DOC material, and
 - The extruded channels are alternately closed at the ends with ceramic plugs.



DPM (soot) trapping and regeneration

- This geometry leads the exhaust gas into the open channel at the inlet face. Because the channel is blocked at the other end, the exhaust gas is forced through the porous ceramic channel wall where it deposits the soot.
- The gaseous components of the exhaust gas pass out of the open end of the adjacent channel and out of the DPF.
- The trapped soot is retained in the DPF until the exhaust temperature rises sufficiently high to burn it off, (oxidize the carbon (C) to CO_2) when the gas can pass out of the filter.



DPF Materials

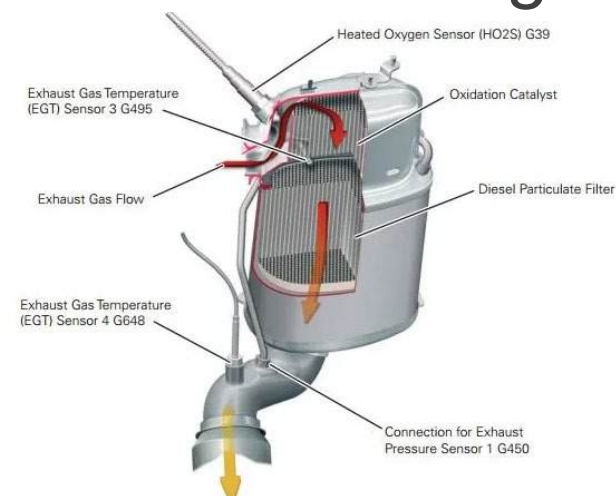
- DPFs are mainly constructed from ceramic (cordierite) or silicon carbide (SiC).
- Ceramic is light and inexpensive but fragile and must be protected from vibration and impact.
- SiC is more durable but still requires impact and vibration protection.

Feature	Cordierite	Silicon Carbide
Melting point (°C)	1,460	2,500
Mechanical strength	Lower	Higher
Filtration efficiency	Up to 90%	Up to 95%
Cost	Lower	Higher
Thermal shock resistance	Good	Lower



