Clean Vehicle Technologies

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Outline

• Vehicle Emissions

• Clean vehicle Technologies
  – Three Way Catalyst Converter
  – Diesel Particulate Filters
  – Exhaust Gas Recirculation
  – Selective Catalyst Reduction

• Clean Vehicles in Nigeria

• Conclusion
Vehicle Emissions

• The main emission of a car engine are:

  – Nitrogen gas (N) – Air is 78% nitrogen gas, and most of this passes right through the car engine.
  – Carbon dioxide (CO₂) – Is one of the product of combustion. The carbon in the fuel bonds with the oxygen in the air.
  – Water vapour (H₂O) – This is another product of combustion. The hydrogen in the fuel bonds with the oxygen in the air.

• These emissions are mostly not harmful although carbon dioxide contribute to global warming.
Vehicle Emissions

As the combustion process is never perfect, small amounts of the following harmful emissions are also produced in car engine:

– Carbon monoxide (CO) – a poisonous gas that is colourless and odourless

– Hydrocarbons or volatile organic compounds (VOCs) – produced mostly from unburned fuel that evaporates. Sunlight breaks these down to form oxidants, which react with oxides of nitrogen to cause ground level ozone (O₃), a major component of smog.

– Nitrogen oxides (NO and NO₂, together called NOx) – contributes to smog and acid rain, and also causes irritation to human mucus membranes.

– Particulate Matter (PM) - The major pollution from diesel engine vehicles is particulate matter smaller than 10 microns (um) (PM₁₀) in diameter and those smaller than 2.5um(PM₂.₅) which cause respiratory illness.
Clean Vehicle Technologies

- Countries started legislating to reduce the harmful vehicle emissions in the 1970s. The table below is that of the European Union:

<table>
<thead>
<tr>
<th>Euro standard</th>
<th>Introduction date</th>
<th>Emission limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New approvals</td>
<td>Petrol NOx</td>
</tr>
<tr>
<td>Euro-0</td>
<td>1 October 1991</td>
<td>1,000 mg/km*</td>
</tr>
<tr>
<td>Euro-1</td>
<td>1 July 1992</td>
<td>490 mg/km*</td>
</tr>
<tr>
<td>Euro-2</td>
<td>1 January 1996</td>
<td>250 mg/km*</td>
</tr>
<tr>
<td>Euro-3</td>
<td>1 January 2000</td>
<td>150 mg/km</td>
</tr>
<tr>
<td>Euro-4</td>
<td>1 January 2005</td>
<td>80 mg/km</td>
</tr>
<tr>
<td>Euro-5</td>
<td>1 September 2009</td>
<td>60 mg/km</td>
</tr>
<tr>
<td>Euro-6</td>
<td>1 September 2014</td>
<td>60 mg/km</td>
</tr>
</tbody>
</table>

*includes NOx and HC
Clean Petrol Engines

The best way to clean a petrol engine emission is through a three-way catalytic converter. It performs three simultaneous tasks:

- Reduction of nitrogen oxides to nitrogen and oxygen:
  \[ 2\text{CO} + 2\text{NO}_2 = 2\text{CO}_2 + \text{O}_2 + \text{N}_2 \]

- Oxidation of carbon monoxide to carbon dioxide:
  \[ 2\text{CO} + \text{O}_2 = 2\text{CO}_2 \]

- Oxidation of unburnt non-methane hydrocarbons (HC) to carbon dioxide and water:
  \[ \text{C}_2\text{H}_4 + 3\text{O}_2 = 2\text{CO}_2 + 2\text{H}_2\text{O} \]

- These reactions works better with low Sulphur fuel, at least 50ppm, preferably 10ppm and below. Unleaded petrol is also required as Lead will poison the catalyst.

- The catalyst is a noble/rare metals (Cerium oxide, Platinum, Palladium and Rhodium) sprayed over a ceramic honeycomb ceramic structure to maximise reaction surface area.
Three Way Catalytic Converter

$N_2, H_2O, CO_2$

Three-way catalyst

$HC, CO, NOx$
Clean Petrol Engines

- These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running at the stoichiometric point of 14.7 parts Oxygen to 1 part fuel.

- When there is more oxygen than required, then the system is said to be running lean, and the system is in oxidizing condition. In that case, the converter`s two oxidizing reactions (oxidation of CO and hydrocarbons) are favoured, at the expense of the reducing reaction.

