Diesel Particulate Control

Dr. A K Agarwal
Department of Mechanical Engineering
Indian Institute of Technology Kanpur

Engine Research Laboratory, IIT Kanpur www.iitk.ac.in/erl

Control of PM Emissions

- Engine parameters
  - Increase fuel injection pressure
  - Optimize structure of combustion chamber
  - Decrease consumption of oil
  - Use of fuel that contains small amount of sulfur
  - Advance fuel injection
  - Increase fuel amount in the phase of burning delay

- Oxidation Catalyst
  - Not able to oxidize the carbon core
  - Collecting efficiency is poor

- Diesel Particulate Filters (DPFs)
  - High filtering efficiency
  - Have prospect of substantially Reducing regulated PM emission
Lubricating Oil Control

![Pie chart showing origins of particulates](chart.png)

- **Origin: Fuel**
  - 66%
  - Sulfates: 13%
  - Soot: 43%
  - Insoluble: 5%
  - SOF fuel: 10%
  - SOF: 29%

- **Origin: Lubricant**
  - 34%
Figure 5: Contribution of lubricating oil to the total exhaust particulate. Percent of total versus engine speed.

Fig 2.9 Influence of lubricating oils on emissions
Because the influence of secondary piston movement cannot be taken as insignificant, the analysis is started with the determination of the lateral and tilting movement of the piston. The chronological sequence of the individual problems and their results is given as follows:

1. Piston secondary movement
   - Lateral movement
   - Tilting around piston pin
2. Piston Ring Dynamics
   - Oil film thickness
   - Inter-ring pressure
   - Axial ring motion and twisting
   - Blow-by
3. Lube Oil Consumption
   - Evaporation
   - Oil Throw-off
   - Reverse oil blow
   - Oil scraping of piston top land

4.7.2.1 Engine Design Factors Influencing Oil Consumption

- Engine Block
  - Rigidity and bore diameter
  - Bore roundness/tolerance
  - Cylinder wall honing quality

- Piston
  - Height and stroke
  - Roundness and tightness in bore
  - Land and skirt clearances
  - Secondary motion and maximum tilt angle
  - Ring positions
  - Grove width/depth

- Piston Rings
  - Profiles and tensions
  - Gaps and side clearances
  - Oil control ring type and effectiveness

- Connecting Rod
  - Misalignment and twist
  - Big end/small and offset

- Crankshaft
  - Oil lip seal effectiveness

- Cylinder Head
  - Valve stem clearance
  - Effectiveness of valve stem and camshaft oil seals

- Crankcase
  - Closed ventilation
### Table 1

List of basic parameters affecting the oil consumption originated from evaporation from cylinder liner surface

<table>
<thead>
<tr>
<th>Effect on oil consumption</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very significant</td>
<td>Temperatures:</td>
</tr>
<tr>
<td></td>
<td>→ t. of oil layer surface $T_1$,</td>
</tr>
<tr>
<td></td>
<td>→ mean t. of oil layer $T_0$,</td>
</tr>
<tr>
<td></td>
<td>→ t. of cylinder liner wall.</td>
</tr>
<tr>
<td>Significant</td>
<td>Temperature of gases in the cylinder $T_{gas}$,</td>
</tr>
<tr>
<td></td>
<td>Coefficient of diffusion $D_b$,</td>
</tr>
<tr>
<td></td>
<td>Coefficient of heat transfer $\alpha$,</td>
</tr>
<tr>
<td></td>
<td>Oil layer thickness $h$,</td>
</tr>
<tr>
<td>Moderate</td>
<td>Absorption-desorption processes rate,</td>
</tr>
<tr>
<td></td>
<td>Mean relative mass fraction of fuel in oil layer,</td>
</tr>
<tr>
<td></td>
<td>Gases temperature variation rate,</td>
</tr>
<tr>
<td></td>
<td>Biot number $Bi$,</td>
</tr>
<tr>
<td>Poor</td>
<td>Fourier number $Fo$,</td>
</tr>
</tbody>
</table>

