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Transportation, Pollution and the Environment

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Abstract

The importance of modern day transport systems and the transportation industry in the world economy cannot be over emphasized. However, it is now widely recognized that air pollution and environmental degradation are directly linked to the rapid growth of automobile, air, rail, and sea modes of transport. These transportation services and their allied industries are key contributors to every nation's gross domestic product. This work will endeavour to highlight the general areas of concern with regard to pollution and environmental degradation as a consequence of this rapid growth and expansion, with a focus on diesel emissions. These areas are (1) Pollution in highly populated urban areas (cities) with their high rate of personal or private transport rather than public transport systems; (2) The effects of modern day transport systems on the depletion of the ozone layer, which is responsible for climatic changes; and (3) The legislative and effective control systems required to meet the current environmental demands, which this work will endeavour to critically present and analyse.

Keywords; Environmental Degradation, Transport Industry, Urban Pollution, Modes of Transport.

Nomenclature and Abbreviations

$\dot{m}_{EGR}$	Mass Flow Rate of Egr Gases
$\dot{m}_{air}$	Mass Flow Rate of Air
$\dot{m}_{exh}$	Mass Flow Rate from The Exhaust
$\dot{m}_{f}$	Mass of Fuel Injected
$\dot{m}_{int}$	Mass Flow Rate from The Intake Side
r_{EGR}	Percentage of Recirculated Egr Gases
CeO_2	Cerium Oxide
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EC	Elemental Carbon
EPA	Environmental Protection Agency
GBD	Global Burden of Disease
HC	Hydrocarbon Emissions
IEA	International Energy Agency
IF	Inorganic Fraction
IPCC	Intergovernmental Panel on Climate Change
NAC	NOX Absorber Catalyst
LNT	Low NO_X Trap
NASA	National Aeronautical and Space Administration
NH3	Ammonia
NNH	NNH Route of NO_X Formation
NOAA	National Oceanic and Atmospheric Administration
NOX	Agglomerates of Oxides of Nitrogen
NSR	NOX Storage Catalyst
OECD	Organisation for Economic Cooperation and Development
PAGASA	National State Weather Bureau of Philippine
PCV	Positive Crankcase Ventilation
Pd	Palladium
PM	Particulate Matter
PM_{10}	Particulate Matter of Size 10nm
$PM_{2.5}$	Particulate Matter of Size 2.5nm
Pt	Platinum
Rh	Rhodium
SAWS	South-African Weather Services
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SO_3	Sulphur Trioxide
SOF	Soluble Organic Fraction
TDC	Top Dead Centre
VOCs	Volatile Organic Compounds
WHO	World Health Organization
ZrO_2	Zirconium Oxide
λ	The Air Excess Factor Symbol Lambda

INTRODUCTION

The word 'pollution' has a wide variety of contextual meanings and applications, but in the context of this work it means the damage caused by human activity to the environment and ecological systems. Considering all sources of the environmental pollution and categories of pollution emitted and excluding land use for the purpose of agriculture, the transport industry in the world is responsible for about one third of all environmental emissions of volatile organic compounds (VOCs) released into the atmosphere and the environment, including two thirds of the carbon-monoxide (CO). The VOCs, which are hydrocarbon based, are a direct result of combustion, particularly inefficient combustion emitted from vehicle tail pipes as exhaust gases when they burn fuel to produce propulsion power. Some hydrocarbons are known carcinogens. Among the greenhouse gases, CO_2 is the main culprit of global warming and has reached 34 billion tonnes per year with an increase of 3 % in 2011 alone [1] and is projected to rise to 41 billion tonnes by the year 2020 [2].

Human activities, especially the use of and burning of fossil fuels, enhance the greenhouse gas effect by increasing their concentration levels in the atmosphere. The major gases emitted through human activity are CO_2, methane, oxides of nitrogen (NO_X), fluorinated gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) [3].

There are several methods of VOC emissions control in the modern day automobile, through the use of high pressure fuel injection systems, catalytic converters and positive crankcase ventilation systems (PCV). However, 20 % of all uncontrolled vehicular emissions are as a result of crankcase blow-by and evaporating oil. The particulate VOC pollutants, which result from incomplete combustion and evaporating lubricating oil, have an emission rate of 0.6 g/bkWh to 2.2 g/bkWh for light duty diesel automotive propelled engines, whereas the large ones have 0.5 g/bkWh to 1.5 g/bkWh [4, 5].

The global threat caused by human activities to the environment is the second most serious issue after war facing the world today. This is due to the rise in global warming levels above the pre-industrial levels by over 0.94 ºC, acidifying of the oceans, and 3.2 cm of sea level rise per decade. Extreme heat waves, global temperature rise and drought have affected food chains across the globe [6, 7] Unless these activities are legislated for, curbed and controlled, it is expected that globally the negative effects of climatic change will cause a warming of 4^{0} C and a sea level rise of 0.5 m to 1.0 m as early as 2060 [8].

The transport industry which is a major contributor to the global economy is also a major cause of environmental pollution and climate change, especially due to the emission from motor vehicles which accounts for 22 % of all the global CO_2 emissions [9]. Air pollution in developing countries and emerging economies accounts for tens of thousands of deaths, with the World Health Organization estimating an annual death toll from air pollution alone to be around 2.4 million people using 2009 estimates and projections [10]. Thus, environmental protection, air pollution control and climatic change management have become issues of global concern, with many agencies such as the Environmental Protection Agency (EPA) of the United States of America, the Organisation for Economic Cooperation and Development (OECD), the Intergovernmental Panel on Climate Change (IPCC), the European Environment Agency (EEA) and the International Energy Agency (IEA) being constituted and empowered to act in this regard. To this end these agencies have recommended legal measures and control systems, as well as supporting relevant technological research and development in research to improve the pollutions standards of the transport service industry.

The reason this study focuses on diesel propelled engines is because they have the highest proportion of usage globally as compared to gasoline propelled engines, given their numerous merits such as low-operational cost, energy efficiency, reliability, and durability. These merits have made diesel propelled engines the top choice of business leaders in the transport industry as power sources for commercial transportation in trucks, buses, trains, ships and for power generation. Their environmental impact is caused by the exhaust gases released via the tail pipe which contain very high amounts of particulate matter (PM) and NO_X emissions and other pollutants. These pollutants are responsible for severe environmental degradation of air quality causing smog, acid rain and disturbance to the ozone balance. They also cause major health problems, especially diseases related to the respiratory system, and cancer [11].

