VEHICLE EMISSIONS AND THEIR EFFECTS ON NATURAL ENVIRONMENT – A REVIEW

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ABSTRACT

Environmental pollution from vehicle sources continues to attract worldwide attention. The danger posed to natural environment and human health is multi-dimensional and bound to grow in significance following the global upsurge in automobile vehicle ownership and use. This paper reviews the status of vehicle emissions and their effects on the natural environment. The implications of emissions such as hydrocarbons, oxides of nitrogen, carbon monoxides, carbon dioxide among others have been discussed. Various methods of effective control of vehicular emissions have also been presented.

Keywords: Automobile Vehicles, emissions, environmental pollutions, control measures.

1. INTRODUCTION

Transportation sector alone utilizes most of the fossil fuels such as petrol, diesel, kerosene and methanol. Considering all major anthropogenic source categories, with exception of agriculture, the transportation sector of our economy releases about one-third of the total emissions of Volatile Organic Compounds (VOCs), nitrogen oxides (NO_x), and lead (Pb) and more than two-thirds of the carbon monoxide (CO). The CO and the VOCs, (almost all as hydrocarbons) are products of inefficient combustion (Henry and Heinke, 1995). Bailey (1995) and Lilley (2000) have also underscored the significance of carbon monoxide (CO) fumes and spilled oil as major pollutants from vehicle sources that gravely endanger human life and nature.

According to Okoko (2005), a study carried out in Germany reported that approximately 3% of all journeys were less than 500 m. One-third of car journeys were not greater than 3 km and one-half not more than 5 km. Often, these journeys are of a short duration of about 15 minutes. The implication of this is that most private cars operate inefficiently in terms of energy consumption. On short-distance journeys, the car engine is cold and runs least efficiently due to incomplete combustion of fuel, which will significantly influence the composition and magnitude of the organic emissions from vehicles

Thus the problems of traffic pollution are particularly acute in a number of major cities, especially in cities where traffic jam is a common experience as considerable amount of fuel is used while cars are trapped in traffic congestion. As congestion in towns and cities increases and traffic slows down, emissions are increasing much faster than the actual growth in vehicle numbers. Also, research carried out by Bull (1991) on emissions from different types of motor vehicle and fuel type reveals that older vehicles and those that are incorrectly maintained contribute a disproportionate amount to aerial pollution.

In most major cities of developing countries the vehicle fleet is quite old and poorly maintained and traffic congestion is more of the rule than exception. The ever-growing body of evidence on the dangers posed by vehicular emissions on the environment therefore ought to lead to heightened public awareness and concern about the problem in developing countries. Unfortunately, this level of awareness is still lacking in many respects, partly because of a lack of appreciation of the scale and nature of the problem.

This paper presents a review of the emissions of pollutants from vehicles and their transformation and impact on the environment. The options for control and management of vehicular emissions have also been discussed.

2. VEHICLE EMISSIONS

Thousands of motorized vehicles ply the major roads and streets of Nigerian cities daily. The same is true of many other countries of the world. In doing this, the vehicles consume millions of litres of petrol daily. The combustion of transportation fuels by these vehicles releases several contaminants into the atmosphere, including carbon monoxide, hydrocarbons, oxides of nitrogen, and lead and other particulate matter. Once emitted into the atmosphere, air pollutants undergo mixing or diffusion, the degree of which depends on topographic, climatic, and meteorological conditions (Zannetti, 1992).

Since the 1950's it has been recognized that transportation engines in developed countries are the major source of air pollution (Milton, 1995), while it is apparent that the proportions to be attributed to various causes vary both in time and from place to place, typical USA, figures are shown in Table 1. It can be seen that transportation is responsible for the biggest share of CO, HC, and NO_x in the atmosphere as well as a large proportion of the particulate matter.

Table 1: Proportion of atmospheric pollutants from various sources

Source	CO (%)	Sul-phur Oxides (%)	Hydro-Carbons (%)	Parti-culates (%)	NO_x (%)	Overall Contribu-tion	Overall Propor-tion (%)
Transport	92	4	65	14	42	217	43.4
Industry	4	32	26	44	21	127	25.4
Electricity generation	O	48	0	21	32	101	20.2
Space heating	3	12	3	14	5	37	7.4
Refuse burning	1	4	6	7	0	18	3.6
Source: Milton, 1995							

The particulates given in the table do not include dust from the road, rubber particles from the tyres, photochemical smog particles or asbestos from brake linings. They are merely the carbon particles that are directly attributable of the exhaust system.