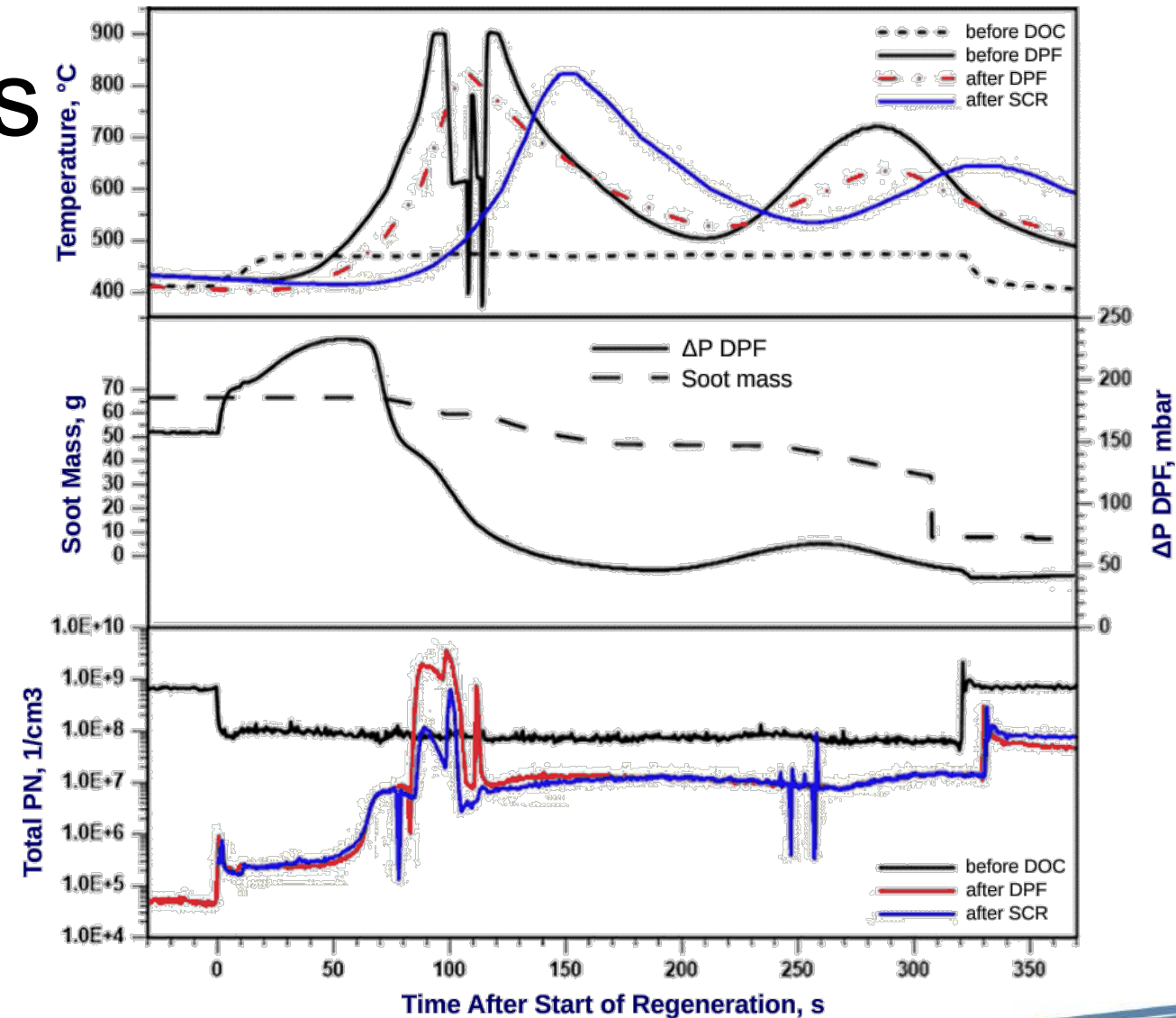
DPF Packaging

- DPF assembly construction and packaging is similar to DOC, however because the DPF weighs more there are additional structural considerations.
- Industrial HD DPF's should not be packaged vertically, as the additional mass combined with low frequency vibration will cause the core to shift and contact the shell where it can be damaged.



