
TECHNICIAN
TRAINING
DORMAN
Training Seminar Series
Presents
Introduction Diesel Emissions
Usage
Diagnosis Part 1

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DORMAN
Aftermarket Innovators

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Your Instructor For This Webinar

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- **Developed trainings that range from four hours to multiple days, specializing in brakes, electrical, regulations and many other subjects relating to our industry.**
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Emissions 101

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- This webinar will provide insight to emissions systems that are used on heavy duty engines/vehicles.
- We will look at why we have emissions reduction.
- We will describe the key components in emissions systems and how they work.

NOTE: This Part 1 gets us familiar with components and systems required for diesel emissions reductions. This lunch and learn topic will be on going, diving deeper each time.

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Why Do We Care About Emissions?

What Do We Know About Emissions?

How Can We Control Emissions?

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What types of emissions are produced by Diesel Engines

- They emit significant amounts of:
  - Oxides of Nitrogen(NOx)
  - Particulate Matter (PM)
  - Hydrocarbons (HC)
- Compared to Gasoline-Powered engines, the lean diesel-air mixture results in smaller volumes of hydrocarbons and carbon monoxide.
- However: High combustion temperatures in diesel engines that result from compression ignition increases NOx formation.
- Note: Lowering the combustion temperature decreases NOx levels, but tends to increase the amount of fuel which is not burned.
- This results in particulate matter and unburned hydrocarbon emission.

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Advantages of Diesel Engines

- Efficient Power Plants
- Superior Fuel Economy
- Emit extremely low concentrations of HC's and CO emissions

What about NOx and Carbon Dioxide (CO2)

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Carbon Dioxide (CO2)

Typically referred to as a " Greenhouse" gas and considered responsible for global warming.

- **Industrial activities, heating and power generation are responsible for about 70% of man-made CO2.**
- **Transportation related CO2 emissions represent about 30% of all man-made CO2.**
- **2022 estimates CO2(Carbon Dioxide) produced from U.S. gasoline and diesel fuel consumption:**
  - **Gasoline- 1,023 million metric tons (MMmt) of carbon dioxide (CO2)**
  - **Diesel- 464 MMmt of CO2**
  - **Total 1,488 MMmt of CO2**

This total was equal to about 81% of total U.S. transportation sector CO2 emissions and about 30% of total U.S. energy-related CO2 emissions in 2022.

***Source: EIA (US Energy Information Administration).**

Not: Biofuels are not included in this.

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GHG3: EPA's Phase 3 of Greenhouse Gas Emissions. (Finalized March 2024)

- Part of Clean Trucks Plan
  - More stringent standard requirements for manufacturers.
- Requires that by 2032 25% of new long-haul and 40% of heavy-duty short-haul and medium-duty vehicles to be zero-emissions.
- Industry opposes this, however there are some engine manufacturers and others like Cummins and Ford that don't oppose it, but said it is challenging, but they can overcome any challenges to achieve that goal.

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2023 Industry Statistics

- 282,354,993 Total registered vehicles.
- 10,715,697 Single unit (Straight trucks).
- 3,143,484 Combination trucks (tractor-trailers).
- 3,132.4 "billion" "By all vehicles". Vehicle miles traveled (VMT).
  - Large trucks traveled 327.0 "billion" of those miles (10.4%) of total.
  - Buses traveled 16.7 "billion" of those miles (0.5%) of the total.
- Approximately 9 million CMV drivers operate in the U.S.

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NOx Emissions

NOTE: This table was used for a baseline to establish emissions standards.

Emissions From Diesel And Gasoline Engines

Test condition	Emissions (g/bhp-h)			
	HC	CO	NOx	PM
Diesel engine-out	0.15	1.50	3.40	0.07
Gasoline engine-out	0.81	30.22	4.30	-----
Gasoline with three-way catalyst	0.07	2.30	0.04	-----

Looking at table – HC and CO on engine out is lower on diesels vs. gasoline engines. Even diesel engine out NOx are almost 1.0 g/bhp-h (grams/brake horse-power-hour) less than the corresponding gasoline engine emissions. WHY? "The three-way catalytic converter" allows the same gasoline engine to emit extremely low: HC, CO, and NOx emissions at the "tailpipe".

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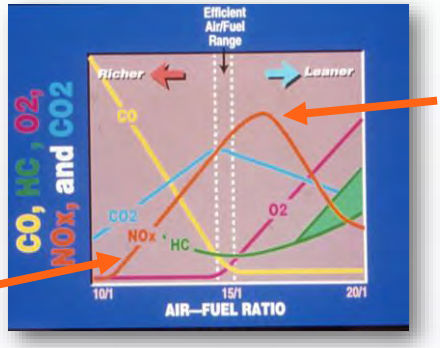
NOx Emissions

Gasoline Engine: Accurate control of fuel and air at a **"stochiometric ratio"** allows the catalyst to perform at its highest conversion efficiency.

Unfortunately, at that instance,
Diesel exhaust is extremely lean.
Reducing NOx in an excess oxygen
Environment is very challenging.

This brought us to
"*2010*"



Look how high NOx is on the lean side

NOx low on rich side

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Particulate Matter (PM)

The average person sees it as the black smoke or soot emitted from diesel cars and trucks. In reality, the emissions of soot also consists of other matter suspended in the exhaust, such as:

Unburned Fuel
Sulfur by-products
Unburned lube oil and
Trace metals

NOTE: Fuel and air mixture preparation in modern diesel engines has greatly reduced this emissions. Diesel particulate filters (DPF's) are used to eliminate it almost entirely.

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Regulated Emissions

- Diesel Particulate Matter (DPM). Also referred to as Particulate Matter (PM) or Total Particulate Matter (TPM), regulated by the "mass of emitted particles".
- Nitrogen Oxides (NOx).
- Hydrocarbons (HC's), including either the Total Hydrocarbons (THC's) or only the nonmethane hydrocarbons (NMHC's).
- Carbon Monoxide (CO).

PM and NOx are the primary focus of diesel emission control technologies.

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Unregulated Emissions

Some unregulated or suspected pollutants found in diesel exhaust, usually at levels much lower than regulated emissions are:

- "SOF", soluble organic fraction, constituting part of "DPM".
- "SO_2", sulfuric dioxide, from sulfur that is present from fuel.
- "N_2O", nitrous oxide. (Nitrous oxide is not included in NOx).
- Aldehydes, R-CHO , which are derived from hydrocarbons.
- "PHA", polynuclear aromatic hydrocarbons. These are heavy organic compounds found mostly in the "DPM".
- "Metal Oxides", derived from some engine lubricating oil additives.

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Composition of Diesel Particulates

Particulate matter is usually divided into three main fractions and further sub categorized as:

1. Solid fraction (SOL)
   a. Elemental carbon
   b. Ash
2. Soluble organic fraction (SOF)
   a. Organic material derived from engine lubricating oil
   b. Organic material derived from fuel
3. Sulfuric particulates (SO4)
   a. Sulfuric acid
   b. Water

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Composition of Diesel Particulates

NOTE: Metal ash compounds derived from lubricating oil additives and from engine wear are also a source of solid material in diesel exhaust.

IMPORTANT: Ash emissions are a great concern for developers of diesel particulate filter materials.

"Ash is corrosive"

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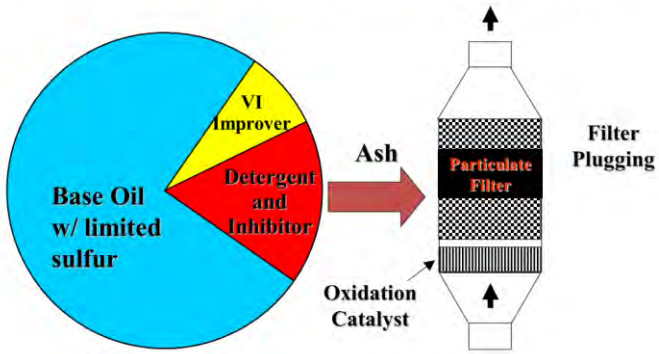
Ash Limits Particulate Filter Life



Goal: Reduce ash to enable extended maintenance intervals on the diesel particulate filter

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CJ-4 Oil

- Designed for high-speed four-stroke cycle diesel engines.
- Designed to meet 2010 model year on-highway and Tier 4 non-road exhaust emissions standards
- As well as applications with diesel fuels ranging in sulfur content up to 500 ppm.
- However, the use of these oils with greater than 15 ppm sulfur fuel may impact exhaust aftertreatment system durability and/or drain interval.
- CJ-4 oils are effective at sustaining emission control system durability where particulate filters and other advanced aftertreatment systems are used.
- Protection/control of:
  - Catalyst poisoning
  - Particulate filter blocking
  - Engine wear
  - Piston deposits
  - Soot handling properties etc.