2.1 Sources of Pollutants (Emissions) from Vehicles

Petrol and diesel engines, both internal combustion engines, are the only engines in wide use in the world's automotive transportation systems. And they are the major source of urban air pollution (John, 1998). Table 2 gives a list of common engine types, fuels and associated emissions. Petrol is a readily volatilized fuel and in the fuel tank the pressure build up which would result from this evaporation is obviated by introduction of a 'breather' vent or pipe into the tank. This still permits evaporation of the fuel.

Table 2: Vehicle types and pollutant for emissions for common engines and fuel combinations.

Engine type	Fuel Type	Vehicle type	Major emissions
Petrol Engine	Petrol	Cars, buses (also some lorries)	HC, CO, NO_x Pb and particulate.
Diesel Engine	Diesel	Lorries, trucks tractors (some buses & cars)	NO_x, SO_x, HC, CO, soot and particulates
Two-stroke Engine	Petrol	Motor cycles	HC, CO, NO_x, Pb and particulates
Source: Henderson-sellers, 1984.			

Evaporation of the raw fuel also occurs in the carburettor at all times except when running at high speed. Some unburned fuel (mixed with air) plus escaping exhaust gases from around ill-fitting pistons leaves the car as crankcase blow by which is a further hydrocarbon loss. Exhaust emissions are more variable in nature and hence more difficult to control. The composition depends on several variables e.g. air/fuel ratio, speed and engine condition. Driving conditions play a major role with exhaust emissions high in CO and HC at low and idling speeds, and NO_x high at high engine speeds. At low speeds, especially when cold and the fuel mixture is fuel-rich, incomplete combustion is common resulting in the formulation of more carbon monoxide. Similarly unburned hydrocarbons can be part of the exhaust. Table 3 shows emissions from petrol engine under various operating conditions.

Table 3: Emissions from petrol engine under various operating conditions

Pollutants	Operating Condition			
	Idling	Acceleration	Cruising	Deceleration
CO (%)	6.9	2.9	2.7	3.9
HC (ppm)	5300	1600	1000	10000
NO_x (ppm)	30	1020	650	20
Aldehyde (ppm)	30	20	10	290
Source: Henderson-Sellers, 1984.				

When cruising, combustion tends to be completed. With excess air, nitrogen can be oxidized to NO and possibly NO_2. These emissions are particularly important in regions of intense solar radiation, which can catalyse reactions leading to the formation of photochemical smog. When vehicle is cruising at high speeds, the exhaust flow is also high, while at low speeds the exhaust flow is low, although emission of partially oxidized compounds is higher. Therefore, highest emissions occur in deceleration on a volumetric basis, which is due to low air-fuel ratio and low exhaust flow.

In the diesel cycle engine, the airflow is constant independent of engine speed, which is regulated by fuel flow only. The diesel "smoke" often observed is largely due to overloaded engines or poor maintenance. Under such conditions at critical fuel-air ratios the emissions may contain a variety of hydrocarbons (including some known carcinogens such as benzo(a)pyrene). Some sulphur dioxide may be formed under various operating conditions as a result of the sulphur impurity in the fuel.

2.2 Types of Emission and Pollutants

2.2.1 Hydrocarbons

Emissions of hydrocarbons indicate low combustion efficiency in internal combustion engines and they arise when vaporised unburned fuel or partially burned fuel products, leave the combustion region and are emitted with the exhaust. Unburned hydrocarbon emissions are independent of air/fuel ratio. They normally arise from shortcomings in the fuel injection system. The level of unburned hydrocarbons in the exhaust gases in generally specified in terms of the total hydrocarbon concentration expressed in parts per million of carbon atoms. The total hydrocarbon emission is a useful measure of combustion inefficiency. Some of these hydrocarbons are nearly inert physiologically and are virtually uncreative from standpoint of photochemical smog. Others are highly reactive in the smog-producing chemistry. Hydrocarbon compounds are divided into non- reactive and reactive based on their potential for oxidant formation in the photochemical smog chemistry. Some hydrocarbons are known carcinogens (Patterson and Henein, 1992).