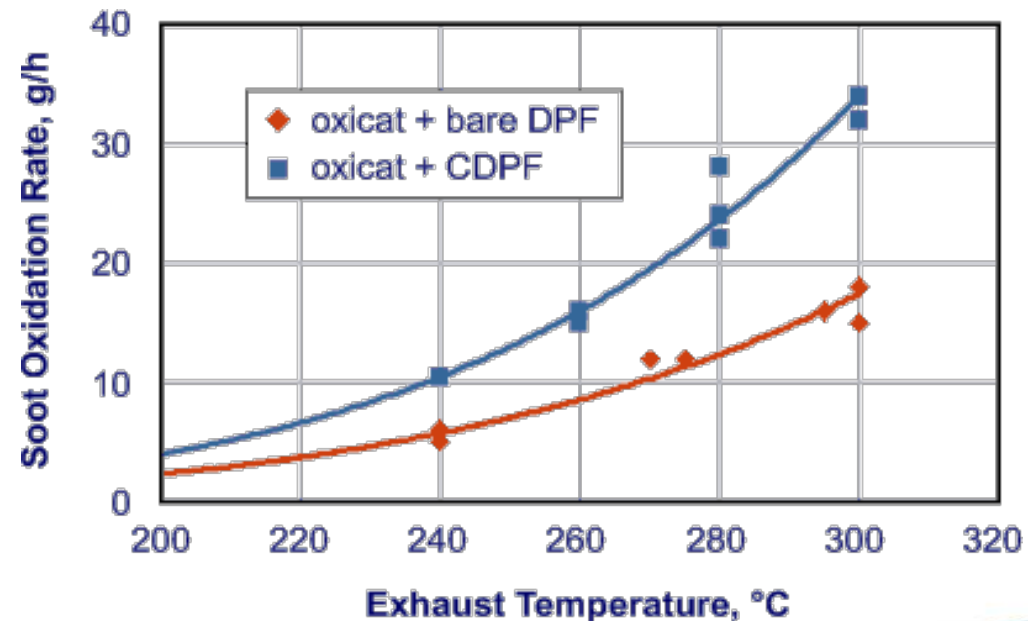
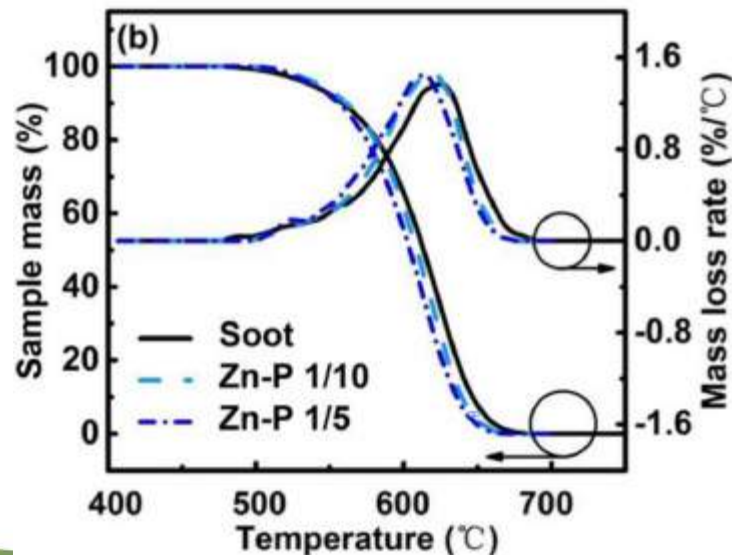
Regeneration Process

- Regeneration is required to burn off the accumulated soot so that the backpressure on the engine does not increase.
- This can be done actively with engine control or passively with catalytic coatings.