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**MECHANISMS FOR PREDICTING LUBE OIL CONSUMPTION**

The applied model for predicting LOC considers all losses which can be assigned to the mass transport of lubricant from the crankcase to the combustion chamber. The total mass transport is determined by [2]:

- Evaporation from the liner wall.
- Throw-off of accumulated oil above the top ring.
- Oil blow through the top ring end into the combustion chamber due to a reverse gas flow.
- Oil scraping of the piston top land edge.
Optimized ring-liner combination – In order to continuously reduce PM formation based on combustion of engine lubricant, several different areas such as dynamic bore distortion, piston ring selection and cylinder liner honing structure as well as honing process will have to be considered for further improvement.

Fig.2: Sources of Particulate Emission
Essig et al. Kolbenschmidt #6
SAE 900 591
Figure 9. Cylinder Bore Deformation

SAE 95054.0 FCV

Fig.1 Oil consumption simulation flow chart in consideration of liner deformation

SAE 2003-01-0982 Riken Corp
ADVANCED POWER CYLINDER
"Balanced Pressure" + High Top Ring

FEATURES:
- LOW CREVICE VOLUME
- OPTIMUM INTER-RING VOLUME FOR STABLE RING DYNAMICS

ADVANTAGES:
- LOWER SMOKE EMISSION
- REDUCED OIL CONSUMPTION
- LOWER PARTICULATES

Fig. 5 Assumptions of oil starvation
Fig 5  Schematic of oil flow paths in a 2 compression ring path

IME C465/008/93 SHELL

Fig 1a  Mechanism of oil loss from the top ring zone of an engine

EVAPORATION FROM CYLINDER WALL
OIL THROW-OFF (BULK LOSS)
CYLINDER WALL
OIL FILM
PISTON CROWN
TOP RING
EVAPORATION FROM CROWN-LAND


11/13/2015
Particulate Trap
Definitions

Substrate - A flow-through substrate used as a support structure for catalyst applications

Particulate Filter - A wall-flow type filter used in diesel particulate filter applications
    commonly referred to as
    diesel particulate filters
diesel filters
    DPF’s
    traps
    filters

Definitions

Regeneration - cleaning of the soot collected in a filter

PM - Particulate matter - hard carbon products of combustion and SOF

SOF - soluble organic fraction - condensed hydrocarbons, unburned fuel and lubricating oil, etc
Diesel Retrofit Products

Diesel Particulate Filters & Substrates

- Filters (traps)
  - Particulate Removal From Diesel Exhaust
    - Trucks
    - Buses
    - Stationary

- Substrates
  - Trucks
  - Bus (Retrofit & OEM)
  - Light-duty vehicles (mainly Europe)

Wall Flow Filter Model
Wall Flow Filter Performance

- PM Reduction
  > 90% efficiency
- Fine Particle reduction
  > 99% larger than 35nm
- CO, HC
  > 70% (for catalyzed or continuous systems)
- NOx
  generally minimal reduction
- Odor Reduction possible

DPX™ Technology Description

- Catalyzed cordierite wall flow filter
- 70 to 98% total particulate matter reduction
- 60 - 80%+ carbon monoxide reduction
- 60 - 80%+ hydro-carbon reduction
- Flexible one substrate design
- Patented technology
- Sulfur tolerant - sulfur does not affect regeneration characteristics
Diesel particulate filters

Diesel Substrates

Sizes, shapes, and cell densities to accommodate a variety of engines sizes and space constraints
Diesel Particulate Filters (DPFs)

- Consists of particle collecting and the regeneration device
- Particle collecting device is mainly made of filler material
- Regeneration is to clean up the filler material

Operational diagram

DPFs Geometries & Filler Media

Filler media and the geometric configuration is a key element and the selection process deserves careful balancing of different criteria including,

- Pressure drop
- Collector efficiency
- Ease of regeneration
- Cost, etc.
Available Filler Media

- Ceramic
  - Cordierite
  - Mulite
  - Silicon Carbide
  - Mulite/zirconia etc.
- Metallic
  - Sintered metal
  - Wire mesh
  - Metal foam

