A Synopsis on Emission of Pollutants and Their Controls in Modern Engines

The currently regulated major emission constituents are CO, HC, NOx, Particulate (Diesel and upcoming GDI engines), and VOC. However, CO_2 has also gained importance and currently is a focus of regulatory bodies and consequently OEMs as well. There are generally either in-cylinder (or combustion) approaches or exhaust after-treatment methodologies to control emission of such pollutants into the atmosphere. Obviously, it is always preferred to optimize the in-cylinder physical and chemical processes in order to achieve emission reduction goals with no adverse effects on the engine specific fuel consumption.

Because nitric oxides (NOx) formation (in burn gases) is dominated by the thermal effect (or Zeldovich mechanism), in-cylinder reduction of the post-combustion burned-gas "*temperature*" and the "*time*" these burned gases spend at such high temperatures must be reduced. It is shown that addition of exhaust gases (even purposely cooled) to the fresh incoming fuel/air mixture does bring down the post-flame burned gases temperature within the combustion chamber and hence reduces the amount of the engine-out NOx emissions. Therefore, the so-called Exhaust Gas Recirculation (EGR) has been used both in gasoline-fueled and diesel engines. In addition, the amount of "*residual burned gases*" left from one cycle to the next cycle also acts to reduce the in-cylinder post-flame burned gas temperature. The amount of residual burned gases can be adjusted (and calibrated) through the so-called "*valve overlap angle*". Despite such in-cylinder measures, some amount of NOx ends up in the exhaust and hence there is a need for a catalytic reduction of NOx in the exhaust system. The commonly used approach is through the so-called *3-way catalytic converter* (for "stoichiometric" air-to-fuel ratio operating spark-ignited engines). For catalytic treatment of the NOx in the exhaust, this requires adequate amounts of species such as CO (and HC) to reduce it to CO_2 and N_2 via the enhanced chemical reaction rate provided by a suitably chosen catalyst formulation.

In diesel engines (which is an "*overall-lean-burn"* engine), as well as gasoline-fueled lean-burn engines, sufficient amount of CO (or reducing agent) is not available. Hence, reducing agents must be introduced externally into the exhaust system. In such engines, this led to what is called as the "*Selective Catalytic Reduction (SCR)"* in which anomia is used as the reducing agent. In recent years, "*lean-NOx catalysts*" (using HC as the reducing agent) have become commercially viable and used in engines designed to operate under lean and/or (overall-lean gasoline-fueled) stratified charged operations. Unfortunately, due to the need for HC, closed-coupled three-way catalysts cannot be used in conjunction with these lean-NOx catalysts. Another commercially available technology is the recent use of the "*storage NOx catalyst*" which is primarily designed for lean-burn engines. Considering the steep trends and regulatory pressures in fuel economy and CO_2 emission reductions, the overall-lean-burn stratified-charged gasoline direct injection (GDI) engines have been considered which use such a storage NOx catalyst. Very intricate calibration is required for its optimum operation.

CO emission progressively increases when air-fuel (A/F) ratio is enriched. Hence, improvements in "*combustion efficiencies*" in engines generally improve engine-out CO emission. However, the degree of control of CO emission within the engine is achieved from either improving mixture uniformity or leaning out the intake mixture. In multicylinder engines, since CO increases rapidly as A/F is enriched, a cylinder-to-cylinder variation in A/F about a mean value is very important. Therefore, improved cylinder-to-cylinder A/F ratio distribution is essential. CO level is also important during the warmup phase which to some extent can be reduced through retarding the spark timing. Oxidation of CO in the exhaust system without the use of special exhaust treatment devices (i.e., catalysts) does not occur to any significant degree because the exhaust gas temperature is too low. Hence, there is a need for catalytic conversion of CO in the exhaust system. Typically, a 3-way catalytic converter is used as long as engine is operated under the "*stoichiometric*" A/F ratio.

HC is another major regulated emission from engines. In certification processes, methane (CH_4) is separated from the total engine-out HC emission and is referred to as non-methane organic compounds (NMOG). Aside from in-cylinder combustion process measures, there is a need for catalytic converter to speed up the oxidation reaction rates at lowered exhaust gas temperatures if sufficient oxygen is available. Again, a 3-way catalytic converter is commonly used for engines that operate under the "stoichiometric" A/F ratio mixtures. In-cylinder mechanisms for gasoline-fueled engines are adsoption/desoption of HC into the cylinder wall deposits and thin oil layers, flame quenching near the cylinder wall surfaces, bulk flame quenching, and crevices. The most important crevice is the top land piston cervices. For in-cylinder mechanisms leading to elevated HC in diesel engines please refer to a tutorial in the *Advanced Technology Consultants* website.

Particulate is another important pollutant from engines, primarily for diesel engines and to a lesser extent for Gasoline Direct Injection (GDI) engines. In-cylinder measures attempt to avoid overly-rich zones through enhancement of fuel-air mixing. This is generally achieved via very high fuel injection pressures in diesel engines. However, to meet stringent regulation standards, after-treatment in the exhaust is also necessary. "*Diesel Particulate Filter (DPF)*" is used for the removal as well as periodic regeneration of soot particles. This should be meticulously calibrated. Ash accumulation is an issue.