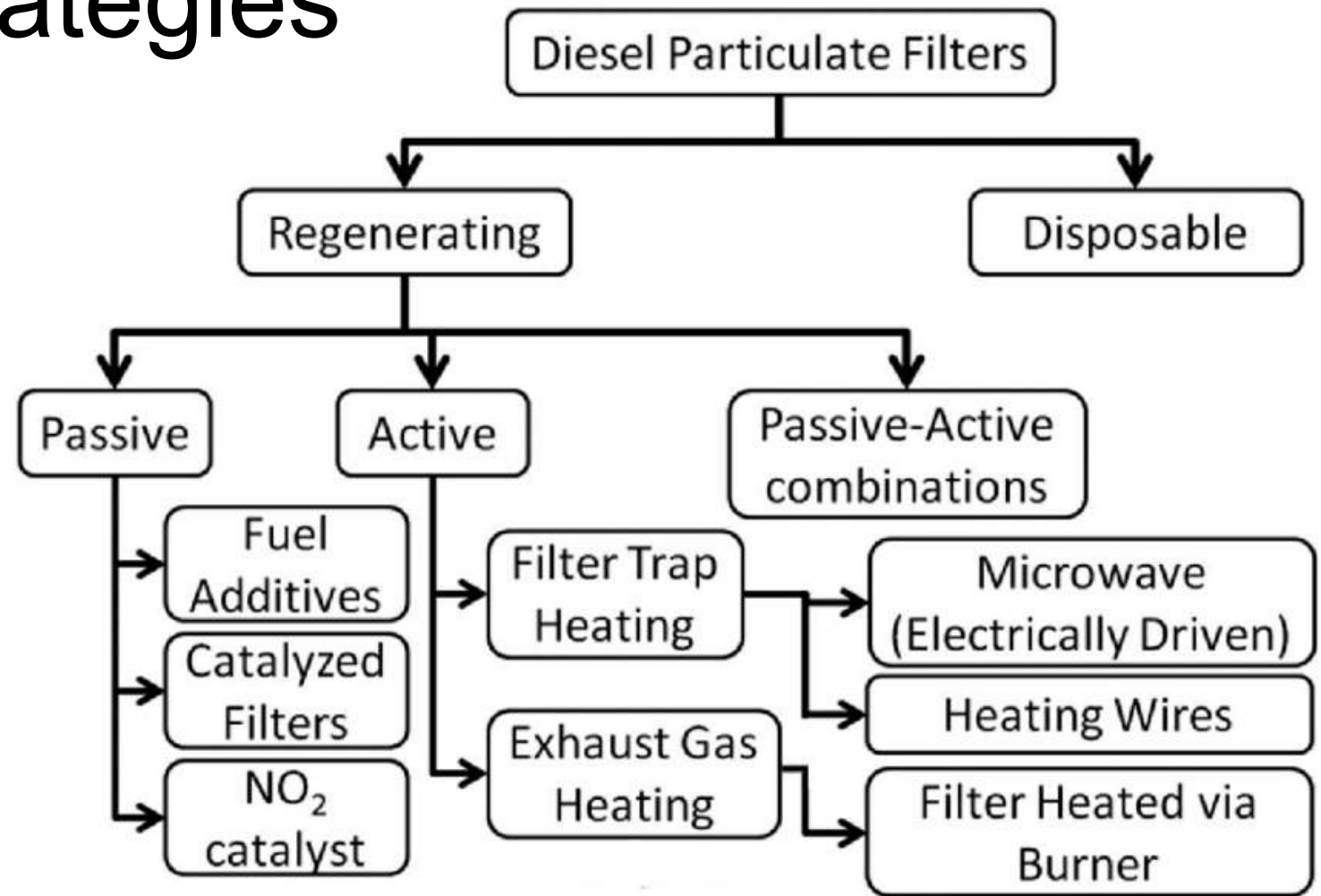
Washcoat and Catalytic material

- Most DPFs are coated with a catalyst to lower the soot regeneration temperature.
- Catalyst formulation trade offs are similar to the DOC application.



Regeneration Strategies

- Most OEM systems can use active control of regen due to integration of engine and aftertreatment.
- Retrofit is usually passive but there are some advanced active systems available.



Selective Catalytic Reduction (SCR)

- SCR is used to reduce NO_x emissions in diesel exhaust.
- Because diesels always operate lean of stoichiometric, there is always excess oxygen in the exhaust gas.
- This is great for the DOC to oxidize CO, DPM and HC, but NO and NO₂ cannot be eliminated by oxidation – in fact NO oxidized to NO₂ is undesired.
- A reduction reaction is required.
- How do we get a reduction reaction to occur in an oxidizing environment?