DIESEL ENGINE STATUS ON EMISSIONS IN THE TRANSPORT SECTOR

From Tables 1 and 2 and presented below it can be seen that transport contributes the largest amounts of NO_X, PM, CO, SO_3 and HC emissions annually, globally. The PM percentage referred to in Tables 1 and 2 does not include dust from the road, rubber particulates from tyres, the photochemical smog particles arising from brake pads and asbestos brake linings used in braking systems of automobiles passenger and commercial vehicles. In addition, there is noise pollution which is predominantly attributed to heavy duty diesel vehicles especially around major urban centres and cities (from highways, ports and stations) and air transport.

Table 1. Atmospheric pollutants and their sources in percentage form

SOURCE	NO_X %	PM %	CO %	SO_3 %	HC %
INDUSTRY	22	44	4	32	26
POWER GENERATION	32	21	0	48	0
SPACE HEATING	5	14	3	12	3
REFUSE BURNING	0	7	1	4	6
TRANSPORT	42	14	92	4	65

Table 2 showing emissions of air pollutants by source in the United States in 2011[12]

Table 2.

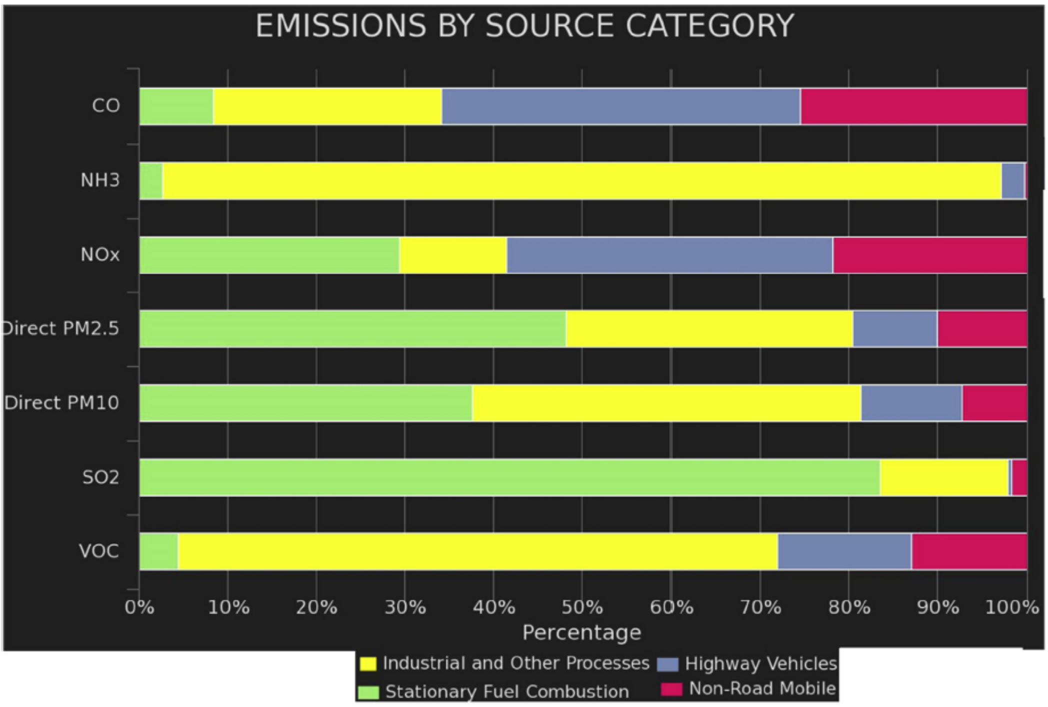

Figure 1 shows the compositions of hydrocarbon pollutant of diesel exhaust gas as analysed at the tail pipe exit [2]. Molecular nitrogen, which is an agent of NO_X emissions, is the largest percentage at approximately 67 %.

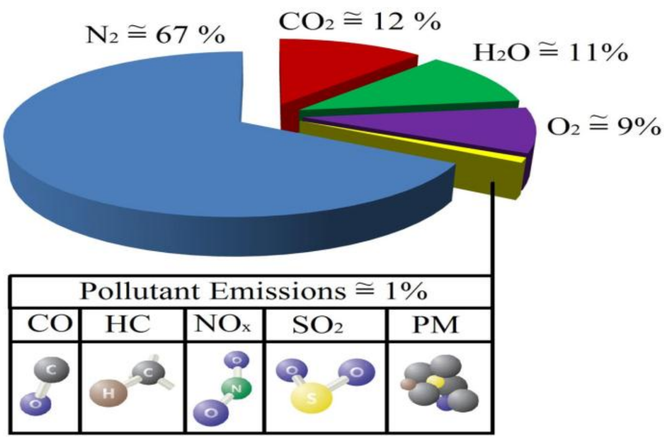

Figure 1. The compositions of hydrocarbon pollutants of diesel exhaust gas as analysed at the tail pipe exit [2].

THE FORMATION OF DIESEL ENGINE POLLUTANTS, AND THEIR EFFECTS

Unburned Hydrocarbons (UHC)

Unburned Hydrocarbon (UHC) emissions are an indication of the quality of combustion within an internal combustion engine, arising from vaporized unburnt fuel and partially burned fuel by-products exiting the combustion chamber and being released to the atmosphere via the exhaust manifold. UHC emissions are inherently independent of the air-fuel ratio of a working engine, as they do not depend on the engine alone but also on other factors outside the engine itself. Such emissions can also be created, for example, if there is a malfunction of other systems or an operational malfunction of other systems, particularly the input data systems in modern injection and engine management systems.

There are two features of a fuel injection systems in spark ignition engines (SI) which cause or can bring about HC emissions, namely, secondary injection and high nozzle sac volumes. However, when it comes to compression ignition engines, which this work is dealing, the hydrocarbon emissions are caused due to insufficient temperature near most cylinder walls of the compression ignition engines. Diesel propelled engines emit low hydrocarbons principally at light loads; the lean air fuel mixture which is the main source of light load emissions is caused by low speed flames which disallow completion of combustion during the normal cycle of the power stroke and secondly due to lack of the actual combustion thus leading to high emissions of hydrocarbons.

There are three main factors that may affect the type of hydrocarbons emitted, namely, engine adjustments, design and fuel type. Engine operating environment can also affect the content of hydrocarbons, where temperatures are 400 ^{0} C to 600 ^{0} C in the combustion cylinder and when oxygen is still available, hydrocarbons will continue to react in the exhaust. Therefore, this will lower emissions exiting the tail-pipe as compared to the engine cylinder prior to it, stated in terms of their CH_4 equivalent content [13, 14]. Emission consists of thousands of chemical species of alkanes, alkenes and aromatics.