Geometric Configurations

- Honeycomb Wall Flow Monolith (a)
- Foam monolith blocks and plates (b)
- Cylindrical Cartridges (c)
PARTICULATE TRAP FILTERATION MECHANISMS

- This is where large particulates suspended in the exhaust gas stream strike, spread and adhere to the surface of the wire-mesh strands, or accumulate on previously impacted particulates Fig. a.
- This is where medium-to-Large particulates, moving with the exhaust gas flow, collide with the mouth of individual passageways Fig. b.
- This is where small particulates entering the filter passageways attach and spread themselves against the porous walls or diffuse onto existing particulate matter which has already become attached to the porous surfaces of the trap Fig. c.

WIRE MESH PARTICULATE TRAP AND OXIDIZER

- The trap substrate is made from a knitted stainless-steel wire-mesh compressed between the perforated cylindrical inner and outer casings.
- The wire-mesh is woven and rolled to give a low density and surface volume ratio on the outer region of the annular-shaped substrate, with an increasing density and surface-to-volume ratio towards the inner diameter region.
SILICA FIBRE CANDLE PARTICULATE TRAP AND OXIDIZER

- This approach incorporates nine filtering elements consisting of punched sheet metal support tubes with one end closed, and around these tubes are woven layers of silicon fibre yarn in a crosswire pattern to form the filtration media.

- Because these elements resemble candlesticks they are known as candle elements.

- The silicon dioxide yarn thread has a diameter of between 0.7 and 1.0 mm which, in turn, is made up of individual fibres of about $9 \times 10^{-6}$ mm.

Choice of Filler Material

- High temperature resistance
- Durability
- Cyclic heating & cooling test
- Exposure test to high temperature

- Sakaguchi et al. conducted above tests on some fibers, ceramics were heated upto 900° C and then cooled to 100° C by air blowing

- SiC is best material strengthwise
Choice of Filler Material

- Exposure test at 900°C for 150 Hrs in electric furnace was also carried out by Sakaguchi et al. Electron Microscope images of fibers after exposure test is shown,

- SiC retains its shape

Diesel Particulate Filters Nearly Eliminate PM

- PM Emissions Well Below 0.02 g/bhp-hr Can Be Achieved on Both Fuels (0.008 with 54 ppm S Fuel)
- Significant Reductions in CO and HC Emissions Can Be Achieved

Source: MECA 1999
**Filters Very Effective in Reducing Ultra-Fine Particles**

- Ultra-Fine Particles Reduced by in Excess of 99.99%

![Graph showing particle diameter and filter effectiveness.

Source: VERT 1998](#)

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**Filters More Effective when Used With Low Sulfur Fuel**

![Graph showing PM emissions with different fuel sulfur levels.

Source: MECA 1999](#)
Filters Destroy Large Fractions of Toxic Emissions

- PAH Emissions Reduced by 89%

Particulate Trap Regeneration
PARTICULATE CONTROL

- Particulates (Pm’s) generated in lean burning systems when combustion oxygen and temperature are low.
- Pm’s can be thermally burned, but need a temperature of about 600 °C.
- The exhaust gas in most lean burn vehicles does not reach this temperature consistently (i.e., regeneration is discontinuous), therefore there is the danger of thermal runaway.

Regeneration of DPFs

Regeneration is difficult
- Process requires temperature above 600 °C
- Obtaining close contact between carbon core of PM and catalytic surface on wall of filter
- High temperature may damage the trap

Method includes
- Reduce combustion temperature by use of
  - Catalytic coating
  - Fuel additives (Ce based catalyst such as EOLYS, Cu fuel additives)
  - Injection of oxidant like H₂O₂
- Burner (Diesel fuel)
- Electric Heating
- Microwave Heating
Exhaust temperature implications

- $T_{30\%}$ is $>325^\circ C$ – a self-regenerating "passive" DPF is possible
- $T_{30\%}$ is $<325^\circ C$ – a manually regenerated "active" DPF is required