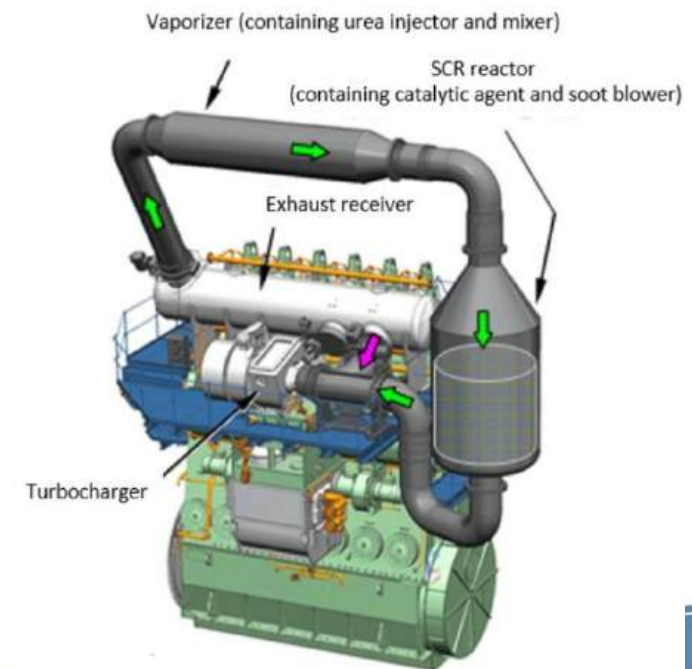
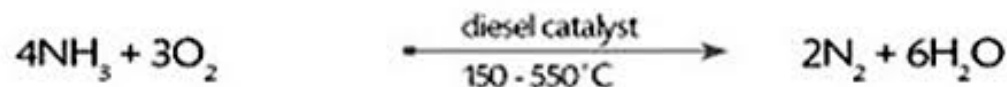
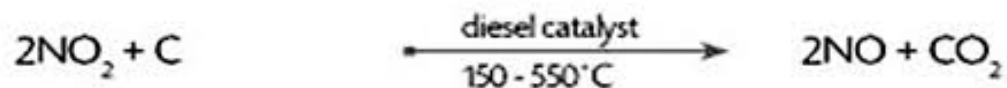
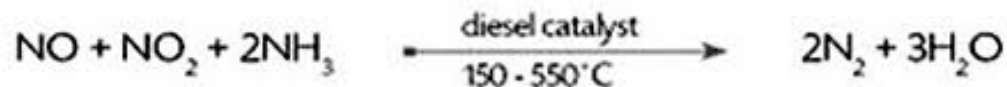
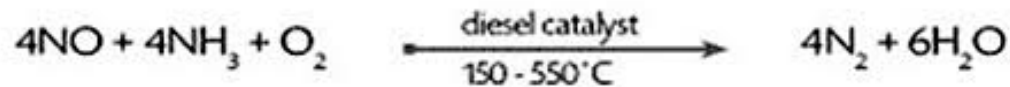
Urea Reductant

- Urea liquid is carried on board the vehicle and injected into the exhaust stream proportional to the amount of NO_x.
- The urea hydrolyzes to ammonia and NO_x is reduced as follows.

Urea decomposition:

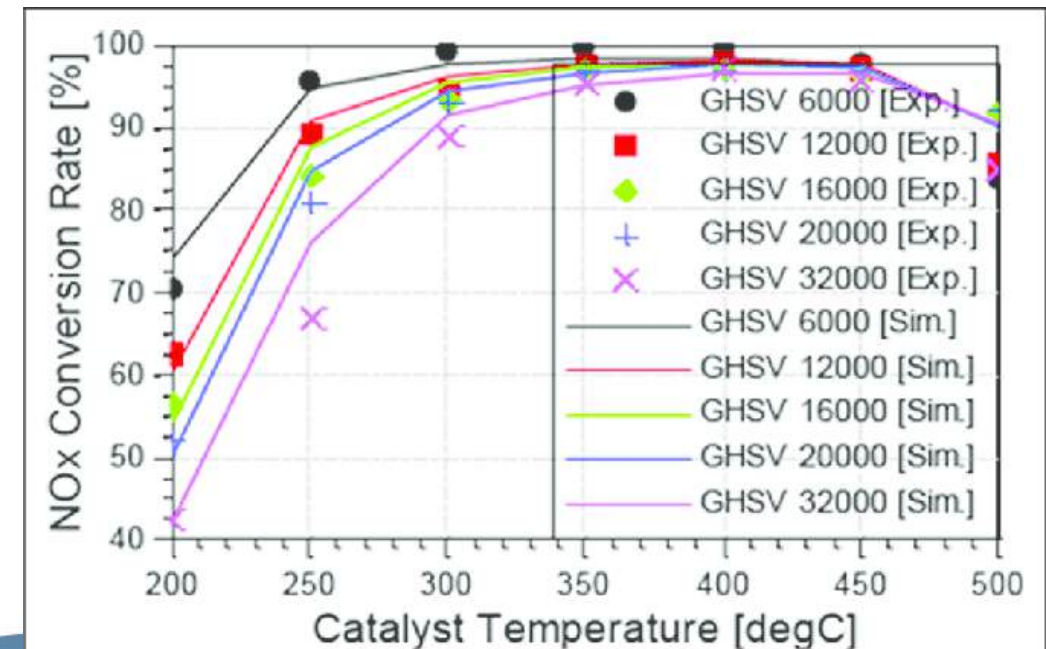
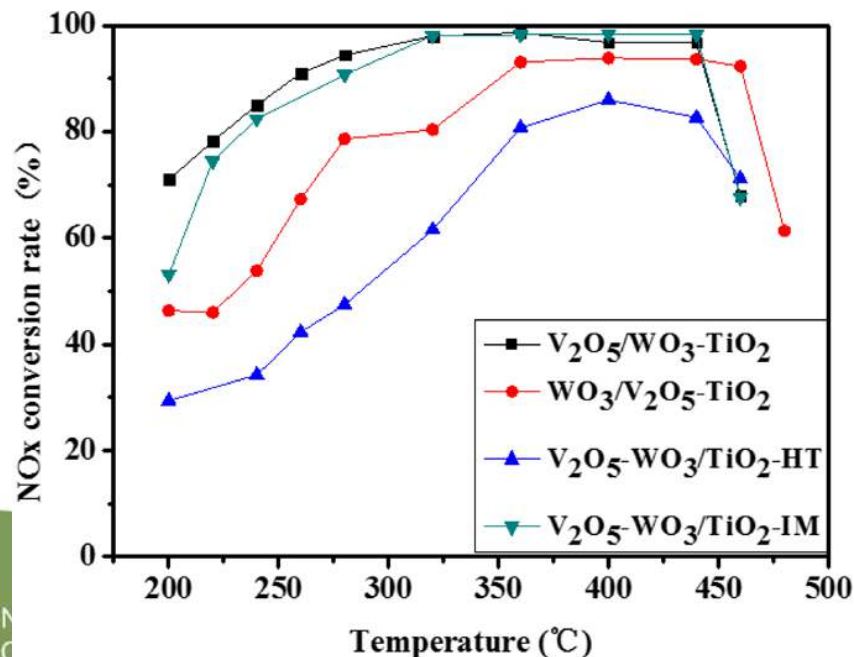


SCR reactions:



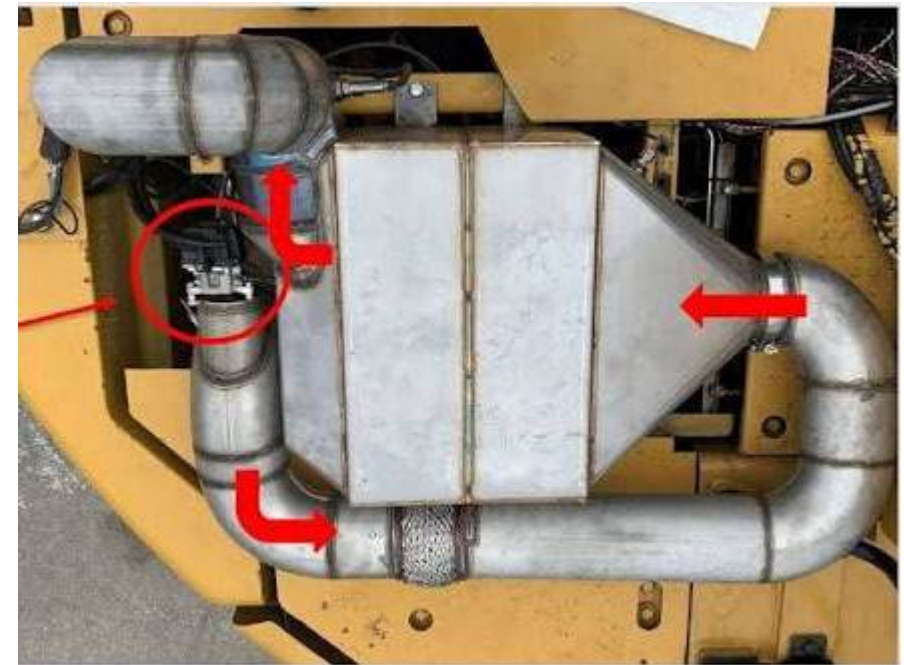
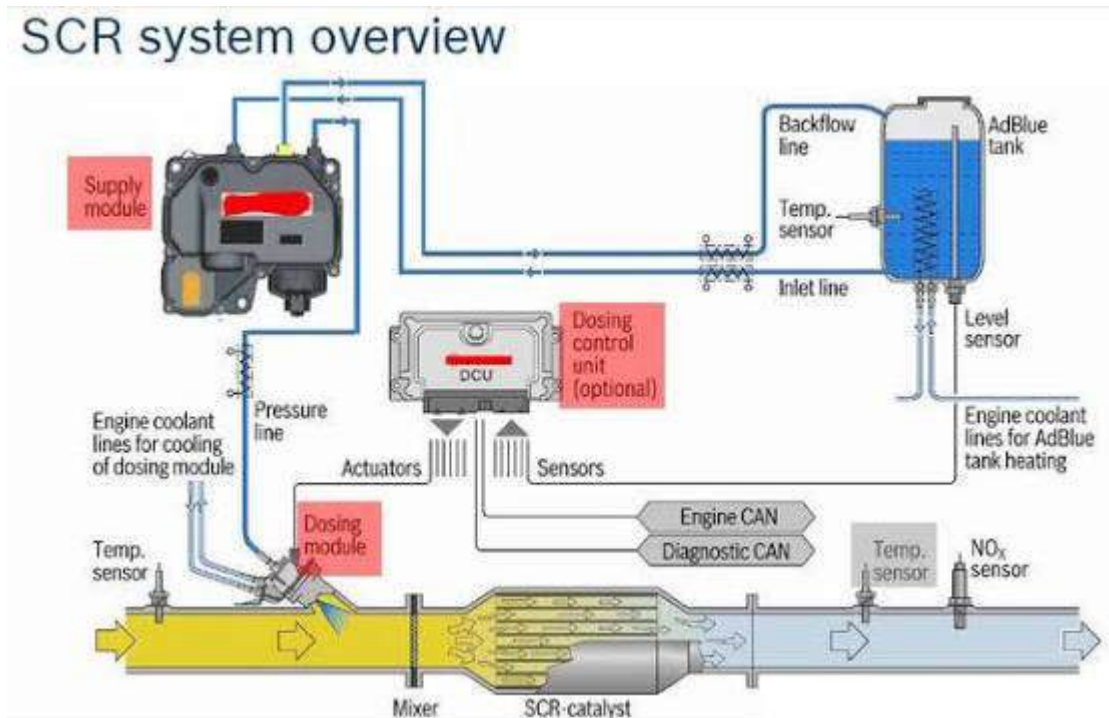
SCR catalyst materials and sizing

- SCR catalyst construction and materials are similar to the DOC.
- The catalytic formula is often vanadium based.
- The design GHSV is about 1/3 of a DOC so the SCR monolith is considerably larger to ensure sufficient time for the reaction.