CK-4 Oil

- Designed to meet 2017 model year exhaust emissions standards.

Information from American Petroleum Institute (API)

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Very Important!!!

- Make sure you put in manufacturers recommended oil.
- The days of 15W-40 for all diesels is gone.
- For example, there is API FA-4 identifying certain XW-30 oils
  - Specifically formulated for use in select high-speed four-stroke cycle diesel engines designed to meet 2017 model year on-highway greenhouse gas (GHG) emissions standards
- API FA -4 oils are not interchangeable or backward compatible with API CK-4.

Note: I wouldn't want to be involved with any engine/emissions issue due to wrong oil. Oil samples are effective when doing PMs, but they can also incriminate us.

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Composition of Diesel Particulates

"Health Concerns". Many of the previous mentioned substances are toxic and may attach themselves to "PM".

When chemical compounds from diesel exhaust are emitted into the atmosphere, secondary compounds may form.

These compounds can be formed in the presence of sunlight, ozone and other radicals and can be just as detrimental to our health as the primary components of diesel exhaust.

FROM DEC: Their presence can increase the toxicity and carcinogenicity of the primary constituents of diesel exhaust and increase the amount of time the primary particles remain airborne.

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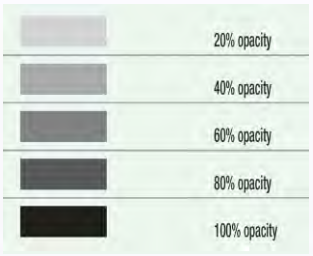
Composition of Diesel Particulates

"Size does matter"

PM smaller than 10 microns is considered "inhalable" and can enter and remain in the respiratory system. Particles smaller than 2.5 microns are considered "respirable" and can enter the respiratory system and be deposited in pulmonary tissue, where they may cause damage. Diesel emissions are known to carry PM as small as 0.2 microns and, therefore, it can be concluded that a portion of the PM from diesel exhaust is penetrating the respiratory defense mechanisms and entering the deepest regions of the lungs where the most harm is done.

Inspection and Maintenance (I&M) Programs

- **These programs are usually maintained by states or provinces in Canada.**
- **These programs typically consist of a periodic or on-road emission check from in-use vehicles.**
- **The intent is to identify "gross polluters" (poorly Maintained) vehicles.**
- **Most "I&M" programs pertain to cars, but some of them extend to heavy-duty diesel vehicles.**
- **The test is usually very simple. In the case of diesels , the test is typically limited to an "*opacity measurement*".**
- **In the event of a failure, the owner is required to perform the necessary repairs to bring the vehicle/engine into compliance.**



Emissions Control Compliance Reminder

- **Federal Clean Air Act, Section 203(a)(3) prohibits the removal of air pollution control devices or modification of a certified engine to a non-certified configuration.**
- **CARB enforces against individual vehicle owners that have violated the law by tampering, modifying, or installing illegal parts on emission-controlled vehicles operated on public highways.**
  - **Violations are subject to penalties up to $37,500 per violation.**
- **Tampering with DEF system is illegal in the U.S.**
- **Modifications, such as reprograming of the fuel system so the engine will exceed the certified horsepower or torque, or removing the mufflers are example of illegal changes.**
- **Changes must not be made to a certified engine that would result in an engine that does not match the configuration of an engine model that is currently certified to meet Federal Standards.**

NOTE to my Canadian friends: The same conditions that apply to U.S. apply to you, with one exception. After the vehicle is sold to a retail customer (end user), the jurisdiction controlling the emission control devices becomes the province in which the vehicle is licensed. If the owner wishes to make any changes, they must check with the provincial authority first.

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Testing

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Emissions Reduction

Pre-Combustion

- EGR
- Turbocharging
- Clean Fuel
- Timing
- Complete Combustion

Combustion

- Electronic Fuel Injection
- High Fuel Pressure
- Swirl Technology

Post-Combustion

- DOC
- DPF
- SCR

Computerization

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Computerization enabled the following to occur:

- **Diesel Oxidation Catalyst (DOC) – HC and CO control.**
- **Diesel Particulate Filter (DPF)- PM control.**
- **Variable Geometry Turbocharger (VGT)- Air Induction.**
- **Common Rail Diesel Fuel Injection (CRD)- Fuel Induction. "High Pressure Diesel Fuel Injection".**
- **Cooled EGR (CEGR)- NOx Control.**
- **Selective Catalytic Reduction (SCR) – NOx Control.**
  "Diesel Exhaust Fluid (DEF)"

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Variable Geometry Turbocharger (VGT)



Conventional Turbo VNT VGT

VGT:

- **Control of internal geometry is motor driven (actuator).**
- **Replacement Only (cannot be serviced)**
- **Actuator has to be calibrated to the ECM.**

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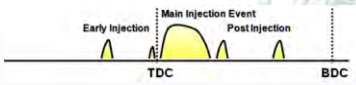
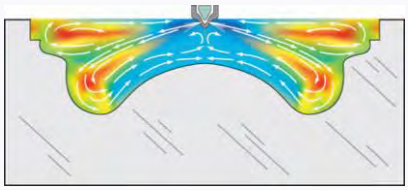
Common Rail High Pressure Fuel Injection (CRD)

- High Pressure "23,000 psi and more"
- Multiple injections per cycle.
- Less NOx created.

- Finer mist.
- Even distribution in cylinder.
- More complete burn.





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Diesel Combustion and Formation of Emissions

- As the piston nears the top of the compression stroke, high pressure fuel is sprayed into the compressed cylinder contents (primarily air, along with some residual combustion products).
- Injection pressure, orientation of the intake ports, piston motion and piston bowl shape enhance the turbulent mixing of the fuel and air .
- Combustion consists of the following phases:
  1. An ignition delay, which starts after the initial injection of fuel, continuing until the initiation of combustion.
  2. Rapid pre-mixed burning of the fuel and air mixture from the ignition delay period.
  3. Diffusion-controlled burning, in which the fuel burns as it is injected and diffuses into the cylinder.
  4. A very small amount of rate-controlled burning during the expansion stroke, after the end of injection.

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Diesel Combustion and Formation of Emissions

- Engine speed and load is controlled by the quantity of fuel injected.
- The cylinder's content are always fuel-lean.
- Time available for combustion and the proximity of oxygen determine if the fuel droplets are either completely or partially oxidized.
- At high temperatures, unburned, non-oxidized fuel is pyrolyzed (stripped of hydrogen) to form elemental carbon soot.
- The soot leaves the engine as a component of PM emissions.
- During combustion. Sulfur compounds present in the fuel oxidizes to form sulfur dioxide (SO_2).
- Approximately 1-4% of fuel sulfur is oxidized to SO_2
- This combines with water vapor in the exhaust to form sulfuric acid (H_2SO_2).

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Diesel Combustion and Formation of Emissions

- Oxides of Nitrogen (NOx), primarily in the form of NO (nitric oxide), form during a high temperature chemical reaction.
- High combustion temperature causes oxygen and nitrogen to react, forming NO and some NO_2.
- The majority of NO_2 formed during combustion is rapidly decomposed.
- Thus, most of the NOx emissions take the form of NO.
- Some organic compounds from unburned fuel and lubricating oil consumed by the engine can form in crevices or cool spots within the cylinder and are not available to conditions that would lead to their oxidization or pyrolysis.
- Ash from oil combustion also contributes trace amounts to PM mass.