Hydrocarbon emissions are not limited to the vehicle exhaust system only but also occur in the vehicle fuel system, from vapors during fuel distribution and dispensing (15 % to 25 %) and the engine crank-case itself (20 % to 30 %). However, the largest culprit of all vehicular hydrocarbon emissions is the exhaust tail pipe which accounts for 50 % to 60 % of all hydrocarbon emissions [15, 16].

Oxides of Nitrogen (NOx) Emissions

As shown and indicated in the literature discussed above, the transport industry (particularly the road component) is the principal and primary source of nitrogen oxide (NO) emission and its oxidized products nitrogen dioxide (NO_2). NO and NO_2 constitute 85 % to 95 %, while NO and N_2 are lumped together as NO_X. There are fundamental differences between the two gases; NO is colourless and odourless, while its counterpart NO_2 is a reddish brown gas with a pungent smell and odour [17]. These two gases are considered to be extremely toxic, especially NO_2 which is five times more toxic than NO, which is a threat to human health as it affects the respiratory system causing irritation and poor resistance to even simple respiratory infections like the common cold and influenza [2].

The temperature dependence of oxides of nitrogen is due to the equilibrium concentration of NO_X compounds of oxygen and nitrogen when they are mixed in a very high flame temperature adiabatically with temperatures of 2000 K to 3000 K [18]. There are basically four types of mechanisms through which the nitrogen oxide emissions are formed and constituted in the combustion chamber and within the automobile combustion chamber, namely: The Zeldovich mechanism, the prompt mechanism, through engine fuel mechanism, and the NNH mechanism [19]. The Zeldovich mechanism is represented in Equation 1, 2 and 3 with Equation 2 as the reaction rate determining step equation [20].

$$O_2 \leftrightarrow 2O \quad \text{Equation 1}$$

$$N_2 + O \leftrightarrow NO + N \quad \text{Equation 2}$$

$$N + O_2 \leftrightarrow NO + O \quad \text{Equation 3}$$

The prompt mechanism, otherwise known as the Fenimore mechanism [21] (named after the man who discovered it), involves reactions of the fragmented hydrocarbons with molecular nitrogen under weak temperature dependency, thus accounting for a relatively smaller portion of the hydrocarbon emissions. Equations 4, 5 and 6 show the occurrence of prompt NO_X [22].

$$O + N_2 + M \rightarrow N_2O + M \quad \text{Equation 4}$$

$$H + N_2O \leftrightarrow NO + NH \quad \text{Equation 5}$$

$$O + N2O \leftrightarrow NO + NO \quad \text{Equation 6}$$

As mentioned earlier, the oxides of nitrogen form an important constituent of photochemical smog besides the greenhouse gas effects, thus contributing in many ways to the depletion of the ozone, causing acid rain, air pollution and a general decrease in the air quality in modern urban metropolises and cities in the world today.

Table 3. Transport patterns and their contribution to overall emissions in selected cities

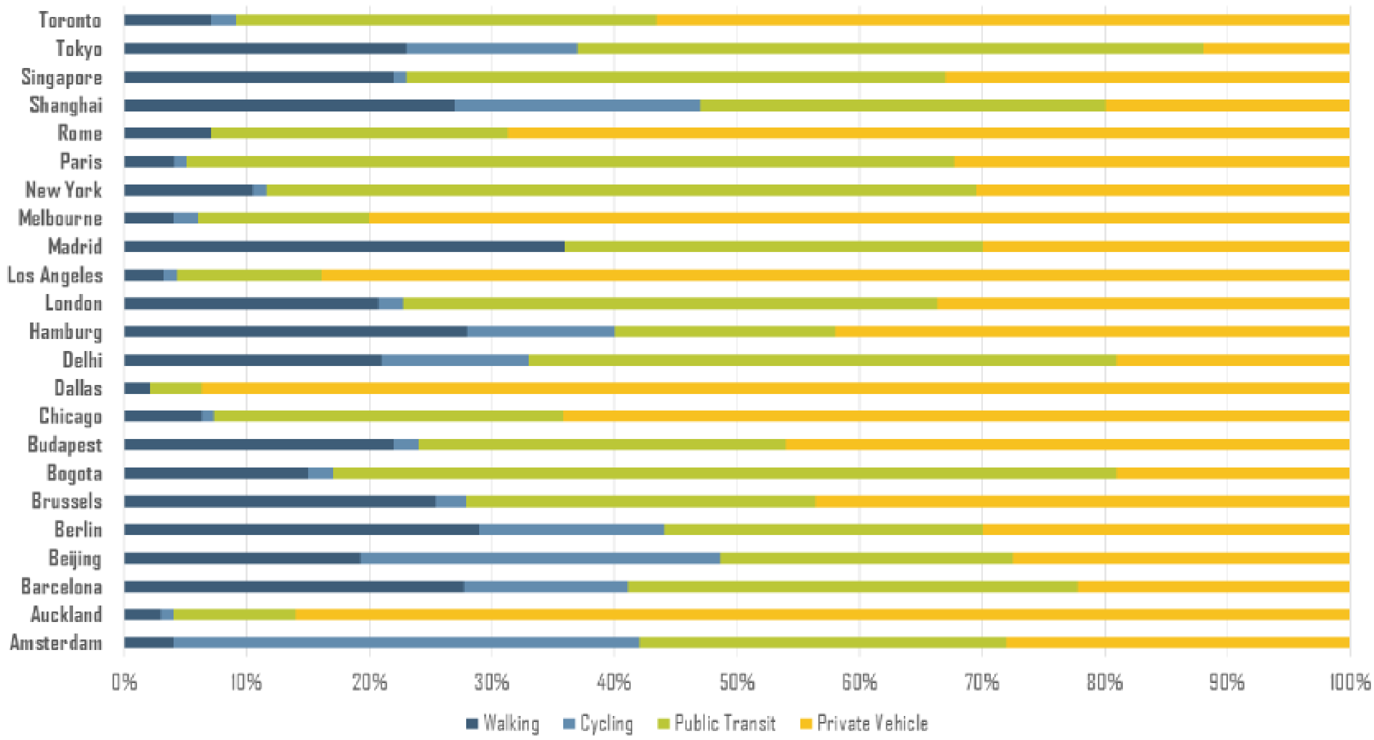

Table 3 shows transport patterns in 23 sampled cities in various regions and the contribution of individual modes of transport to the overall emission percentages in these cities. The leading percentages of pollution by source as seen in Table3 is caused by public transport and private public transport vehicles, with Dallas in USA as the leading city in terms of private public transport pollution, and Tokyo in Japan is the leading city in in terms of public transport pollution.

