Motors Inc Training

Exhaust After treatment

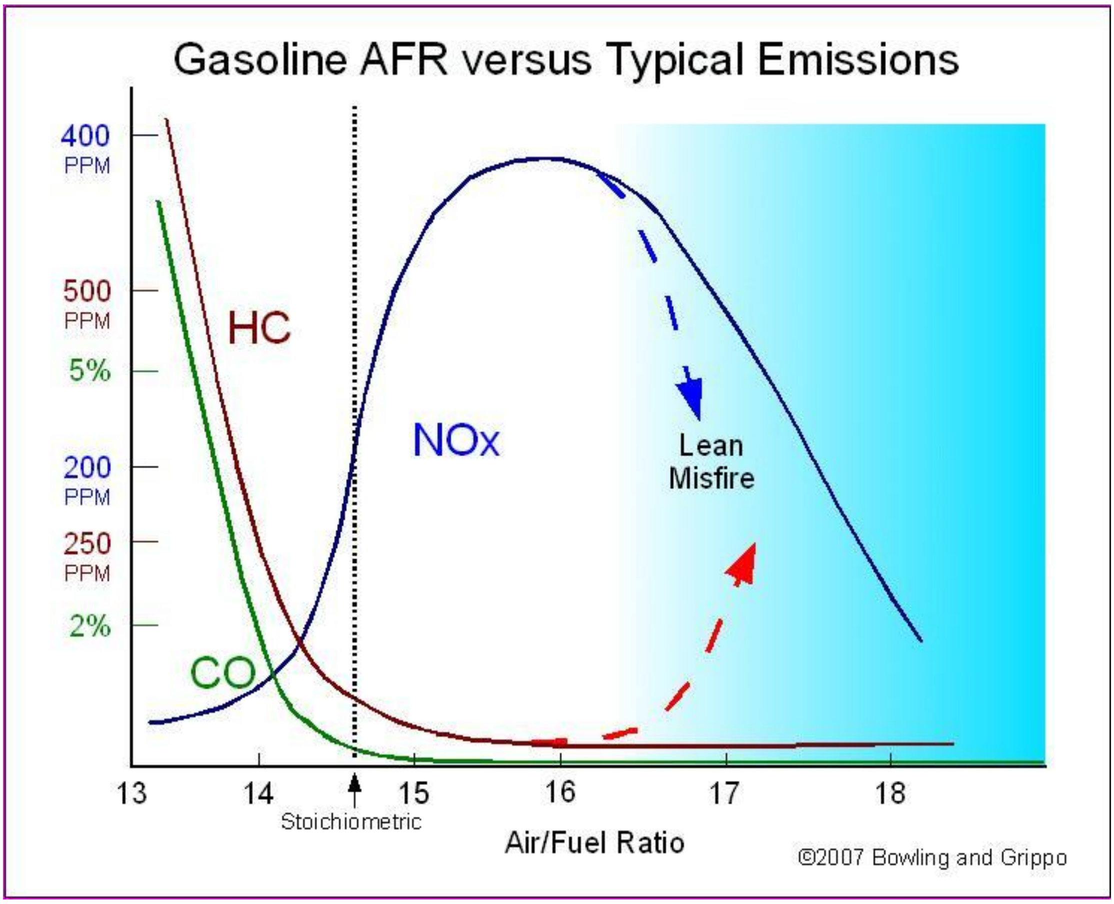
Exhaust from an engine is intended to be with low levels of harmful gases and particulates so that engines can pass emission standards. Manufacturers try to design the engine to have low emissions coming out from the cylinder exhaust port. This is typically referred to as ‘engine-out’ emissions. However, legislative emissions for the last decades cannot be achieved by engine-out levels and hence aftertreatment is used to reduce the toxicity from the engine-out levels to the acceptable legislative limits measured at the tailpipe.

Petrol / Gasoline aftertreatment

The typical aftertreatment of port fuel injection petrol engines is by means of a three way catalytic converter. The three way catalytic converter is called so because it acts on three different chemicals at the same time, Unburned Hydrocarbons (HC), Carbon monOxide (CO) and NOx (NOx refers to NO and NO_2 which are both oxides of nitrogen). The treatment required for HC and CO is oxidation which means that oxygen is required to oxidise the HC and CO to Carbon Dioxide (CO_2) and water (H_2O) respectively . On the other hand, the NOx needs to be stripped off the oxygen to become Nitrogen (N_2), the stripping off of the Oxygen is called reduction (the opposite of oxidation). The three-way catalyst therefore needs some excess oxygen and also the lack of oxygen thus the engine ECU commands fuel quantity to go rich and lean repeatedly even within one second. Typically, the excursion into rich and lean is just by 2%. An oxygen sensor in the exhaust is what the ECU monitors to be able to keep track of the exact amount of fuel required for stoichiometry and oscillates by 2% into the rich and lean. The ECU will be continuously making and experiment to fine tune the fuel quantities from the base tables supplied originally from the factory to take account for the local fuel supply and other factors that may be affecting the exact stoichiometry.