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Diesel After Treatment Emission Requirements

Four Types of pollutants:

- Particulate Matter (PM)
- Nitrogen Oxides (NOx)
- Hydrocarbons (HC)
- Carbon Dioxide (CO)

Diesel after-treatment focuses on 3 areas of emission control:

- Oxidization of HC and CO
- Reduction of NOx
- Reduction of PM

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How do we control Diesel emissions?

Two Ways:

- **The source: Modifying engine design**
- **Add on controls: Treat the diesel exhaust**
- **History Lesson: 2002/2004 emission regulations targeted NOx levels. All engine makers used some version of EGR to meet those levels.**
- **For 2007, the EPA focused on particulate matter. Now all on- highway trucks come with a diesel particulate filter to trap the "SOOT" in the exhaust.**
- **For 2010, the focus is back on NOx. (maximum levels at 0.2 gram/brake horsepower hour.**
- **This would be 90% reduction from pre-2004 levels.**

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Exhaust After-treatment Systems 101

Exhaust after treatment systems are classified as either "active" or "passive"

Active systems contain actuators that must be controlled electronically to provide emission reduction

Passive systems are "pass through" systems that have no actuators. Therefore, no need for electronic controls.

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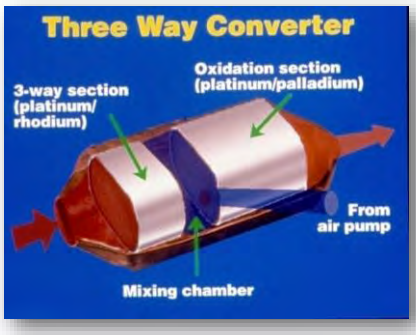
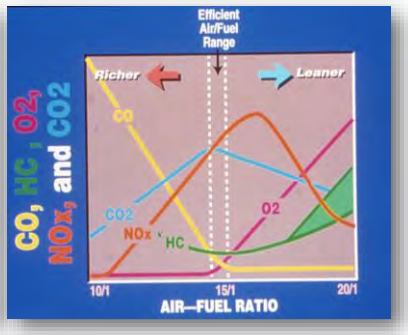
Emission Control Catalysts

This is typical of a gasoline engine system





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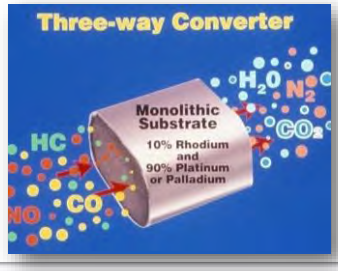
Emission Control Catalysts

The Three-way catalyst (TWC) utilizes the operating principle of non-selective catalytic reduction of NOx by CO and HC's, requiring that the engine operates near a *"stochiometric" A/F ratio.*

An Oxygen sensor combined with a closed-loop electronic control system is used to maintain this *A/F ratio.*

Diesel Engines use a Selective Catalyst Reduction (SCR) - Nox



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Catalytic Converters

- **Catalytic converters are fitted to both gasoline and diesel engines and contribute to the reduction of harmful exhaust gases, such as hydrocarbon (HC) and carbon dioxide (CO).**
- **The exhaust gases pass through a honeycomb brick, which is coated with noble metals, for example platinum, palladium and/or rhodium, which convert undesirable unburnt hydrocarbons and carbon monoxide to carbon dioxide and water, nitrogen oxides to nitrogen and water.**
- **Faulty combustion can cause extensive damage to the catalytic converter, this is why it is important that the engine runs efficiently, and the air-fuel ratio mixture is in the correct proportions.**

New

Fouled

Clogged

Broken

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Emission Control Catalysts

Oxidation Catalysts were introduced in the 1990's to the diesel-fueled cars in Europe and to heavy-duty diesel buses and some truck engines in the United States.

Note: Diesel catalysts have been also in use such as underground mining since 1970's.

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What is a DOC?

- **Diesel Oxidation Catalyst (DOC) and Exhaust Catalyst Assembly are two types of passive after treatment systems.**
- **DOC systems are not new. Used on some light and medium duty engines since 1991.**
- **DOC systems are used to promote the "oxidation" of many pollutants such as CO, HC, soluble organic fraction of diesel particulates into less toxic compounds such as CO_2 and H_2O.**
- **A typical configuration consists of a deposit of "active" material on a subtrate or carrier. The subtrate is configured as a monolithic honeycomb.**
- **Oxidation catalysts rely on precise blends of precious metals such as: platinum, palladium and rhodium, oxides of silica, titania and zirconia, and base metals such as vanadium, molibdenum and niobium.**

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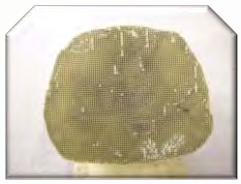
"DOC" combined with "Exhaust Filter"

- Oxidizing catalysts by themselves do a "poor job" of oxidizing particulate matter.
- For that reason, "*Exhaust Catalyst Assemblies*".
- This assembly consists of the "*diesel oxidation*" section and an "*exhaust gas filter*" section.
- This section "*Traps*" the particulate matter or soot.



More commonly known as the :
"Diesel Particulate Filter" (DPF)

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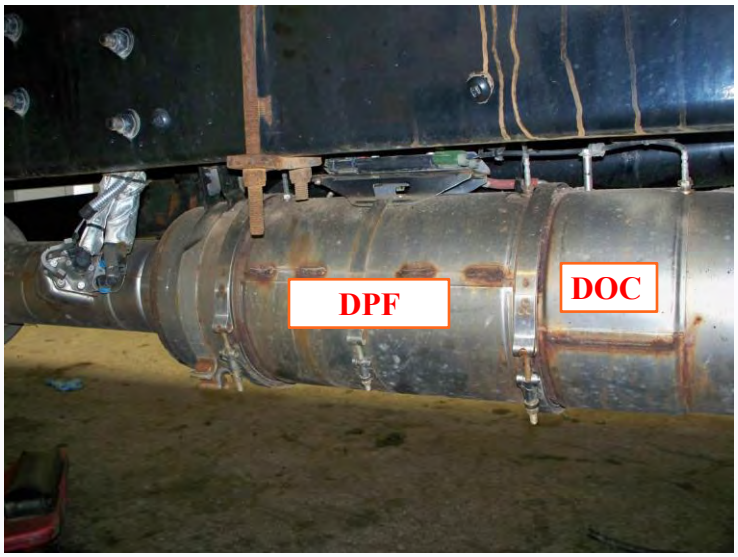

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Emission Control Catalysts

Advantages:

- *Durability*
- *Maintenance free*
- *Negligible effect on fuel economy (low –pressure drop)*
- *Simplicity and passive character of catalyst system*

Disadvantages

- *Temperature dependence for performance*
- *Loss of activity due to poisoning and/or thermal problems (sintering)*

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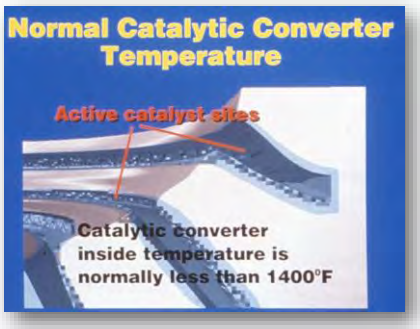
Emission Control Catalysts



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Emission Control Catalysts

- DOCs at high temperatures provide a very effective control of HC and CO emissions with reduction efficiencies in excess of 90%.
- High conversion is realized through the use of noble metals such as platinum.
- These same "CATS" also are used for PM conversion with an efficiency in the 15% to 30% range.

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Emission Control Catalysts

Common to all "Emission Control Catalysts":

Dependency of conversion efficiency on *"temperature"*.

- Conversion is near zero at low temperature (100ºC/212ºF)
- Conversion increases slowly at first as temperature rises (150ºC/302ºF)
- Conversion reaches its peak at high gas temperatures (300ºC/572º) and higher.

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Emission Control Catalysts

NOTE: Some Catalysts have a catalyst temperature window:

Increasing the temperature may increase the conversion efficiency only up to certain point.