The amount of NO_X produced during emission from the engine is a function of three factors, namely: the amount of time taken or the combustion duration, the level of concentration of oxygen, and, because NO_X is temperature dependent, the maximum existing temperature in the combustion cylinder. Most of the NO_X emitted is formed in the early combustion phase process with the engine piston nearing the end of compression or top dead centre (TDC) at which period the combustion process propagated flame temperature is at maximum or at peak levels. The amount of NO_X increases three-fold for every 100 ^{0}C increase in the cylinder combustion temperature [16].

Particulate Matter (PM) Emissions

PM emissions can be defined as the agglomerations of small particles resulting from the combustion process due to partly burned lubrication oil, ash content of the fuel used by the engine, sulphates from the engine cylinder wall lubrication oil, and water from condensation and the combustion process. For example, in an experimental study of a heavy duty diesel engine, the researchers classified and characterized the emissions as 41 % as carbon, 7 % as unburned fuel, 25 % as unburned oil, 14 % as sulphates and water, and 13 % as ash and other component emissions [23]. In an earlier study conducted by Agarwal (2007)[24] it was observed that PM emissions consisted of ≅ 31 % elemental carbon, ≅ 14 % sulphates and moisture, ≅ 7 % unburnt fuel, and ≅ 40 % unburnt lubricating oil, with the remaining percentages being metals and a variety of other substances.

Diesel PM are particles usually in the region of $15\ nm\ to\ 40\ nm$ measured by diameter, though almost 85 % to 90 % of all PM emissions are less than 1 μm in measured diameter. PM emissions can be divided into three forms or main components: soluble organic fraction (SOF), soot, and the inorganic fraction (IF) of which 50 % is emitted as soot in the form of black smoke in exhaust tail-pipes. SOF is made up of absorbed or condensed hydrocarbons that are embedded within the soot emissions in very fine particles derived partly, as already mentioned, from lubrication oil, unburned fuel and compounds of the combustion process from the combustion chamber (Table 4). These emissions are more pronounced when starting and during idling when the exhaust temperatures are low [25].

Table 4. The components of SOF emissions and their total fraction percentages [4].

Fraction	Components of fraction	Percentages of total fraction
Acidic	Aromatic or aliphatic Acidic functional groups Phenolic and carboxylic acids	3-15
Basic	Aromatic or aliphatic Acidic functional group Amines	< 1-2
Paraffin	Aliphatic, normal and branched Numerous isomers From unburned fuel and /or lubricant	34-65
Aromatic	From unburned fuel, partial combustion, recombination of combustion, from lubricants, Single ring compounds Polynuclear aromatics	3-4
Oxygenated	Polar functional groups but not acidic or basic Aldehydes, ketones, or alccohols Aromatic phenols and quinones	7-15
Transitional	Aromatic or aliphatic Carbonyl functional groups Ketones, aldehydes, esters, ethers	1-6
Insoluble	High molecular weight organic species Hydroxyl and carbonyl groups Inorganic compounds Glass fibre from filters	6-25

The size distribution of particles exhausted from diesel engines generally has two peaks: the nucleation mode which includes all volatile hydrocarbons that are below 50 μm, and the accumulation mode which is made up of soot and particles that are above 50 μm [26, 14]. PM emissions formation is controlled by a number of factors such as the combustion process, fuel quality (sulphur and ash content in the fuel), the power stroke or the expansion process of the fuel, the engine lubrication quality, the fuel consumption per engine cycle and the exhaust gas cooling [27].

PM emissions impact negatively on human health as well as the environment. For example, in 2010 alone the global burden of diseases (GBD) index attributed 3.2 million deaths to ambient pollution [28] where $PM_{2.5}$ emissions were the main contributor, thus highlighting the seriousness of air pollution from the transport industry.

Figure 2 shows the cause specific global mortality attributable to ambient $PM_{2.5}$ emissions.

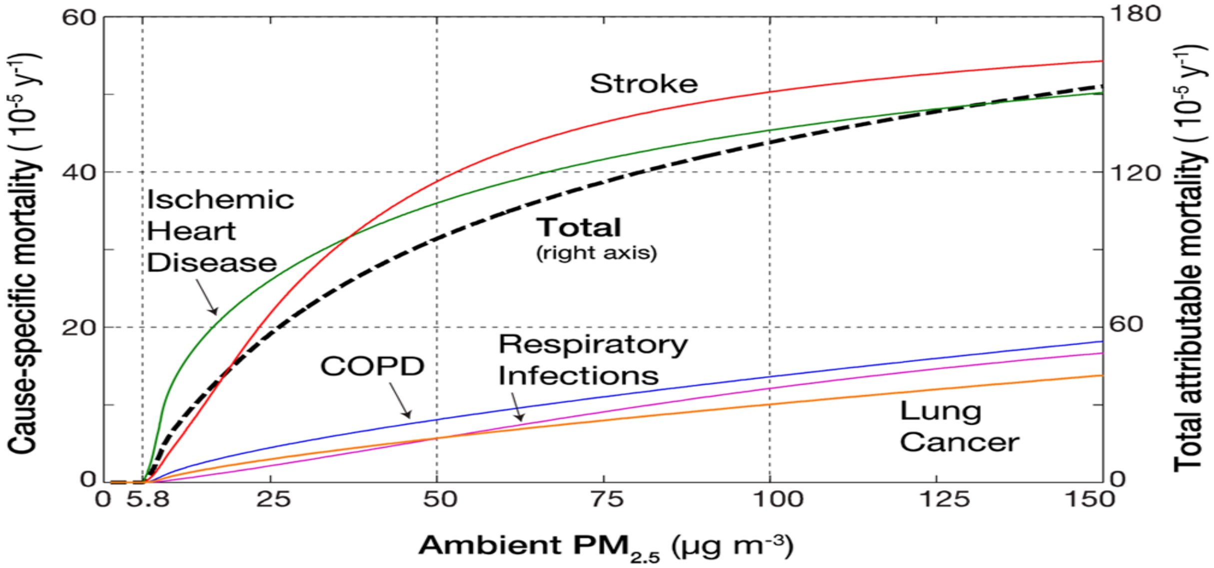

Figure 2 shows global and regional distributions of deaths as a function of ambient $PM_{2.5}$ concentration.