Self-regenerating (Passive) DPFs

<table>
<thead>
<tr>
<th>$T_{30%}$</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&gt;550-600^\circ C$</td>
<td>Uncatalyzed &quot;bare&quot; DPF</td>
</tr>
<tr>
<td>$&gt;380-420^\circ C$</td>
<td>Base-metal catalyzed DPF</td>
</tr>
<tr>
<td>$&gt;300^\circ C$</td>
<td>&quot;5g&quot; Pt catalyzed DPF</td>
</tr>
<tr>
<td>$&gt;340^\circ C$</td>
<td>Lightly Pt-catalyzed DPF + fuel borne catalyst</td>
</tr>
<tr>
<td>$&gt;325^\circ C$</td>
<td>&quot;50g&quot; Pt- catalyzed DPF</td>
</tr>
</tbody>
</table>

The above temperatures are approximate; only the DPF supplier can recommend the proper DPF system.

Catalytic Oxidation of Diesel Particulates-Carbon Fraction

Carbon is oxidised by:

- Oxygen: $C+O_2 \rightarrow CO/CO_2$
  - Many metals promote $C+O_2$ reaction
  - but have no reaction with NOx

- $NO_2$: $C+NO_2 \rightarrow CO/CO_2 + NO$
  - Platinum promotes $2NO + O_2 = 2NO_2$

- $NO (+O_2)$: $2C+O_2+2NO \rightarrow 2CO_2+N_2$
  - Reaction is catalyzed by Platinum + cerium
  - Platinum + cerium oxidizes both the carbon and hydrocarbons (SOF) present in the exhaust at temperatures as low as 200°C
Active Regeneration

Burner regeneration system

Electrical Regeneration
Strategy for Complete Regeneration

Regeneration Cycle Of Diesel Particulate Filter
Fuel Borne Catalyst

- Although there are a number of methods for regenerating a particulate filter, the most widely used and the most cost-effective is to use a fuel borne catalyst.

- A fuel borne catalyst works by reducing the ignition temperature of the trapped soot.

- FBC help to burn off the soot deposits in a filter by lowering the temperature at which the particles combust.

- This regenerates diesel particulate filters without compromising engine performance.

Principle of Operation of Fuel-Borne Catalyst Technology

- Continuous and fresh catalyst supplying.

- Best 3D-Catalyst dispersion (highest contact point numbers).

- To favour propagation of soot combustion process to the entire soot layer (complete regeneration).
Fuel Borne Catalyst

- Provides catalytic properties to the diesel fuel to:
  a) Improve the combustion process in the engine
  b) Improve the performance of flow through after treatment devices i.e. DOC’s
  c) Assist soot regeneration in a DPF

- Dosed directly into the bulk diesel fuel or via an on board dosing unit

Key Benefits – Emission reductions

- When used as a performance additive
  PM reduction of 5 to 20% engine out – EPA Registered additive
  Reduces NOx and particulate emissions from bio diesel blends

- When used with an emission control device
  PM reduction of 40 to 50% with DOC* – EPA Verified
  PM reduction of 60 to 75% with CWMF* – EPA Verification Pending
  PM reduction of Over 90% with DPF – DPF
  Regeneration additive (VERT approved additive)

CWMF = Catalysed Wire Mesh Filter
**Key Benefits – Performance**

- Does not require special Ultra Low Sulphur Diesel
- Works with a wide range of engine size and age
- No secondary emissions of unwanted NO\textsubscript{2}
- Allows for significant reduction (up to 90%) in base Pt catalyst used on the retrofit device
- Continual replenishment of the catalyst during operation life ensures long term device durability and reliable service.

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**Fuel Borne Catalyst**

[Image of fuel borne catalyst system]
Criteria for Fuel-Borne Catalysts Selection

- Health and environmental legislations.

- In European Area, only Cerium-based and Iron-based Fuel-Borne Catalysts have been approved by European Union authorities.

- Compatibility with filter materials and vehicle parts (fuel injection system, engine parts, fuel tank materials, on-board dosing system, oxidation catalyst...).

- Compatibility and solubility in common diesel fuels.

- Temperature and time stability.