Temperature increase beyond that window causes a decrease in catalyst conversion efficiency.

This type of conversion utilizing a conversion temperature window is typical for "Selective Reductions of NOx" by hydrocarbons or ammonia.

Emission Control Catalysts

Diesel Catalysts

- **Oxygen is ineffective in reducing NOx.**
- **Diesels are lean-burn, containing high concentrations of oxygen in their exhaust gases at all operating conditions.**
- **For this reason, the three-way cat cannot be used for NOx control on diesel applications.**
- **However, CO and HC's can be controlled with high efficiency by today's catalyst technologies.**

NOTE: SCR is utilized for the reduction of NOx.

Emission Control Catalysts

- The oxidation reactions convert CO, HC's and HC derivatives into CO2 and water vapor (H2O).
- The key to reducing PM (sulfate PM emissions) was the reduction of *"Sulfur"* in fuels:

  (‹500ppmS) and now (‹15ppmS)

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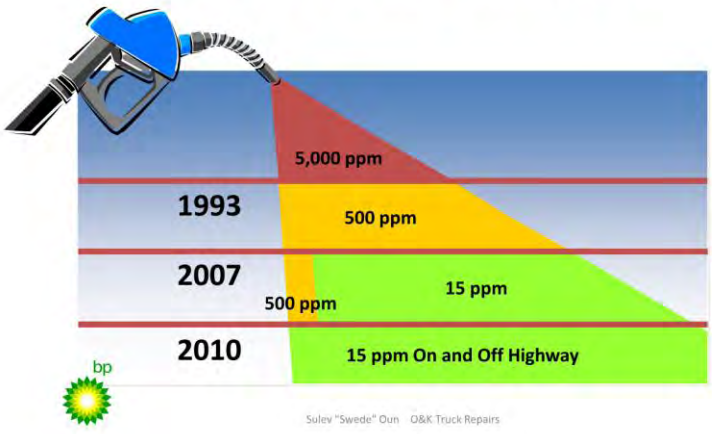
Ultra Low Sulfur Diesel Fuel



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Diesel Particulate Filter "REGENERATION"

- **Diesel Oxidation Converter (DOC) provides additional heat during oxidation period and additional oxygen to aid in regeneration of the soot in the "Filter".**
- **DPF filter require 1100-degree heat to convert soot into CO2 gas.**

  This also filters out ash or additives from engine oil burnt in the combustion process.
- **WARNING: Exhaust gas temperatures leaving the "DPF" during regen. can exceed 1000 degrees.**

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- **Which way does the exhaust flow?**
- **Which one is the DOC?**
- **Which one is the DPF?**
- **Which one is SCR?**

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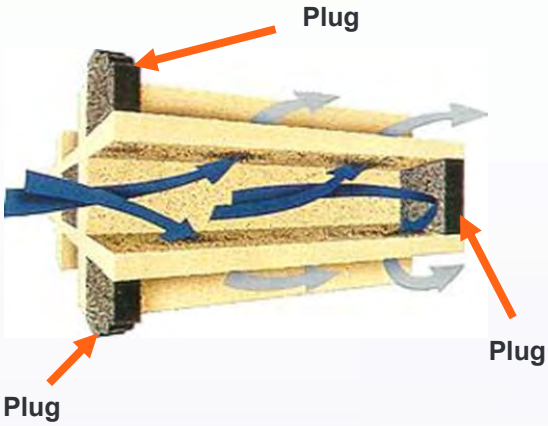
Wall-Flow Monoliths

Diesel Particulate Filtration

- 2007 requirement DPF
  - Soot removed using porous ceramic media.
  - Captured particles accumulate
    - On media surface
    - Inside pores
  - DPF must Regenerate to clear PM
    - Require high heat
    - Oxidizes soot and clears PM filter.

Diesel particulate filters (DPF) remove > 90% PM



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Basic Passive Regeneration process.

Normal on highway operation
- Normal highway operation will generate enough exhaust temperature from engine to provide the heat to clean the DPF

Under light load
- Under a light load and exhaust temperature too low, fuel is added to the exhaust gas to cause a chemical reaction in the DOC before the filter to add additional heat to clean the filter without driver input. Takes approximately 20-30 minutes. Under 6 MPH regen. stops

Stopped vehicle
- Driver requests for regen when vehicle is stopped. DPF warning light has to be on and a switch must be turned on. Regen. Will then take place for approximately 30 minutes.
- WARNING: Should be done outside of building, overhangs etc.

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Diesel Particulate Filtration

The real world

- **Duty cycle impacts filtration**
  - **Fully loaded "Line Haul" operation will have less problems.**
  - **Passive regeneration is more likely due to the higher exhaust heat to regenerate DPF.**
  - **Engine must be operated such that the exhaust maintains a minimum temperature for a certain period of time.**
- **Stop and GO Operation/Cold Weather would probably require "Active" regeneration.**

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Active Diesel Particulate Filtration

- **Performs the same function as a passive DPF.**
- **Active DPF does not use heat from the engine exhaust to oxidize the trapped PM.**
- **Better suited for engines with high PM emissions and low exhaust temperatures.**
- **Need to add heat. Most common methods:**
  - **Electrical regeneration-passing an electrical current through the filter medium**
  - **Injecting fuel to provide additional heat to oxidize the trapped PM**
- **DPF Regeneration**
  - **Automatically on-board the vehicle when specified back pressure is reached.**
  - **Also, utilizing an indicator, such as a warning light, alerting the driver that a. regeneration is needed, requiring the driver/operator to initiate the regeneration process.**

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Hydrocarbon Injector Driver Module

- This one shown is used by Volvo and Mack 2017-12
- Integrated Dosing system.
- Typically located between fuel filter assy. And fuel pump.
- Typically used to inject extra fuel into exhaust to bring temperature up for active regeneration.

NOTE: Active regeneration occurs when temperatures during normal engine operation are insufficient to ignite the soot particles collected in the DOC and DPF.

- A reaction between the fuel and precious metals in the DOC increases the temperature of the exhaust, causing the soot particles in the DOC and DPF to oxidize.

59

Off-Board Filter Cleaning

- Generally, **Exhaust Gas Filter** cleaning must be done every 150,000 miles or 4,500 hours to remove accumulated ash.
- This means removing the exhaust gas filter from the exhaust catalyst assembly, or removing complete assembly , depending upon system.

NOTE: These are numbers that were assumed when these systems came into existence.

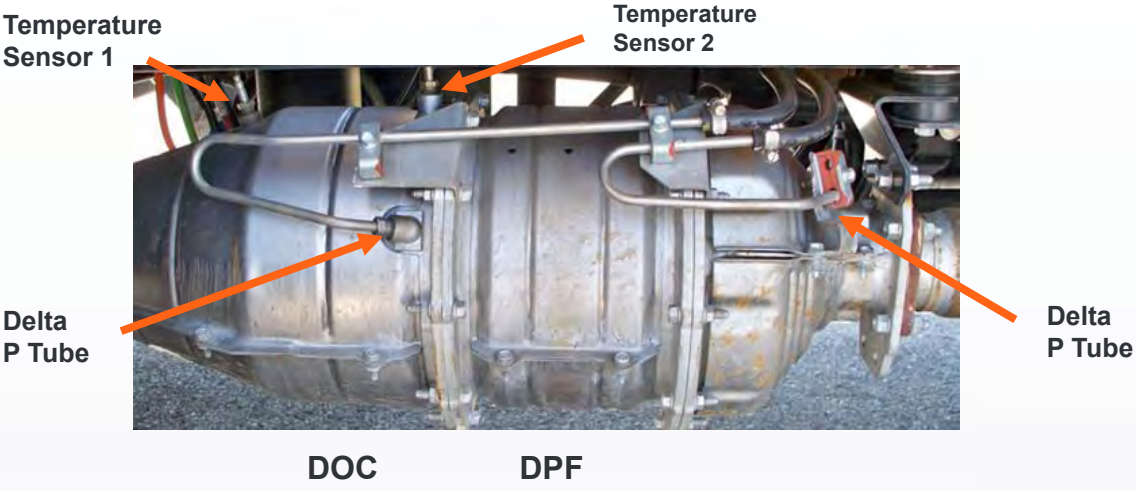
- Send component or assembly out for cleaning unless you can afford a cleaning machine.