The three-way catalyst is typically a honeycomb like mesh structure , mostly of ceramic substrate, with a wash coat of noble metals. The noble metals are spread out as much as possible on the large surface area of the substrate to interact in the most effective way with the flowing exhaust gases. The catalyst requires a certain temperature to start operating around 250 or 300 Celsius. When the catalyst reaches this temperature it is said to be ‘lit-off’ and the chemical reactions within it which are mostly exothermic (give off heat) make the temperature downstream of the catalyst go higher than the temperature at the inlet (typically around 50 degrees higher). Lit-off is typically determined by seeing this increase in temperature. Operation at very high temperature of the catalyst leads to reduction of catalyst performance as there is a tendency for the wash-coat to coalesce into patches of thicker layer.

The use of direct injection in petrol engines was motivated to reduce fuel consumption at part load as the throttling of the engine can be reduced. However, the direct injection of the fuel reduced the fuel evaporation opportunity and leads to more particulate formation. Thus, the direct injection of petrol has lead to the Gasoline Particulate Filter (GPF).



Diesel aftertreatment

The diesel engine operates always lean but as it is loaded further it approaches stoichiometry and it will have the tendency to generate smoke. There is therefore a smoke limit in the diesel ECU tables that limit the quantity of diesel to maintain the engine particulate soot quantity at an acceptable level. Nonetheless, the legislative limits require a much lower particulate matter quantity, soot, to be coming off the tailpipe. Therefore, the most typical method nowadays is that a Diesel Particulate Filter (DPF) is installed to block and store the soot. The DPF will thus need cleaning from the trapped soot that is done in three modes.

Passive regeneration, meaning that through a catalytic function of the DPF and the Oxidation Catalyst just upstream of it, the soot is oxidised to form Carbon Dioxide (CO_2), which is a gas and hence flow out. However, this oxidation cannot happen at low temperatures say below 350C. Since in normal commute driving diesel exhaust temperature is lower than the say 350C this passive regeneration cannot be a full solution to get rid of the trapped soot.

Active regeneration, meaning the ECU which is monitoring the soot quantity by means of a delta-P (difference in pressure) sensor across the DPF, will start an active regeneration by injecting extra diesel later in the exhaust stroke so that it will burn in the catalyst and thus increase the temperature in the oxidation catalyst and DPF to a temperature high enough that the soot will burn, that is oxidise, and thus it will be exhausted as CO_2. This active regeneration will be generating temperature of over 400C up to 600C as measured by the temperature sensor typically installed in between the oxidation catalyst and the DPF.

Forced Regeneration, is the regeneration that is initiated by the use of a scan tool. Typically the mechanic will do this type of regeneration to get the soot level back to a low acceptable value. The method with which soot is burned is practically the same as that used in active regeneration, that is the injection of extra diesel so that the extra diesel burns in the oxidation catalyst and DPF and raises the temperature in the DPF high enough so that the accumulated soot can burn off.

Exhaust Gas Recirculation EGR

The quantity of NOx emitted by an engine can be reduced by lowering the combustion temperature. The reduction of combustion temperature can be achieved by diluting the charge air with something that has a lower capability of burning fuel, that is which has less oxygen. This is often done by using exhaust gas because the exhaust gas does not have much oxygen and hence diluting the fresh air with exhaust gases makes the combustion in the cylinder less aggressive which in turn produces less NOx. However, this dilution can only be done at part load as at full load the full air quantity is required to be able to burn enough fuel to produce the desired power output. Many times an EGR cooler is also used to lower the temperature of the exhaust before it is admitted into the intake so that the density of the charge is not lowered as much, that is the quantity mass of charge is not reduced much.

The Selective Catalytic Reduction (SCR) and AdBlue

The Euro 6 legislation requires the NOx to be at a low level which cannot be obtained by engine out and EGR alone. Therefore a Selective Catalytic Reduction catalyst is typically used that is able to strip off the oxygen from the NOx by the use of Ammonia (NH_3). Ammonia has a big affinity to Oxygen and hence it is able to ‘steal’ the oxygen from the NOx and therefore the NOx is turned back to Nitrogen N_2. Since ammonia is toxic itself, it is not prudent to carry ammonia in vehicles and hence ammonia is carried in the form of urea which is itself then blended with water and carried as a solution of urea in water called AdBlue. Typically AdBlue is consumed at 1 litre per 1000km in passenger vehicles. AdBlue is only injected in the exhaust after the exhaust system, actually the SCR, if the exhaust is hot enough for the chemical reaction to be able to take place (typically over 150 degrees).
The quantity of AdBlue injected is determined by the ECU by using the reading from two NOx sensors, one upstream and one downstream of the SCR catalyst.
The Continental type NOx sensor also has an integrated Oxygen sensor which is also used by the ECU to determine how much oxygen is available or produced in the SCR.