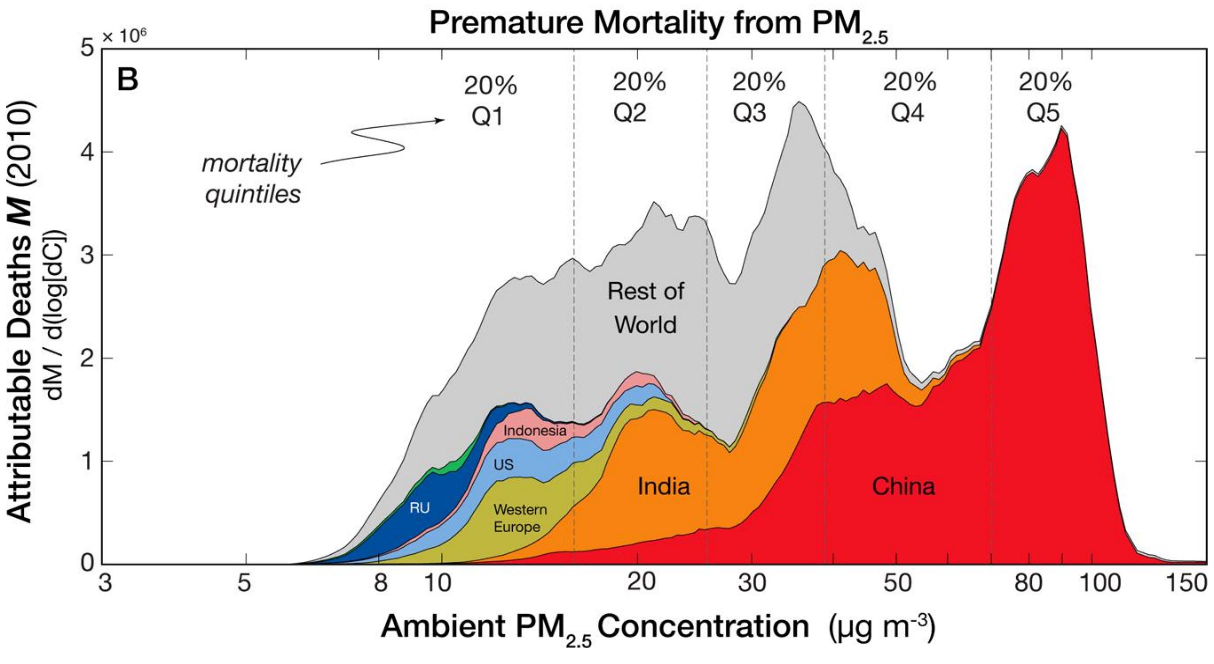

Figure 3. Global and regional distribution of deaths as a function of ambient $PM_{2.5}$ in different countries in quantile percentages.

Carbon Monoxide Emissions

Carbon monoxide emissions result from the incomplete combustion of hydrocarbon fuels as a result of failure of oxidation during the combustion process in a diesel engine, particularly where excess air factor λ satisfies the condition $\lambda < 1$ for SI engines and thus the mixture is classified as a rich mixture, which occurs especially during start-ups and sudden acceleration where rich mixtures are a conditional requirement. CO is defined as a colourless, tasteless and odourless toxic gas produced primarily due to the incomplete combustion of the carbon containing fuels. The United States of America is the single largest producer of this pollutant gas and a leading producer of pollution from anthropogenic sources – anthropogenic sources being the major contributor of this gas, as seen from Figure 4.

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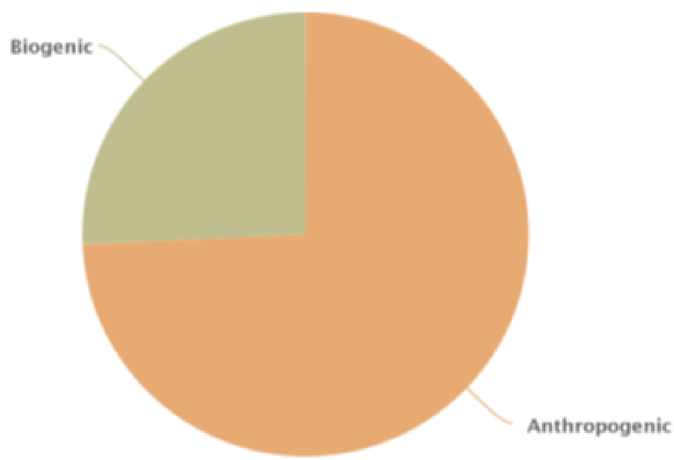

Figure 4. carbon monoxide (CO) emissions by anthropogenic and biogenic sources in the USA [29].

The measured average CO concentration for fuel rich mixtures is very close to equilibrium in burned gas especially during the expansion process. However, for lean fuel mixtures of which diesel engines form a large segment, measured CO emissions are higher than most prediction models of any kind. One possible explanation for this is that from a practical point of view, CO oxidation mechanisms are determined by the fuel air equivalence ratio. This phenomenon in the rich mixture areas and lack of availability of enough oxygen makes the reactant concentration fail to convert fully during combustion, thus exhausting a smaller portion through the tail-pipe due to the kinetic effects. CO emissions tend to form and accumulate in areas of heavy concentrated traffic, parking garages, and under building overheads and overhangs. Among the human health effects of CO emissions due to exposure are headaches, dizziness and in extreme cases of exposure, death.

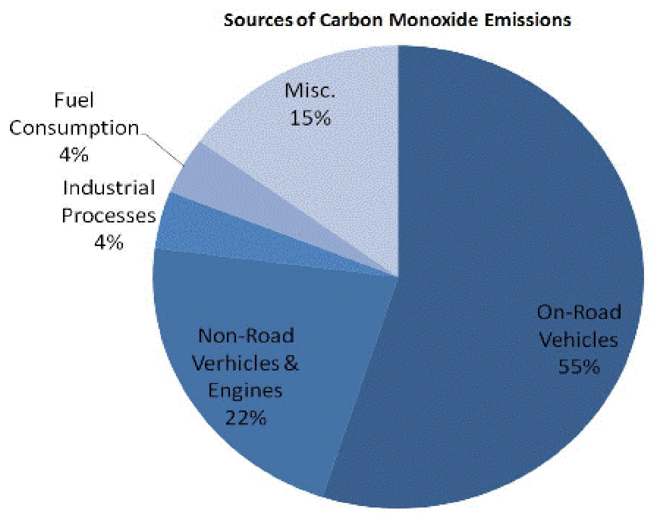

Figure 5 is a pie chart showing how anthropogenic sources contribute to carbon monoxide emissions with the largest share of 55 % being contributed by the transportation industry whose core players are heavy and light duty vehicles on the road [30].

Effects of Traffic Pollutants on the Natural Environment

The demand for energy supply associated with economic growth and development causes emissions which deplete the ozone layer. The ozone layer raises particular concern for ecology since it leads to sun radiation exposure to ultra-violet rays in the $200\,\mu m$ to $300\,\mu m$ range which is toxic to unicellular organisms and most surface cells of animals and [31].