Practical Requirements for Serial Applications

- Automatic On-Board Dosing System for Fuel-Borne Catalyst

- Diesel Particulate Filter :
  - Efficiency
  - Durability
  - Integration in exhaust pipe line
  - Robust (highest soot loading limits).

- On-Board Diagnosis System :
  - Detection of DPF cracking,
  - Stop the Fuel-Borne Catalyst addition
Automatic On-Board Dosing System

Impact of Fuel-Borne Catalyst

Engine operating map where domains are outside continuous regeneration area
Temporary Heat Injection Strategy

For durable and reliable trap regenerations, strategies in after-treatment technologies need a global system approach and engine management.

Optimization of Strategy

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On-Board Diagnosis System via Back-Pressure Sensor

![Graph showing back-pressure vs. air mass flow with different states: DPF full, DPF empty, DPF damaged, regeneration to be started, and warning.]

CRT Filter System
Continuously Regenerating Trap

- Principle
- Oxidation of NO to NO\textsubscript{2} inside Pt catalyst
- Conversion of stored soot in trap by NO\textsubscript{2}

![Diagram of CRT filter system with Pt catalyst and soot filter. Reaction equations: 2NO + O\textsubscript{2} ⇌ 2NO\textsubscript{2}, C + 2NO\textsubscript{2} ⇌ CO\textsubscript{2} + 2NO, C + O\textsubscript{2} ⇌ CO\textsubscript{2}]

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Continuously Regenerating Trap (CRT)

- Utilize the strong oxidizing property of NO₂
- Unit consists of Pt based catalyst upstream of Filter to oxidize NO to NO₂
- NO₂ oxidizes the soot(C) into CO₂ in the trap

\[
\begin{align*}
\text{C(s) + NO}_2(g) & \rightarrow \text{CO(g) + NO(g)} \quad (1) \\
\text{CO(g) + NO}_2(g) & \rightarrow \text{CO}_2(g) + \text{NO(g)} \quad (2) \\
2 \text{NO(g) + O}_2(g) & \rightarrow 2 \text{NO}_2(g) \quad (3)
\end{align*}
\]

- This system is very sensitive to sulphur content of fuel (S<10 ppm)
Substrate

- Mechanical & thermal characteristics
- Porosity and filtration mechanism
- Pressure drop characteristics
- Packaging design
Washcoat is composed of various compositionally distinct domains Pt, Pd, BaO, CeO$_2$-ZrO$_2$

$BaO > CeO_2 -ZrO_2$ & $BaO < CeO_2 -ZrO_2$

imply existence of different Ba morphologies (e.g. surface vs. bulk)

Pt, CeO$_2$, MgAl$_2$O$_4$, Rh, Al$_2$O$_3$
DPF Variables

1. Substrate
   • Dimensions (geometry, diameter, length, location/packaging)
   • Properties (density, thermal and mechanical properties, max. safe temperature)
   • Cell configuration (density, dimensions, wall thickness)
   • Pore size (porosity, permeability)
   • Packaging design
2. Engine Exhaust - Variation with duty cycle
   • Mass flow rate
   • HC, O2, NO/NO2 concentrations
   • Temperature
   • PM concentration
3. Regeneration Strategy
   • Thermal
   • Chemical & thermal
4. Fuel and lube properties - ash, sulfur

DPF Performance and Durability

Performance
• Filtration Efficiency
• Pressure drop performance (FE)
• Thermal survivability
• Normal thermal cycle
• Thermal shock
• Loading and regeneration
• Catalyst efficiency

Durability
• Thermal aging
• Ash accumulation
• On-vehicle durability
DPF Performance –cont.

- Trap temperature and temperature gradient profiles
- **Durability (Temperature gradient and ash interaction)**
- DPF exhaust composition
- Energy consumption
- Control strategies

DPF Needs to Survive Vehicle Lifetime

- For light-duty vehicles (e.g., passenger cars), DPF maintenance may not be considered during the entire vehicle lifetime.
- For heavy-duty vehicles, the maintenance interval may not be less than 150,000 miles during the 435,000 mileage of vehicle durability (Cost of cleaning)
- DPF Durability and Survivability
- DPF regeneration
- On-vehicle DPF performance
Uncertainty of soot generation rate and continuous soot combustion rate (especially for CRT and catalyzed traps).