- When there is excessive fuel, then the engine is running rich. The reduction of NOx is favoured, at the expense of CO and HC oxidation.
Clean Petrol Engines
Clean Diesel Technology

- Clean diesel technology is the use a number of exhaust after treatment options such as:
  - Diesel particulate filters (DPF),
  - Diesel oxidation catalysts (DOC),
  - Exhaust gas recirculation (EGR), and
  - Selective catalyst reduction (SCR) with the use of diesel exhaust fluid (DEF)
- These however, require low Sulphur (S) fuels. DOC requires 500 ppm S and below, while DPF requires 50 ppm S and below. Introduction of ultra-low sulfur diesel fuels for both on- and off-road applications is a central part of the clean diesel system designed to meet near zero emissions standards. DOC are similar to petrol engine catalytic converters.
Diesel Particulate Filters

- Diesel particulate filters usually remove 85% to 100% of the soot. Some filters are single-use, intended for disposal and replacement once full of accumulated ash. Others are designed to burn off the accumulated particulate either passively through the use of a catalyst or by active means such as a fuel burner which heats the filter to burn the soot.
Diesel Particulate Filters
Particulate matter (PM10) emissions fell 96% from Euro-1 to Euro-6, and are today equivalent to one grain of sand per km driven.

<table>
<thead>
<tr>
<th>Year</th>
<th>Emissions (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>0.14</td>
</tr>
<tr>
<td>Euro-1</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>0.10</td>
</tr>
<tr>
<td>Euro-2</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>0.05</td>
</tr>
<tr>
<td>Euro-3</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.025</td>
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<tr>
<td>Euro-4</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>0.005</td>
</tr>
<tr>
<td>Euro-5</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>0.005</td>
</tr>
<tr>
<td>Euro-6</td>
<td></td>
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</tbody>
</table>
Exhaust gas recirculation (EGR) is a nitrogen oxide (NOx) emissions reduction technique used in petrol and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. This dilutes the O₂ in the incoming air stream and provides gases inert to combustion to act as absorbents of combustion heat to reduce peak in-cylinder temperatures. NOx is produced in a narrow band of high cylinder temperatures and pressures.
Exhaust Gas Recirculation
SCR Technology

• Selective Catalytic Reduction (SCR) is an advanced active emissions control technology system that injects a liquid-reducting agent through a special catalyst into the exhaust stream of a diesel engine. The reducing source is usually automotive-grade urea, otherwise known as Diesel Exhaust Fluid (DEF).

• The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide ($CO_2$), natural components of the air we breathe, which are then expelled through the vehicle tailpipe.
SCR Technology

• SCR technology is designed to permit nitrogen oxide (NOx) reduction reactions to take place in an oxidizing atmosphere. It is called "selective" because it reduces levels of NOx using ammonia as a reducing agent within a catalyst system.

• The chemical reaction is known as "reduction" where the DEF is the reducing agent that reacts with NOx to convert the pollutants into nitrogen, water and tiny amounts of CO₂. The DEF can be rapidly broken down to produce the oxidizing ammonia in the exhaust stream. SCR technology alone can achieve NOx reductions up to 90 percent.
NOx reductions 2001-2015

Emissions of NOx from diesel cars have fallen by 84% since the millennium

- 2001 Euro-3, 0.5g/km
- 2006 Euro-4, 0.25g/km
- 2011 Euro-5, 0.18g/km
- 2015 Euro-6, 0.08g/km
Real world tests

A Euro-6 bus emits 95% less NOx than a Euro-5 bus

Tests conducted by Transport for London using the cross-city London 159 Bus Route show a 95% reduction in emissions of NOx over older technology vehicles.
Clean Vehicles in Nigeria

• In Nigeria, we phased out leaded gasoline in 2003 and in 2012, introduced vehicle emission standards equivalent to Euro 2. The Sulphur max limits in our fuel specifications (3,000 ppm and 1,000 ppm for diesel and petrol respectively) precludes a higher standard.

• We are working with the Standards Organisation of Nigeria to reduce the Sulphur limit to 50 ppm.

• The vehicle testing for road worthiness certification (aka MOT test) is under the control of the state governments. We are working with them to modernise the testing, including emission testing.

• We are also building a reference vehicle emission test centre in Lagos.
Conclusion

• Technologies exist to drastically reduce harmful vehicle emissions.

• However, they require low Sulphur fuels and frequent vehicle testing to ensure their effectiveness.

• Nigeria needs to have an air quality monitoring of our major urban centres because:
  – There are about 15m vehicles on our roads, concentrated in our urban centres. About 400,000 vehicles are added annually, about $\frac{3}{4}$ of which are used.
  – There is also a lot of power self generation with small petrol and larger diesel generators.
  – It will take some time in Nigeria before we can have low Sulphur fuels.
  – Our vehicle testing for roadworthiness and emissions are yet to take-off in many states.