Pollution from automobiles is one of the leading causes of global warming, as cars (light duty and heavy duty) release greenhouse gases and carbon dioxide into the atmosphere through their exhaust systems. These types of gases tend to trap heat in the atmospheric environment thus causing a global rise in temperatures. Because of the combustion of increasing volumes of fossil fuels, global temperatures have risen by 0.5 ^{0} C to 1 ^{0} C since the pre-industrial age. The global rise in temperature or global warming affects the natural environment by causing higher sea levels, damaging farming activities which have a bearing on food security, damaging wild life, and destroying natural habitats and landscapes

Effect of Greenhouse Gases and Global Warming

Since the first recorded temperatures in 1860, earth temperatures have risen by over 1 ^{0} C, and 2017 was one of the hottest years after 2016 in human history. The first six months of 2017 recorded an average surface temperature of 1.1^{0} C above the 1950 to 1980 averages [32].

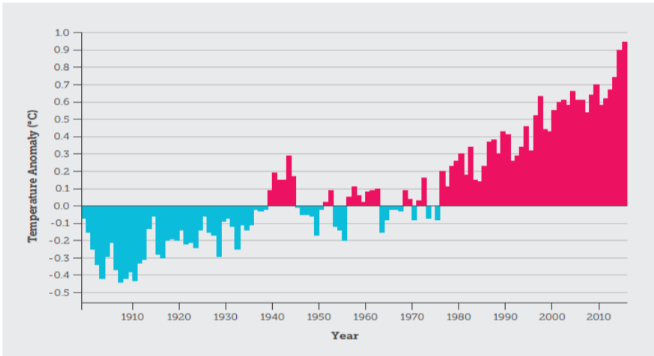

Figure 6. Annual global temperature anomalies from 1901 to 2016 relative to the global annual average temperature for the 20th century (1901-2000) [32].

Figure 6 shows the way in which the annual global temperature has consistently been above the global average for the 20th century, climbing steeply since 2010. Data is from the US National Oceanic and Atmospheric Administration (NOAA) as cited in [32].

Coming closer home to South Africa, the Western Cape province has experienced unprecedented drought and severe unpredictable weather patterns for the last three years. South Africa had intense 2016 January heatwaves in about 62 locations nationally with recorded temperatures reaching up to 46 ^{0} C in Tosca in North West province according to the South African Weather Services (SAWS) [33] 2016. Botswana recorded and broke a national record of 72 years for its maximum temperature in Maun at 44^0 C.

Alaska in the United States of America had its warmest month in February 2016 breaking a 96-year national record predating the 20th century average with increment levels of 6.9 ^{0} C according to the NOAA, with California and Australia recording unending wild fires due to excessive drought and heat, leading to massive loss of life and property besides the economic loss suffered by individuals and the state [32].

The Effects of Traffic Pollution On Agriculture and Food Security

As a result of the climatic changes that have been enumerated and discussed in previous sections, there has been a shift in the meteorological equator leading to changed forecast trends and scenarios of desert expansion, drought and change in weather patterns across the globe [34]. The following are examples of scenarios that have already started happening:

- Reduction of rainfall, turning some areas like California into deserts, with similar changes being experienced in the Cape provinces in South Africa, where the water conditions are worsening. Punjab in India and other areas are facing intense heat waves with the countryside experiencing droughts of untold proportions.
- There has been an increase in the intensity of severe weather conditions, where the severity of typhoons has been increasing in places like Philippines with 2016 alone accounting for more than 20 tropical cyclones according to PAGASA, the national state weather bureau of Philippines. In 2013 35 000 to 39 000 people lost their lives and damage of more than 40 billion USD was caused by extreme weather conditions, according to the national disaster risk reduction management council of Philippines [35, 36].
- Expansion of the African desert beyond Africa, to Spain Greece and Italy, besides the sub-Saharan countries known as the Sahel countries, which are currently experiencing severe drought and food insecurity.

AUTOMOBILE POLLUTION CONTROL MEASURES

The world is now pre-occupied by environmental protection and the dangers of human activities that degrade the environment. From the United Nations to organizations in regional blocks and individual countries, everyone is embarking on saving and preventing extensive damage to the environment and human health as a result of emissions of pollutants.

Due to the effects of diesel engine emissions on human health and the environment, government agencies in charge of human health and the environmental development have put forward requirements and permissible standards to curb vehicular emissions. In Europe the European Environmental Agency (EEA) has been in operation since 1993 with recommendations and standards of Euro I to Euro IV, as shown in Table 5.

Table 5. EURO standards for heavy duty vehicles according to Delphi 2016 to 2017 as per Walker (2016) [37] and [2].

	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Euro I	4.5	1.1	8.0	0.61
Euro II	4	1.1	7.0	0.15
Euro III	2.1	0.66	5.0	0.13
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2.0	0.02
Euro VI	1.5	0.13	0.4	0.01

From Table 5 it can clearly can be seen that the standards have become more stringent, thus obliging the vehicle manufacturers and industry service providers to work harder towards reducing emissions from public, private, and commercial vehicles. For almost two and a half decades now (from 1993 to 2017) studies have been carried out on engine modifications and electronic control systems for fuel injection have been introduced, along with tremendous improvement on fuel properties and development. Among the techniques investigated to cut down emissions in combination with other techniques are: the use of exhaust gas recirculation (EGR), lean NO_X trap (LNT), diesel oxidation catalyst (DOC), diesel particulate filter (DPF) and the selective catalytic reduction (SCR) technique [38]. However, these developments have failed to attain sufficient reduction of pollutant emissions to the required regulatory standards as prescribed by the controlling environmental protection agencies.

Exhaust Gas Recirculation

Exhaust gas recirculation is a system which allows the recirculation of the exhaust gases back into the combustion chamber for mixing and reburning with the fresh charge [39] (Figure 7). This technology, though able to reduce NO_X, leads to other problems such as an increase in HC and CO emissions due to the lowered combustion temperature besides affecting overall engine efficiency. While it is accepted that universally there is no standard definition of EGR to be able to quantify the amount of EGR recirculated, there are two methods that are widely accepted and are commonly used to define EGR: the mass based method and the gas concentration method [40].

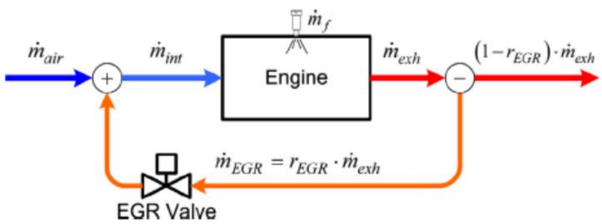

Figure 7. Schematic representation of an EGR system and some of its nomenclature and control design for the EGR valve.