Origin of soot significantly affects both qualitative and quantitative results (possibly one of the reasons of controversy of the literature data).
DPF Filtration Process

Soot Cake Shape and Porosity by SEM
“Passive” regeneration via NO$_2$ in catalyzed filters
Due to concentration gradient, O2 is transferred from the axial flow to the soot layer and increases availability and reaction rates - results in higher max. temp in channel.

- DPF pressure-drop (doesn’t have good correlation to PM loading in real world)
- Controls to avoid runaway regenerations, handling incomplete regenerations
- DPF Poisoning – lubricant poisoning and ash accumulated may affect DOC light-off and efficiency
DPF Pressure drop “hysteresis” - Wall-scale effects

Incoming soot does not re-penetrate the wall. The correlation of pressure drop Vs. soot loading is depends on partial regeneration history.

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DPF Pressure drop hysteresis effect

Following an incomplete regeneration, the cake soot does not allow the incoming soot to penetrate the wall. The pressure drop correlation with soot loading changes dramatically.

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Key Technical Hurdles – wall flow DPFs

- filter plugging
  - carbonaceous materials
  - ash deposits
  - face plugging
- thermal failures
  - cracking
  - melting
  - catalyst absorption into the bulk
- filtration performance
  - trapping effectiveness
  - sulfate particulate production
- size and cost
  - high soot ignition temperature – precious metals and/or enthalpy

Ash Plugging With Particulate Filters

Base Oil

Detergent and Inhibitor

VI Improver

Engine Exhaust
- Large exotherms,
- non-uniform reactant concentrations,
- non-uniform flow,
- non-uniform reaction

Soot filters
DPF - issues

- Maximum temperature during uncontrolled regeneration
- Particle morphology, oxidation characteristics
- PM spatial distribution and impact on maximum temperature
- Ash creation, composition, and transport vs. operation
- Gas emissions during regeneration

Hot spots may melt DPF walls and destroy it
DPF Regeneration System Requirements

- operate under all anticipated conditions.
- transparent to the driver
- acceptable product packaging on vehicles
- minimal effect on engine performance and fuel economy
- reliable and durable (1.5 million km)
- emission compliance
- maintenance interval requirements
- acceptable environmental impact (no unreasonable risks due to unregulated emissions)
- end-product and service life cost (acceptable to the customer)
Regeneration Methodology & Control for Reliability and Durability

- Must operate within the operational limits of temperature, thermal and mechanical stresses of trap substrate.

1. Oxidation temperature requirements
   - O2 based
     - Catalysts
     - Additives
     - Exhaust composition (HC, NO...)
   - NO2 based - Exhaust composition (NO, C ..)

2. Regeneration Temperature Generation
   - Engine
     - Operating conditions
     - Supplemental measures (Post Injection/DOC...)
   - External to engine
     - Fuel oxidation - Burners etc.
     - Electrical
       - Heaters - configuration
       - Microwave
   - Combination of both

Regeneration Methodology & Control for Reliability and Durability-contd..

3. Regeneration Rate Control - Compatible with Substrate
   - Gas or substrate temperature
   - Space velocity
     - System configuration (Full or partial flow..)
     - O2 availability
   - Soot loading

Velocity, temperature and loading gradients are important

4. System Controls
   - controlled effective regeneration under all operating conditions
     - Transient operation
De-Sooting During Expressway Cruise

DPF Regeneration Related Failure Modes
Classification of Uncontrolled Regeneration

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Cause</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Excess exotherm at start of regeneration</td>
<td>1. High SOF</td>
<td>1. Close coupled DOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. High temp ramp rate</td>
<td>2. Control temp ramp rate</td>
</tr>
<tr>
<td>B</td>
<td>Temp. spike when runaway regeneration happens</td>
<td>1. High soot load</td>
<td>1. Higher EGR rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. High O2 (at idle) concentration</td>
<td>2. Intake air reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Low exhaust flow rate (reduced ht)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Hot spots- uneven temp distribution during regen.</td>
<td>1. Incomplete Regeneration</td>
<td>Improved flow distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Uneven flow/temperature distribution</td>
<td></td>
</tr>
</tbody>
</table>