60

DPF Pressure Sensor

- This sensor is an input to the PCM, used to measure the pressure before the DPF.
- The DPF pressure sensor is a differential-type sensor that is referenced to atmosphere pressure.
- The DPF pressure sensor is used by the PCM to monitor the amount of exhaust pressure produced by the DPF.
- An active regeneration is performed when the reading reaches a certain point.

61



The delta pressure differential sensor is used to measure the pressure differential across the DPF. A large pressure differential indicates the filter is restricted.

62

Exhaust Gas Temperature (EGT) Sensors

- The EGT sensors are inputs to the PCM.
- They measure the temperature of the exhaust gases passing through the exhaust system at various points.
- Some systems might use three of them .

(Inlet, Catalyst outlet, and Outlet)

- Some systems might use four EGT's

DORMAN 63

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Exhaust Gas Temperature Sensor

- **OE Fix**:
  - **Convenient solution** - this replacement EGT sensor comes with a bung repair kit in case the bung is damaged during removal
  - **Cost-effective fix** - bung repair kit allows direct repair of damaged bung instead of replacing entire exhaust pipe
  - **Complete kit** - comes with sensor, new bungs, weld-on plates and zip ties

64

Dayton Parts DRIVEN BY DORMAN

64

Exhaust Bellows

- **Function**: Designed to limit the motion/kinetic energy passed along from the engine to the high-cost emissions systems by absorbing displacements and vibrations and accommodating thermal expansion
- **Failure Mode**: Joints wear down and typically fail from the inside
  - Cold ambient air enters exhaust stream
  - Crack as small as 5mm can reduce DPF inlet temp by 80F-100F
  - Lower temperature leads to incomplete regenerations
    - Excess levels of soot build up over time
  - Excessive fueling at the 7th injector increases regen temps (Compensation)

65

65

Exhaust Clamps and Gaskets

- **Function**: The role of exhaust clamps and gaskets is to prevent leakages and prevent air from entering the exhaust system

If Air Enters System = Catastrophic

- **Failure Mode**: Components wear and warp over time which will allow air into system
  - Allows cold ambient air into exhaust stream
    - EGT Temp Sensors will pick that up leading to low inlet DPF temperatures
    - Low inlet temp = poor regen performance
    - Poor regen performance = more regen attempts
    - More regen attempts = more thermal cycling on DPF
    - More thermal cycling = premature DPF failure

66

66

Why would you care about what sensors are being used?

- Absolutely for diagnostics
- How about as a requirement because of OBD.
- The following is partial list of HD OBD Diesel Monitoring Requirements.
  - NMHC – Conversion Efficiency Emission Threshold
  - NOx Catalyst – Conversion Efficiency Emission Threshold
  - NOx Adsorber – NOx Adsorber Performance Emission Threshold
  - PM Filter – Filter Emission Threshold
  - Upstream Exhaust Gas Sensor- Filter Emissions Threshold
  - Downstream Exhaust Gas Sensor- Emission Threshold
  - NOx Sensor #1 – Emission Threshold
  - NOx Sensor #2 – Emission Threshold
  - PM Sensor – Emission Threshold

VERY Important: These requirements get further defined to catch out of range, opens, shorts etc. Just like cars, OBD gives everybody a path for diagnosing issues.
How comfortable are you with HD OBD Strategies?

67

Why Worry About NO_x?

- NO_x is created in the cylinders by high combustion temperature

- NO_x causes ground level ozone and smog
- NO_x can be reduced by:
  - Chemical reaction in the exhaust
  - Lower combustion temperatures

Side Note: Today's diesel engines are 90% more cleaner than diesel engines of 2000.

NOx emissions from 10.7 grams per brake horsepower-hour to 0.2.

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Selective Catalytic Reduction (SCR systems)

- Unlike HC, CO, and PM, NOx cannot be removed by oxidation.
- NO_x must be reduced.
- HOW?
- Accomplished by combining HC and CO with NOx to form nitrogen, CO2 and H2O.
- How can we do that if the diesel engine are lean burn engines with no excess amount of HC and CO available for this process.
- This requires help from an outside source.
- An SCR system introduces a "urea " or aqueous ammonia, into the exhaust stream of the engine before the catalyst bed.
- The reductant introduced into the exhaust stream creates a stoichiometric environment. This allows NO_x to be reduced on the catalyst.
- NOTE: Three-way Cats in cars have been using the same concept for years. To oxidize HC's and CO's you need to be lean. To reduce NO_x you need a rich condition. To accomplish both at the same time ,the O2 sensor tithers from rich to lean and back.

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NOx Reduction Catalysts

The following catalytic approaches have been researched and worked on for the control of *NOx* in lean exhaust gases. Not just diesels but also lean burn "SI" engines.

- NOx decomposition catalyst
- Selective catalyst reduction (SCR) with ammonia
- SCR with hydrocarbons (deNOx or lean NOx catalyst)
- NOx absorber catalyst system

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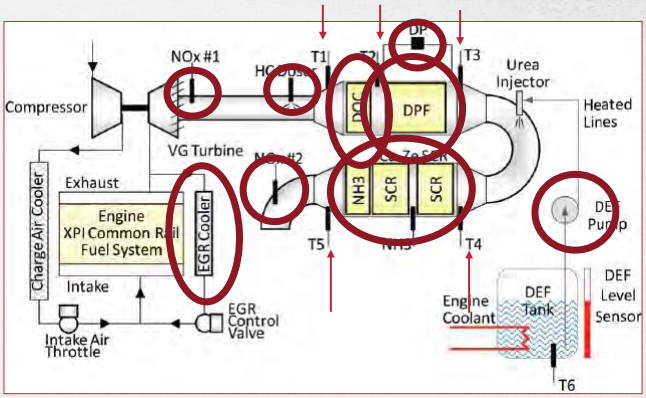
Aftertreatment Architecture

Dayton Aftertreatment Offering:

- EGR Cooler
- NOx Sensor, Inlet
- Hydrocarbon Dosing Module
- Exhaust Gas Temperature Sensor
- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Differential Pressure Sensor
- Diesel Exhaust Fluid Module
- Selective Catalytic Reduction (SCR)
- NOx Sensor, Outlet
- Clamps and Gaskets



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NOx Reduction Catalysts

- **NOx decomposition catalyst was recognized in the late 1980's. At that time copper exchanged zeolite was suggested to exhibit catalyst activity for reducing NOx in a *stochiometric* exhaust gas composition.**
- **SCR reduction of NOx is realized if a reducing agent is injected into the gas upstream of the catalyst bed. The SCR process utilizes nitrogen-containing reductants such as ammonia or urea.**

72

NOx Reduction Catalysts

The main advantage of "SCR" is its high NOx conversion efficiency, as high as 90% or more.

Disadvantage is initial capital outlay, ongoing operating costs and space requirements.

How about electrical requirements?

NOTE: SCR has been successfully adapted to control NOx emissions for years from large, stationary diesels.

73

SCR Simplified

What is SCR? A technology that injects *urea*, " a liquid reductant agent" through the catalyst into the exhaust stream of a diesel engine.

What is Urea? Commonly referred to as *Diesel Exhaust Fluid (DEF).*It is a solution made up of purified water and 32.5% automotive grade urea that is used as a carrying agent for the ammonia needed to reduce NOx emissions from vehicles into nitrogen, water and carbon dioxide (CO2).

NOTE: DEF is monitored for quality and certified by the American Petroleum Institute (API)

74

SCR Simplified

For SCR to work the following are requirements of DEF:

- **Quality and Purity**
- **Availability**
- **Transportation and Distribution**
- **Dispensing equipment and packaging**

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SCR Simplified

How does SCR work?