Fuel composition can significantly influence the composition and magnitude of the organic emissions. Fuels containing high proportions of aromatics and olefins produce relatively higher concentrations of reactive hydrocarbons. Oxygenates are present in engine exhaust, and are known to participate in the formation of photochemical smog. Some oxygenates are also irritants and odorants. The oxygenates are generally categorized as carbonyls, phenols, and other non-carbonyls. The carbonyls of interest are low molecular weight aldehydes and aliphatic ketones. The volatile aldehydes are eye and also irritants. Carbonyls account for about 10 percent of HC emissions from diesel passenger car engines, but in spark-ignition engine HC emissions are very low. Phenols are odorants and irritants but their levels are much lower than aldehyde levels (Adamczyk et al., 1983; Kaiser et al., 1982).

2.2.2 Oxides of nitrogen (NO_x)

Motor vehicles are the principal source of NO and of its oxidation product NO_2. Nitric Oxide (NO) and Nitrogen dioxide (NO_2) are usually grouped together as Nitrogen oxides (NO_x) emissions. Nitric oxide is the predominant oxide of nitrogen produced inside the engine cylinder. The principal source of NO is the oxidation of atmospheric (molecular) nitrogen. However, if the fuel contains significant nitrogen the oxidation of the fuel nitrogen – containing compounds is an additional source of NO.

In the combustion of near-stoichiometric fuel-air mixtures, the principal reactions governing the formation of NO from molecular nitrogen are:

$$O_2 + 2N_2 = 2NO + N_2 \qquad (1)$$

$$N_2 + 2O_2 = 2NO + O_2 \qquad (2)$$

$$N_2 + 2OH^- = 2NO + H_2 \qquad (3)$$

Hilliard and Wheeler (1979) worked on chemical equilibrium of burned gases at typical flame temperatures, their studies reveal that NO_2/NO ratio is negligibly small for spark ignition engines. While in diesel engines, NO_2 can be 10 to 30 percent of the total exhaust oxides of nitrogen emissions. NO formed in the flame zone can be rapidly converted to NO_2

$$NO + O_2 = NO_2 + ½O_2 \qquad (4)$$

It is customary to measure total oxides of nitrogen emissions, NO plus NO_2, with a chemiluminescence's analyzer and call the combination NO_x (Lavoie and Blumberg, 1980). It is always important to check carefully whether specific emissions data for NO_x are given in terms of mass of NO or mass of NO_2, which have molecular weights of 30 and 46 respectively. Oxides of nitrogen are important constituents of photochemical smog. In addition to the greenhouse effect, oxides of nitrogen contribute to environmental pollution in three ways: depletion of the ozone layer, production of acid rain and general air pollution.

2.2.3 Carbon Monoxide (CO)

Most of the CO in the ambient air comes from vehicle exhaust. Internal combustion engines do not burn fuel completely to CO_2 and water; some unburned fuel will always be exhausted, with CO as a component. For rich air/fuel mixtures, CO concentration in the exhaust is high, since the amount of excess fuel (unburned fuel) will be high. While for weak air/fuel mixtures, CO emissions are very low, therefore, they are not considered as important. According to John (1998), the levels of CO observed in spark-ignition engine exhaust gases are lower than the value measured within the combustion chamber. Therefore, some of the CO that formed in the combustion process are oxidized to CO_2 before they are discharged into the atmosphere.

2.2.4 Carbon dioxide (CO_2)

Combustion of petrol takes place in the internal part of the engine of a vehicle. If a typical hydrocarbon octane, is taken to represent petrol, an equation may be written for the combustion occurring in the engine as follows:

$$2C_8H_{18} + 25O_2 = 16CO_2 + 18H_2O \qquad (5)$$

The fuel consists of organic molecules, which are mostly hydrocarbon. When such compounds are burnt in automobile engines they yield carbon dioxide and water. Carbon dioxide also contributes to the acidity of rainfall, but more important, CO_2 is transparent to short-wavelength radiation from the sun but opaque to longer wavelengths radiated back to space from the earth. Therefore, increased concentrations of CO_2 may result in a heating of the earth's atmosphere and global warming.