Thermal Ageing

- Controlled DPF regeneration has limited thermal aging effect (<7500°C)
  - 150-200 cycles for vehicle
- Uncontrolled (runaway) regeneration has the largest impact on DPF thermal aging (850-13000°C)
  - Less than 5% in real-world statistics
  - Ways to avoid runaway regeneration
- Higher soot loading has added exothermal during regeneration (incomplete regeneration)
Quickly reduce O₂ when Engine goes to idle

- Engine out NOx increased significantly during DPF regeneration.
- Intake throttling required reducing EGR to maintain sufficient O₂ for given load.
- Reduced EGR resulted in higher engine out.

Throttle Assisted Regeneration

Fuel injected ahead of the DOC with intake throttling assistance

- Engine out NOx increased significantly during DPF regeneration.
- Intake throttling required reducing EGR to maintain sufficient O₂ for given load.
- Reduced EGR resulted in higher engine out.
Runaway regeneration occurs when DPF is very hot and:
- Exhaust flow rate is suddenly lowered in mode transitions
- Excess O2 is available in exhaust

Prevent runaway regeneration
A: by intake throttling to reduce available O2 in exhaust
B: Air injection into exhaust
Cool air removes heat from soot oxidation reactions

Vehicle Driving Cycle for DPF Soot Loading

![Diagram of DPF Wall Temperature vs. Time for different modes and locations (Inlet, Midpoint, Outlet).](image-url)

![Diagram of Vehicle Speed vs. Time for a driving cycle.](image-url)
• DPF can reduce PM emissions by about 95% but fuel economy is an important issue for future emission control measures.

• Future emission standards will require DeNOx technologies.

• Currently, the NH3-SCR and Lean NOx-Trap (LNT) technologies show most promise.
**DPX™ Catalyzed Diesel Particulate Filter**

![Image of DPX™ Catalyzed Diesel Particulate Filter]

**DPX FTP Emission Performance**

![Bar chart showing emission performance for different engines](chart)
The Mitsubishi DPF System

A device that vastly reduces emission of particulate matter (the main particle component of black smoke) from diesel engines of buses
Mitsubishi DPF System

- Mitsubishi put this system for practical use first time in Japan in buses
- Succeeded in removing 80% of PM even removes 100% of black smoke

Overview of the Mitsubishi DPF System

The Mitsubishi DPF System traps particulate matter in a porous ceramic filter, and this accumulated particulate matter is periodically burned. By regularly exchanging two filters to continuously trap and burn particulate matter, it can be continuously collected while the bus is running.
Overview of the Mitsubishi DPF System

System Overview
- Two filter assembly
- Exhaust gas control valve
- Air flow sensor, temperature & pressure sensors
- Electric heater & convector

Particulate matter collection
- The filters use a heat-resistant, finely porous ceramic material. These pores form parallel channels,
- Using 2 filters, exhaust gas is passed through one filter until the accumulation level reaches a specified point, at which the exhaust gas flow is switched automatically by the switching valve to resume particulate matter collection by the other filter.
Overview of the Mitsubishi DPF System

Particulate matter combustion

- After the filter end is heated to 600°C by the electric heater, the exhaust gas control valve is opened and part of the exhaust gas is conducted into the filter. The accumulated particulate matter inside the filter is then gradually burned over about 25 minutes by flame propagation.

Effectiveness of exhaust gas cleaning

- Approximately 80% of particulate matter is eliminated, achieving output levels of only half those specified in the 1988 long-term exhaust gas restriction (JIS) target.

- Moreover, black smoke, which accounts for most (65%) of particulate matter, is 100% eliminated, making exhaust invisible to the eye.
Effectiveness of exhaust gas cleaning

Effectiveness of particulate matter reduction. Effectiveness of black smoke reduction.

Thank you