The technology is designed for NOx reduction reactions to take place in an oxidizing atmosphere. The reducing agent (ammonia) reacts with NOx to convert the pollutants into nitrogen, water and small amounts of CO2.

The urea (DEF) is hydrolyzed to produce the oxidizing ammonia in the exhaust stream. *"Heat breaks the urea down into ammonia"*

NOTE: Fuel efficiency should increase by 3%-5% because engines can be tuned to maximize fuel efficiency.

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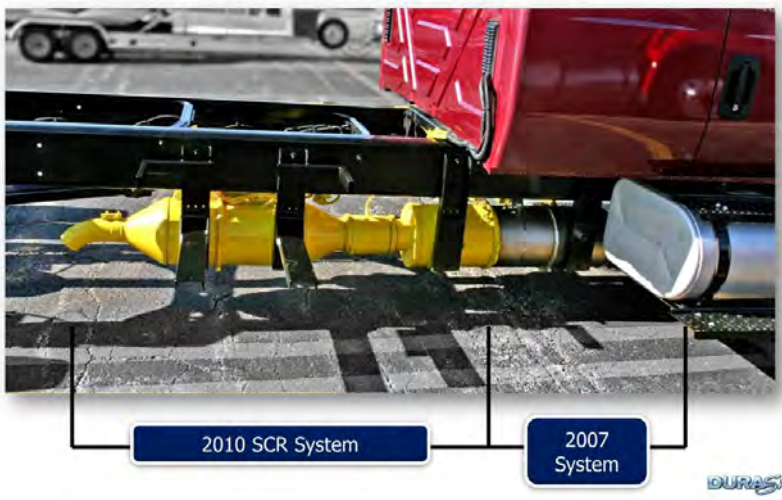
SCR Components (Right)



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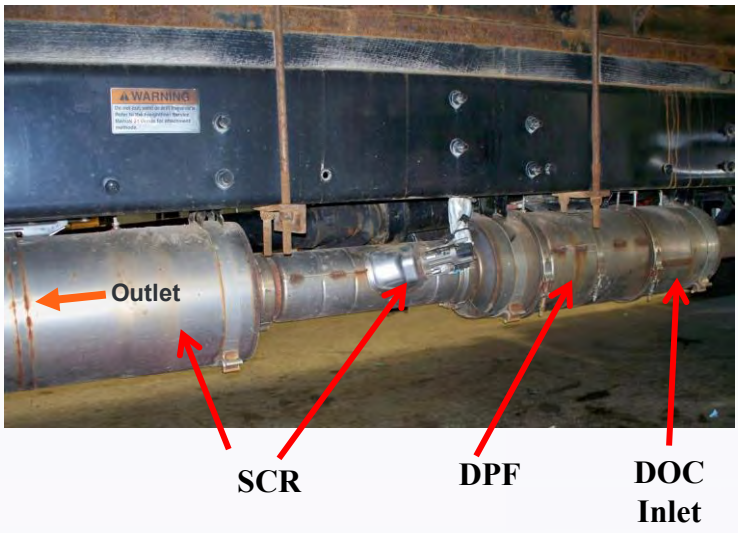
Review

- Exhaust flows out of engine through DOC and then into the DPF where the PM is collected on the walls of the DPF.
- The collected PM is oxidized to remove it from the DPF.
- This is known as “regeneration”.
- During sufficient exhaust temperature operating conditions, the DPF is continually self-regenerating. This is known as “*passive regeneration”.*
- On infrequent occasions, an “*active self regeneration”* is required to remove a build-up of PM in the DPF, due to insufficient exhaust temperatures.



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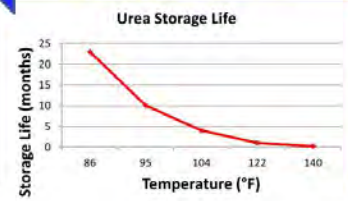
Storage and Handling

122° F (50°C) Ammonia Gas Forms

85° F (30°C) Urea Breaks Down

12° F (-11°C) Urea Freezes



High ambient temperatures

If AdBlue® in the reservoir heats up to above 122°F (50°C) for a long period of time, for example due to direct sunlight, ammonia gas vapors may escape when opening the AdBlue® tank.

⚠ Warning!

When opening the filler cap of the AdBlue® tank ammonia gas vapors may escape. Refill AdBlue® in a well ventilated area only. Ammonia gas vapors have a pungent odor and are particularly irritating for your skin, mucous membranes, and eyes. Inhaling ammonia gas vapors will cause burning eyes, nose, and throat, as well as coughing and watering eyes.

AdBlue warnings from Mercedes owners' manual.

Urea is corrosive to aluminum and must be stored in Stainless Steel or heavy-grade plastic tanks.

Sulev "Swede" Oun O&K Truck Repairs

80

EPA Requirements

- Tamper-proof systems
- Progressive warning
  - Audible and visual indicators
  - Engine de-rate
  - No start

Without urea, the vehicle WILL NOT RUN

81

Selective Catalyst Reduction (SCR)

The typical SCR system includes the following components:

- **Reductant or Diesel Exhaust Fluid (DEF)**
- **Reductant (DEF) tank.**
- **Reductant dosing module.**
- **Reductant pump and heater assembly.**
- **Reductant tank heater and sensor assembly.**
- **Reductant purge valve.**
- **Reductant pressure sensor.**
- **NOx sensor and module.**
- **Exhaust mixing system.**

FIVE Main States
- **Initializing**
- **Priming**
- **Dosing**
- **Purging**
- **Heating**

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FIVE MAIN STATES:

- **Beginning**
  - Key switched on but not start engine.
  - System initializes and self-tests.
  - Priming stage begins.
- **Priming State**
  - Engine starts.
  - Exhaust temperature is higher than preset value.
  - Pump starts to build up constant DEF pressure.
  - Dosing valve goes through a test (dosing valve opens for 2 seconds).
  - DEF pressure should decrease and should d recover quickly.
  - Ends with hopefully DEF pressure ok and dosing valve is okay.

Note: Can be monitored with scan tool if available (definitely by Cummins Insite).

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FIVE MAIN STATES continued

- **Dosing State begins:**
  - When system is successfully primed (ready to dose).
  - Pump runs continuously to maintain system pressure around 900 kPa (130 Psi).
  - Dosing valve is closed. No DEF spray into exhaust.
  - When ECM determines the need to dose it will energize the solenoid with PWM signal.
  - DEF will be delivered into exhaust by impulse injection.
  - DEF pressure is kept in DEF that is supplied by pump and is returned to the DEF tank through a backflow valve.

Important: Required conditions for "Dosing"

- Temperature above 392° F at both Catalyst Inlet and Outlet.
- **No active SCR related fault codes.**
- DEF "Tank Level" above 6%.
- **Above – 37.4° F (DEF temp).**
- Cummins NOx Calibration.

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FIVE MAIN STATES continued

➢ **Purging State**

When key is turned off, the dosing system will shut down with a purge cycle to prevent DEF from being left in the system to prevent potential freezing in a cold climate.

- **After complete purge, the majority of the system will be free of any remaining DEF.**
- **The DEF dosing unit slides its internal return valve and causes changes in change in the flow direction of the DEF control.**
- **The DEF dosing unit pulls all of the DEF out of the dosing valve and the lines and then return the unused DEF to the DEF tank.**
- **In this process, the dosing valve will open, eliminating the vacuum created in the lines for a more complete purge process.**

NOTE: If the main power to DEF controller was removed for example battery cutoff or other means before the purging state was completed, an internal fault will be logged in the ECM.

The complete purge counter can be viewed in INSITE.

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FIVE MAIN STATES continued

➢ **Heating State (Tank)**

If the ambient air temperature is below -4º C (25º F), the DEF controller will command the dosing system to go into the defrost state.