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Both of these methods can be demonstrated from the diagram shown in Figure 7 and can also be expressed mathematically as follows in Equations 7 and 8 [41].

$$r_{EGR} = \frac{\dot{m}_{EGR}}{\dot{m}_{air}+\dot{m}_f+\dot{m}_{EGR}} \qquad \text{Equation 7}$$

$$r_{EGR} \approx \frac{[CO_2]_{int}-[CO_2]_{amb}}{[CO_2]_{exh}-[CO_2]_{amb}} \approx \frac{[CO_2]_{int}}{[CO_2]_{exh}} \qquad \text{Equation 8}$$

Where the $\dot{m}_{EGR}$ is the mass flow rate of the gas recirculated, $\dot{m}_{air}$ is the mass flow rate of fresh air, $\dot{m}_f$ is the mass flow rate of the injected fuel and r_{EGR} is the mass fraction of the recirculated exhaust gases.

Low NOX Trap (LNT)

The low NOX trap **(**LNT) system is has two other names by which it is also known: NOX storage reduction (NSR) and NOX absorber catalyst (NAC). The LNT has three main components, namely, the oxidation catalyst made of platinum (Pt), the NOX storage ambience made up of barium (Ba) together with other oxides, and a reduction catalyst made up of Rhodium (Rh). A platinum catalyst is preferred due to its ability to reduce NOX emissions even at very low temperatures while still offering stability in the presence of sulphur and water moisture. However, this technology cannot offer all the solutions to vehicular emissions as a stand-alone technology.

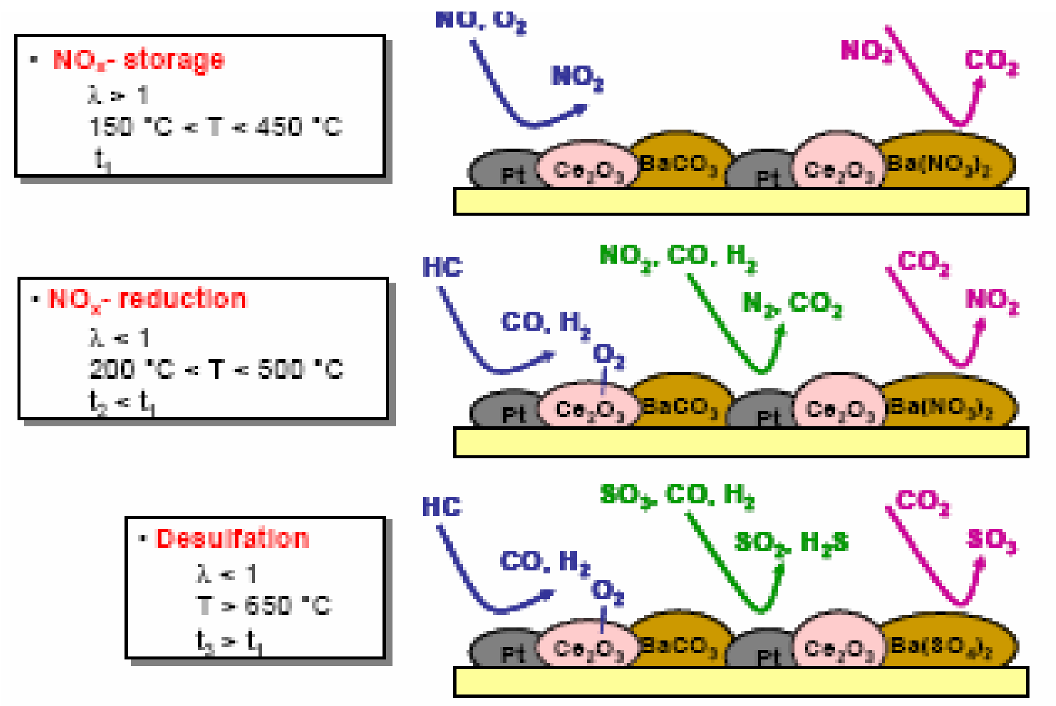

Figure 7. The low NOX trap (LNT) has three operating modes of operation: NOx storage during lean engine operation, NOx reduction during rich operation phases, low NOX trap (LNT) desulfurization under rich conditions and high temperatures [42].

Selective Catalyst Reduction

The most recent developments have seen the introduction of the SCR technology especially for heavy duty vehicles [43]. It has already been in use with light duty vehicles. For example, Audi motors and Volkswagen motors have widely adopted these technologies for most of their passenger vehicles. SCR works by utilizing ammonia as a reductant to minimize NOX emissions in the exhaust gases emitted releasing N_2 and H_2O. There are two processes that an SCR catalyst system undergoes namely hydrolysis and thermolysis. Equation 9 for the hydrolysis process and Equation 10 for the thermolysis process summarizes the two processes [2] and [22].

$$HNCO + H_2O \rightarrow NH_3 + CO_2 \qquad \text{Equation 9}$$

$$(NH_2)_2CO \rightarrow NH_3 + HNCO \qquad \text{Equation 10}$$

After the hydrolysis and thermolysis process, the following are the chemical reactions which take place in the SCR catalyst as indicated by Equations 11, 12 and 13 [22] and [4].

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \qquad \text{Equation 11}$$

$$2NO + 2NO_2 + 4NH_3 \rightarrow 4N_2 + 6H_2O \qquad \text{Equation 12}$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O \qquad \text{Equation 13}$$

Figure 8 shows a schematic diagram of a car exhaust gas emissions control system comprising an oxidation catalyst, wall-flow particulate filter, and flow-through SCR catalyst. Key components include a urea solution tank (heated in cold weather), dosing spray module and static mixer, temperature and NOX sensors (Robert Bosch GmbH) [44].