2.2.5 Photochemical smog.

The Components of automobile exhaust are particularly important in the formation of atmospheric ozone, and are primary contributors to smog. Smog is a mixture of ozone, aldehydes, oxides of nitrogen and hydrocarbon. It results from reaction of these compounds in the atmosphere through a complex chain mechanism requiring photolysis due to the action of sunlight. The amount of smog depends on the concentration of reactants, their reactivity, and the temperature and light intensity. Photochemical smog causes severe irritation of the eyes, throat and respiratory system. In addition to this, it causes damage to some materials and is therefore, a major problem especially when it is held down in the local atmosphere of major cities by a temperature inversion.

2.2.6 Lead emissions.

Vehicle exhaust is one of the sources of lead pollution in the environment. In order to raise the octane number of petrol to achieve super grade level, tetra-ethyl lead is added and during combustion in the engine, we have:

$$2(C_2H_5)_4Pb + 27O_2 = 2PbO + 16CO_2 + 20H_2O \quad (6)$$

The combustion of gasoline containing lead (Pb) additives gives rise to large amounts of lead particulates, which are deposited downwind of highways. High lead levels from automobile exhaust are controlled by elimination or phasing out of lead from gasoline i.e by using unleaded gasoline.

3. DISTURBANCE OF NATURAL ENVIRONMENT

3.1 Thermal Air Pollution

This type of pollution is applied generally to the discharge of heat into the air environment from the combustion of fuels. The increase in the temperature of any place at a given time above its normal ambient air temperature is evidence that thermal air pollution has occurred in that place. The mean temperature of our planet is fixed by a steady-state balance between the energy received from the sun and the quantity of heat energy radiated back into space by the earth. Disturbance in either incoming or outgoing energy would upset this balance, and the average temperature of the earth's surface would drift off to a different steady state value.

The sun's energy travels to earth surface to warm it and bathe it with light without hindrance. The infrared radiation that sends heat energy back into space cannot travel freely though air as water vapour and CO_2 both absorb infrared. In this way they act like blankets around the earth, hindering the escape of heat into space. As more CO_2 is produced by combustion of fuels, the CO_2 causes hindrance to the escape of the infrared radiated from the earth surface and so the earth warms the more.

3.2 Greenhouse Effect

Unlike the sunlight, the infrared radiation cannot travel freely through the earth mantle of air as it contains H_2O vapour and CO_2, which absorb infrared radiation. In this way, both H_2O vapour and CO_2 act as blankets around the earth and the escape of heat into space. With additional H_2O vapour and CO_2 poured into the atmosphere from other sources, the effect would be that of adding a blanket that hinders the escape of heat the more and so the earth would heat up. This blanketing is the essence of the greenhouse effect.

The greenhouse effect takes its name from the warmth of greenhouses, a warmth stemming in part from the ease with which warming sunlight enters through the glass panes, and the difficulty encountered by infrared radiation in escaping off through the same panes with the greenhouse heat. This means that the glass panes act in such the same way as the atmosphere, which allows the free passage of incoming radiation but interferes with outgoing radiant energy. The outgoing radiant energy is absorbed by H_2O and CO_2. With energy escape hindered, the earth becomes warmer than it otherwise would be. Any addition of H_2O and CO_2 would cause additional greenhouse effect.

3.3 Ozone Depletion

The culprits causing ozone depletion are water vapour and nitrogen (II) oxide, NO. The pollutants enter the stratosphere where the ozone layer is. Photochemical reaction occurs in the stratosphere whereby oxygen molecule splits to oxygen atoms. The oxygen atom combines with oxygen molecule leading to the production of ozone

$$O_2 + [O] = O_3 \quad (7)$$

Oxygen atom reacts with water to give hydroxyl ions and which reduce ozone to oxygen molecule:

$$H_2O + [O] = 2OH \quad (8)$$

$$OH + O_3 = H\text{-}O\text{-}O + O_2 \quad (9)$$

This step accounts for 11% depletion of ozone. Again, ozone is attacked by NO and is reduced to molecular oxygen.

$$NO + O_3 = NO_2 + O_2 \quad (10)$$

Thus we have ozone depletion as given by equations (9) and (10). Unfortunately, eq.(10) is not the end of the story. Further reaction occurs between NO_2 and [O] which regenerates NO molecules from NO_2 viz:

$$NO_2 + [O] = NO + O_2 \quad (11)$$

$$NO + O_3 = NO_2 + O_2 \quad (12)$$

Thus the cycle can proceed over and over again, consuming quantities of O_3 with small initial amounts of NO.