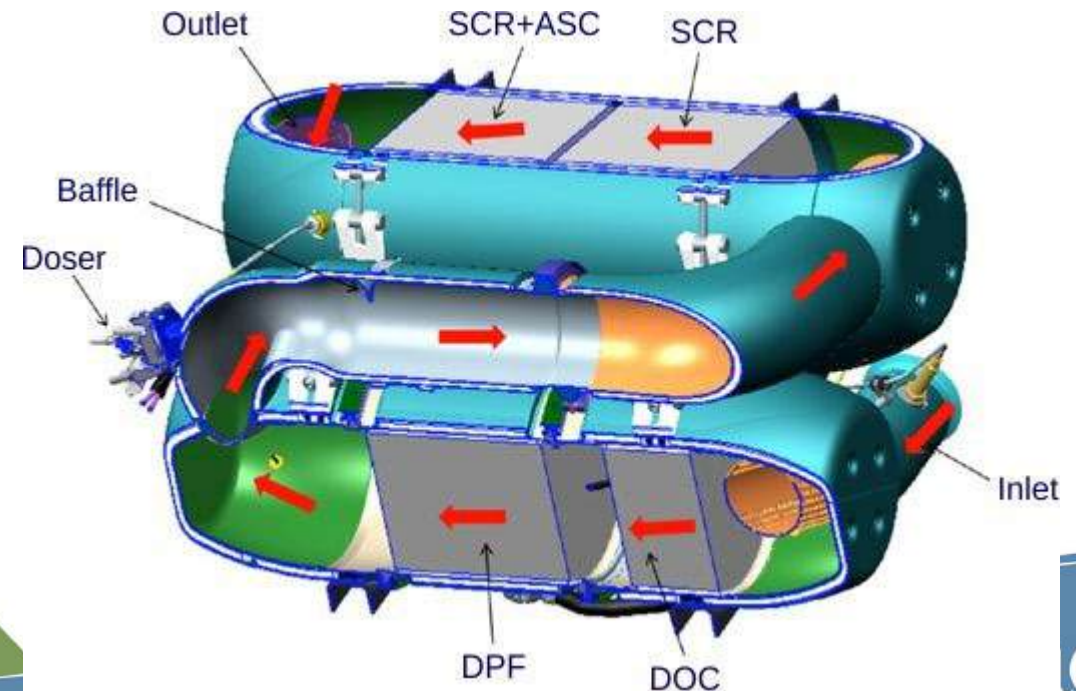
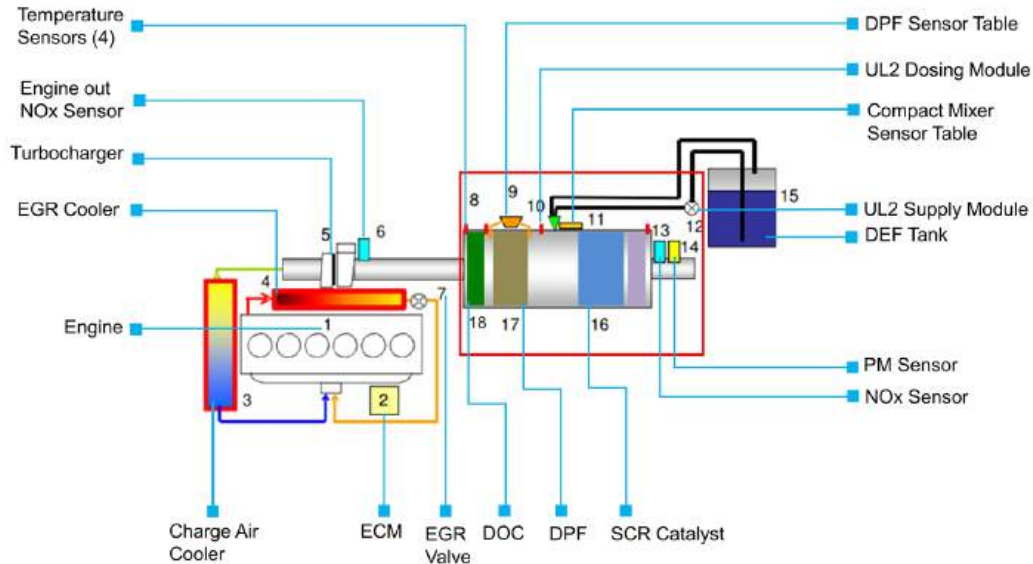
SCR system configuration

- The components of a production SCR system are shown here:



Conclusions: T4F / Stage 5 Integration

- An OEM aftertreatment system now integrates a DOC, DPF and SCR system into a single combined module for emissions control.
- Each component needs to be optimized to work with the next downstream piece to meet regulatory requirements.



Thank you!