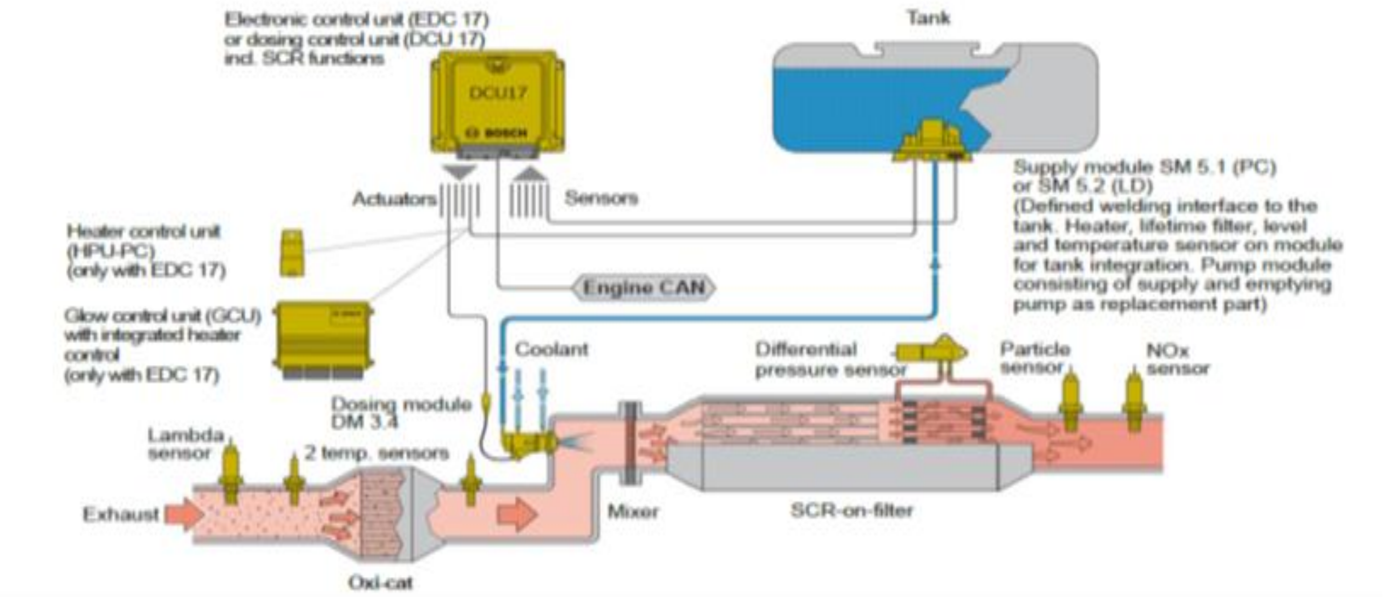

Figure 8. Schematic diagram of the SCR NO_X control system as used in a standard production vehicle [44].

Diesel Particulate Filters (DPF)

DPF have been applied in automotive manufacturing production units since the year 2000 and are primarily used to remove PM emissions from the exhaust gases through physical filtration. Most of the DPFs are made in a honey comb structure of silicone carbide or cordierite ($2MgO - 2Al_2O_2 - 5SiO_2$) with both ends of the monolith structure blocked so that particulate matter is forced through the porous substrate walls thus acting as a mechanical filtering system. The walls of the DPF filter are made in such a way that they enable exhaust gases to pass through the walls with little resistance while maintaining the capability to collect PM emissions particle species as shown on Figure 9.

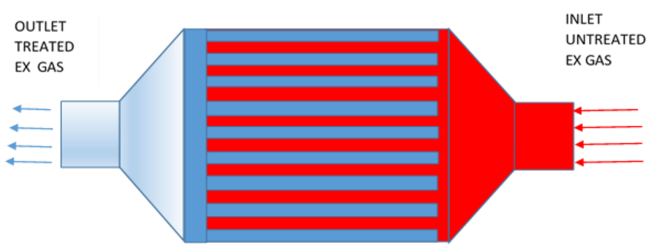

Figure 9. Schematic of the working mechanism of a diesel particulate filter (DPF) filter. With DPF, care must be taken to avoid excessive saturation of the filter as this builds up back pressure which is harmful for engine operation and durability, increases fuel consumption, increases engine stress levels and premature failure of the filter and engine [45].

The Diesel Oxidation Catalyst (DOC)

The main purpose of a diesel oxidation catalyst (DOC) is the oxidation of the CO and HC emissions by the reduction of the PM through oxidation of the hydrocarbons absorbed into the carbon particles. The DOC is made up of a metal or a ceramic structure with an oxide mixture (wash coat) composed of aluminum oxide (Al_2O_3), cerium oxide (CeO_2), zirconium oxide (ZrO_2) and an active catalytic metal such as platinum (Pt), palladium (Pd) and rhodium (Rh) [46].

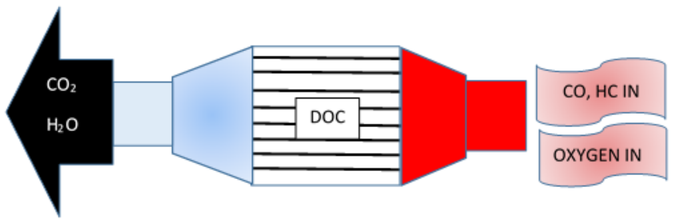

Figure 10 shows a schematic diagram of a DOC and its operation in reducing emissions through the process of oxidation.

There are six factors which influence the choice of DOCs, namely conversion efficiency, temperature stability, light-off temperature, tolerance to poisoning, the cost of manufacturing, and parametrical factors. Parametrical factors include channel density measured in channels per square inch, the individual channel wall thickness, the cross-sectional area, and the length of the channels (external dimensions) [47].

The DOCs are the preffered choice for most emission control systems for heavy duty and light duty vehicles in Europe, the USA and Japan, with the DOCs that contain platinum and palladium being the most popular among manufacturers and consumers alike in the world market. However, DOCs cause a reaction with sulphur oxide and sulphur tri-oxide thus generating sulphates and sulphuric acid which shortens the life of such control systems and causes several environmental and human health issues.

CONCLUSION

From the current work and as discussed in the literature, the road transport industry accounts for the major part of atmospheric and environmental pollution through emission of harmful compounds and elements. It has been shown that pollution from the transport industry has serious health effects and a negative impact on the natural environment.

Technological development has evolved in order to reduce and mitigate these effects. There are a number of technologies that have been implemented to reduce harmful pollutant emissions, with the after treatment systems offering the greatest potential to considerably reduce pollution from diesel propelled vehicles and other sources of emissions. Therefore, more research funds should be directed towards improving their efficiencies and working systems. At the same time, more needs to be done regarding the change of behavior and attitudes, where instead of putting commercial and economic interests first, human and environmental interests should take precedence.

From the control strategies discussed from literature, the ammonia SCR system looks set to become the natural choice for the control and reduction of NO_X emissions for light and heavy duty vehicles. There is a wide variety of materials that are catalytically active with ammonia and are established commercially with very good selectivity and longevity and with thermal durability in relation to N_2O formation.

More stringent measures, legislation and penalties for companies and organizations or even countries should be encouraged, for example emission cheating companies like Volkswagen should be put out of business. Although it would look harsh it would to serve as a lesson to other companies flouting emission regulations and standards. Due to the fact that diesel fuel is the major emission generating fuel in diesel engines, besides the control systems to control emissions the use of alternative fuels should be encouraged and developed through allocation of more funds towards reducing over dependency on diesel fuel. In addition, new combustion control strategies and schemes need to be developed, and these require further study and research and development to realize their full potential. The issue of fuel recovery where waste will be turned into green energy thus reducing fossil fuel must be further investigated.

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