- **The dosing unit will turn on its internal heater to defrost any remaining DEF inside it.**
- **If the application has the heating line option, the heated DEF lines will also be commanded on.**
- **If the DEF tank temperature drops below -5º C (23º F), the DEF coolant valve will be commanded open by the DEF controller and engine coolant will flow through the tank to defrost the frozen DEF.**
- **The system will not prime until every component is defrosted.**

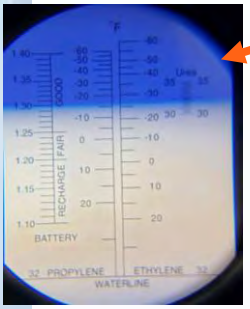
NOTE: If ambient conditions continue to be cold after priming, the DEF controller will command a maintenance heating feature to prevent the system from freezing again.

- **This feature cycles the heating ON and OFF to the DEF lines, DEF tank and dosing unit.**

This valuable information is from CUMMINS.

86

2014 Hino



Urea Scale

87

Reductant (DEF) Unit

The reductant unit supplies reductant to the dosing module and performs other functions. This unit consists of the following subcomponents:

- **Pump**
- **Reverting (Reversing) valve**
- **Pressure sensor**
- **Temperature sensors**
- **Filter**
- **Heating elements**

NOTE: The pump supplies reductant to the dosing module. A unique function of the pump is that when the ignition is turned off, the pump pulls all the reductant out of the lines.

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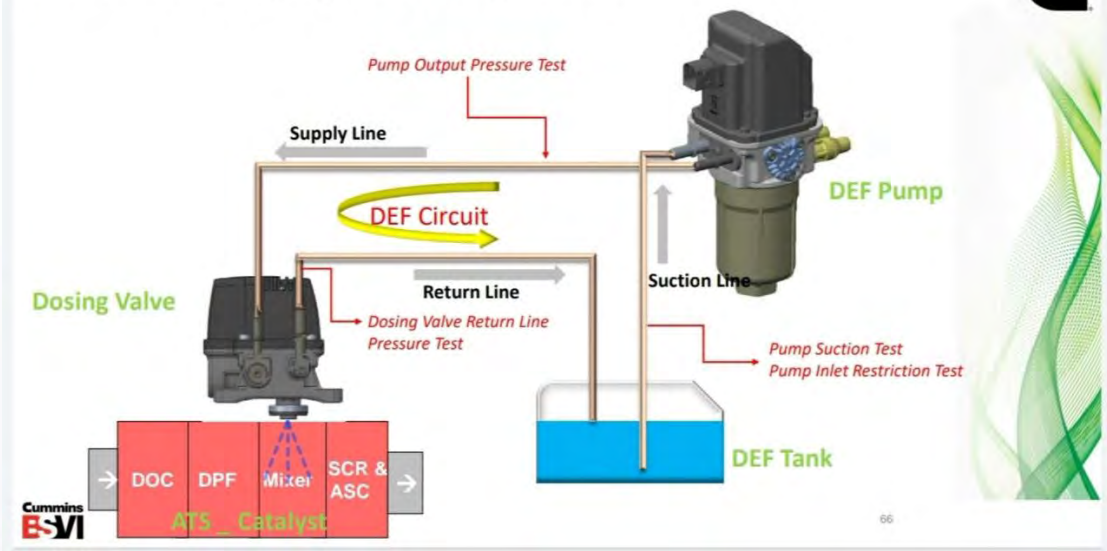
UL 2.2 Dosing System Layout ...



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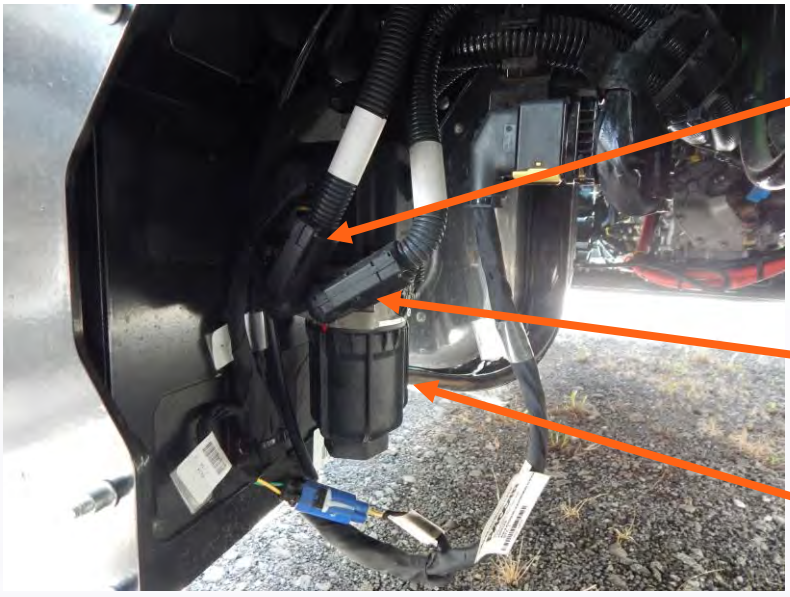


Suction Line

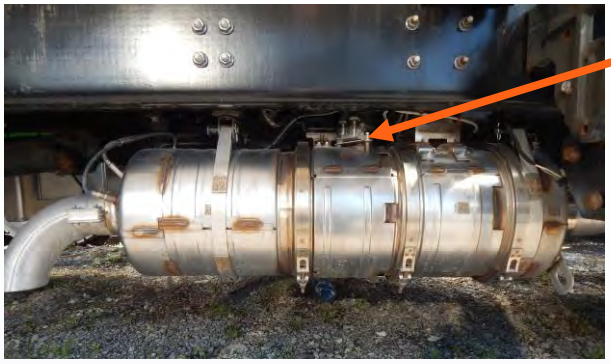
Cummins UL2.2 Urea Dosing System

Supply Line

DEF Pump/Filter

90

Mack with a
Cummins engine



Dosing Valve utilizes convection heat transfer in combination of:

- Urea fluid
- Surrounding air
- Exhaust gas

Conduction occurs between solid parts (w/ or w/o air gap.

UL2.2 Urea Dosing System: Continual presence of Urea within this unit prevents doser crystallization. The only liquid-only dosing system to offer freeze-robustness.
Benefits:

- No power requirement after key-off.
- Quicker dosing readiness at key on (avoiding priming issue with pump).
- Quicker NOx treatment

91

Exhaust Heat Shield—924-5021

- **Function: Covers joint between lower muffler housing and SCR. This protects the DEF module from exhaust heat. Lack of heat shield can cause catastrophic ATM failure.**
- **Failure Mode: material failure, external debris causes cracking or become rusted.**
- **Applications: 2017-2011 Mack MP7, MP8 Volvo D11, D13**
- **OEM Numbers: 21533402, 22983867**

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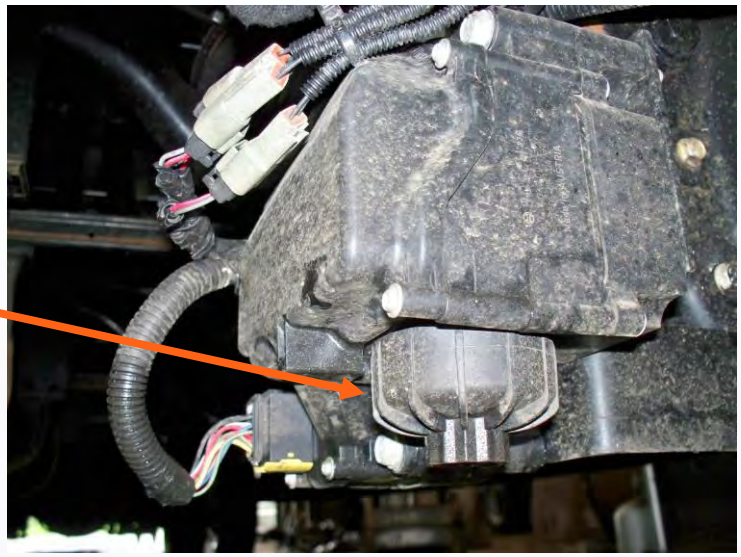
DEF Unit Filter



93

Urea Filter — 904-7934

- **Function**: This diesel exhaust fluid (DEF) urea filter kit prevent crystals and contaminants from entering the DEF system.
- **Failure Mode:** Filter clogs, check engine light comes on and diesel exhaust fluid pressure drops.
- **Applications:** 2012-2017 Cummins ISB, ISL, ISC, PX7, PX9
- **OEM Numbers:** 21516229, 2880298, 2888182, 5303604, 68087337AB, UF101

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Reductant Dosing Module

- **The reductant dosing module injects reductant (DEF) into the exhaust system to reduce NOx.**
- **Mounted on exhaust pipe with flange.**
- **Water cooled.**
- **Integrated filter: 40 micron.**

95

Reductant Exhaust mixer.

Quite often there is an exhaust mixing system in the exhaust stream to mix the reductant with the exhaust gas.

96

NOx Sensor Module

- Controls NOx sensor
- Controls heater circuit.
- Communicates to the PCM via the CAN2 on most vehicles to report NOx and O2 concentrations.
- Reports sensor and controller errors.

The NOx sensor module controls the NOx sensor.

Typically, seven wires are used to heat the NOx sensor and transmit voltages from multiple gas chambers to the NOx module for signal processing.

97

NOx Sensors

- **Function**: Monitor the level of nitrogen oxide emitted by a diesel vehicle to ensure compliance with emissions regulations
- NOx Sensors contain a ceramic chip that operates at high temperature.
  - First section of chip separates Oxygen from NOx
  - Second section operates as a catalyst to breakdown NOx into Nitrogen and Oxygen.
  - Ceramic chip is very susceptible to soot build-up and moisture contamination from water or coolant

The sensors have an internal heating element that allows typical moisture to be evaporated before the monitoring process occurs, however coolant will not evaporate in this time

First failure occurs between 100,000-300,000 miles

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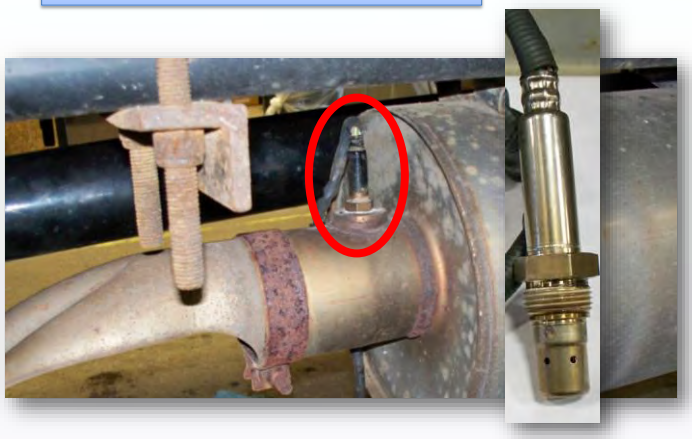
NO_x Sensor

- 2 per vehicle
  - On engine
  - Tailpipe outlet
- Rapidly reach operating temperature to communicate Nox data to ECM.

Note: This is a Zirconia Oxide chamber that is heated to 600° Celsius (1,120°F)



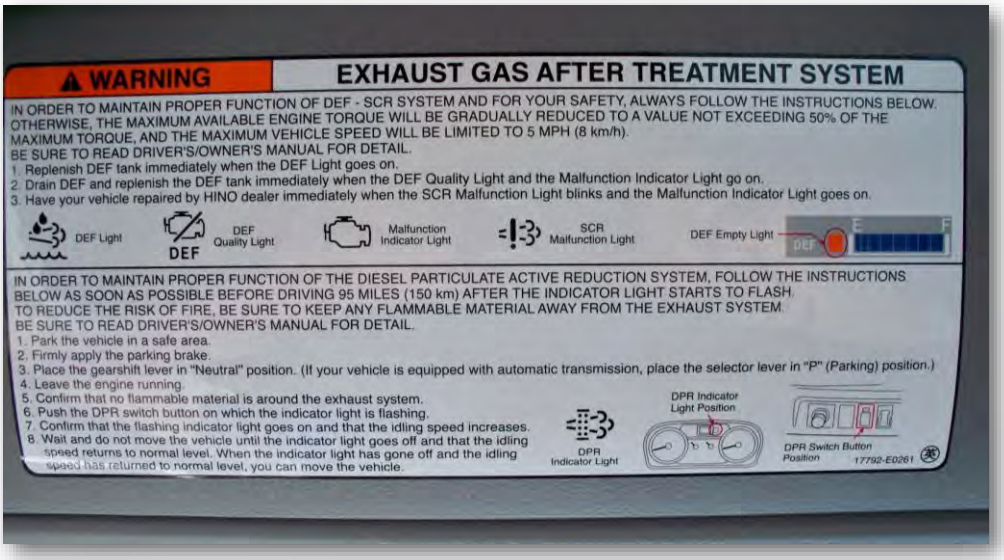
Note: This sensor is somewhat similar to a HO2 sensor in its construction.

The NO_x sensor is used primarily to sense O_2 and NO_x concentrations in diesel exhaust gas.

99

2014 Hino

100



2014 Hino **I wonder how many people read these labels?**

101

Notes From Cummins

- **On Vehicles with Cummins engines: Cummins supplies the aftertreatment DEF controller, DEF dosing unit, DEF valve and SCR catalyst. The vehicle manufacturer supplies the DEF tank, DEF lines and the DEF tank temperature and level sensor, and all wiring between the components.**
- **The aftertreatment DEF dosing unit pumps DEF from the DEF tank to the aftertreatment DEF dosing valve. The DEF dosing unit is electrically heated and contains a filter that is a maintenance item.**
- **The aftertreatment DEF dosing valve is coolant cooled, and sprays DEF into the exhaust.**
- **The DEF controller controls the amount of DEF sprayed into the exhaust. It also controls the DEF tank heater, DEF line heaters, and reports the DEF tank temperature and level back to the engine ECM.**

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Notes From Cummins

- A vehicle with SCR will be equipped with an additional lamp on the dashboard, the aftertreatment DEF lamp. This lamp , along with the check engine lamp and stop engine lamp, alert the driver to the level of DEF in the tank. As the DEF tank level approaches empty, the DEF lamp will illuminate, and engine power will be reduced. Attempting to operate the vehicle with no DEF in the tank will result in the vehicle speed being limited to 5 mph.
- DEF is sprayed into the exhaust when the temperature in the aftertreatment SCR catalyst reaches approximately 250°C (482°F).
- Even though DEF freezes at approximately -12°C (11°F), the SCR system is designed to be frozen and thawed. The DEF tank is heated by engine coolant, and the DEF lines and DEF dosing unit are electrically heated. No operator interaction is needed when operating in cold temperatures. Heating and thawing are controlled automatically by the engine ECM and aftertreatment DEF controller.

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Notes From Cummins

- After turning the keyswitch "OFF" on a vehicle with SCR, a pumping sound may be heard from underneath the vehicle. This sound is the DEF dosing unit purging any unused DEF from the system and returning it to the tank. This is normal system operation. The purge process takes approximately 60 seconds to complete.

Note: Do not disconnect the vehicles batteries during this process to avoid system damage.

- Under certain conditions (cold or very dry), water condensation, in the form of water vapor, can be seen coming from the vehicle tailpipe. This is normal operation and will clear within a few minutes of normal vehicle operation.

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DPF Ash Cleaning - What is Ash?

- Ash is the mineral residue from burned oil, mostly the result of oil additives.
  - Comprised mainly of MgO, CaO, SO_3 and P_2O_5
- Ash will accumulate in a particulate filter over time as the by-product of burned soot.
  - Significant accumulation of ash will result in increased pressure drop through the filter.
- Therefore, ash has to be physically removed from the filter at some point in the filter's life.

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DPF Ash Cleaning - Process

- The filter is removed from the vehicle and baked to burn off any soot in the filter.
  - Baking temperatures vary between 450 and 700˚C
  - Baking times vary between 9 to 12 hours
- The ash is then removed from the filter.
  - Use pressurized air on the exit side with a vacuum on the inlet side to collect the ash.
- The filter is then inspected by weight or by pressure drop to ensure that it is clean.
- The filter is reinstalled on the vehicle.

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Please use this QR Code to fill out a quick Survey

Thank You !

108