3.4 EFFECTS ON AGRICULTURE

Optimum plant growth requires adequate light, heat, moisture, nutrients and appropriate soil conditions. An imbalance in any of these results in a stress to the plant, which may result in restricted growth or foliage markings. Pollution provides an extra undesirable stress. If this stress is too high, then the plant will die, despite the relatively complex biological defence mechanisms (e.g. rebuilding of damaged tissue).

Plants absorb gaseous pollutant through their leaves because one of their major functions is to absorb atmospheric gases. Examination of leaf structure reveals three regions: the epidermis (out layer), the mesophyll and the veins, which transport water and nutrients around the plant. Gases and small particulates enter the leaf through the stomata (leaf pores), to the air spaces of the mesophyll (Posthumus, 1983). Symptoms of damage to the examined leaves are:

(i) necrosis and bleaching of leaf margins;
(ii) glazing and silvering of surfaces, especially the undersides;
(iii) chlorosis (loss of chlorophyll);
(iv) flecking or stippling of upper surfaces.

3.5 Health Effects of Air Pollution

Air pollution has serious economic repercussions. Human health itself has an economic component by virtue of medical costs and work-days lost. Damage to health occurs as pollutant molecules interact unfavourably with the intricate molecules and fluids of the human body. Living systems are so complex that the detailed chemistry of these interactions is unclear in all but a few exceptional cases.

3.5.1 Effects of Carbon (II) Oxides, CO

The one activity of CO in the human body that gives it notoriety is its strong inclination to combine with the haemoglobin of blood. Heamoglobin is an iron-containing protein that carries vital oxygen to body tissues, may be represented by the symbol Hb. It picks up oxygen in the lungs thus:

$$Hb + O_2 = HbO_2 \qquad (13)$$

Where HbO_2 is called oxy-haemoglobin
This association is reversible and so the bound oxygen is released once HbO_2 reaches the tissue thus:

$$HbO_2 = Hb + O_2$$

The free Hb returns to the lungs for fresh supply of oxygen. Now, CO is a good chemical imitation of O_2 because it is diatomic, stable, oxygen containing and having comparable size to O_2. therefore, when CO is present in the lungs through inhalation, it combines with Hb to form carboxy-haemoglobin:

$$Hb + CO = HbCO$$

This process ties up free Hb in the blood, immobilizing this essential carrier of oxygen. The association can be reversed to yield free Hb again but with difficulty.

Research has shown that CO has a much greater affinity for Hb than O_2. So when both are present in equal concentration, CO ties up about 220 times more Hb than does O_2, leading to almost complete O_2 starvation and sure death. With 220-fold advantage, low level of CO in the lungs can immobilize enough Hb to cause dangerous shortage of oxygen. As much as 100 mg/l CO can kill quickly and 250 mg/l CO will cause loss of consciousness (Henderson-Sellers, 1984). The upper limit for industrial exposure to healthy workers is 100 mg/l. At this level, many people experience dizziness, headache and lassitude (Ademoroti, 1996)

3.5.2 Effects of NO and NO_2.

The compound NO is moderately toxic. Like CO, NO can combine with haemoglobin (Hb) forming methemoglobin and thus reducing oxygen transport. In contrast to NO, NO_2 is set at 5 ppm, rabbits exposed to concentrations as low as 1 ppm over a period of one hour have suffered protein changes (Henderson-Sellers, 1984).

3.5.3 Effects Particulate Matter

Inhaled particles greater than 10 µm are lodged in the nostrils. Particles in the size range from 5 µm to 10 µm are captured by the mucous lining in the upper airway; they are carried to the throat and swallowed. Particles less than 2 µm in size are the greatest threat: they penetrate the deeper structures of the lungs, including alveolar sacs, where no protective mucous blanket exists. Some of these particles may be retained in the lungs. It has been suggested that particles enhance the damage to lungs caused by SO_2 because they carry SO_2 to deep regions of the lung that are not otherwise reached (Waller, 1983).

Particles also catalyze the conversion of SO_2 to SO_3, which is more corrosive and then to H_2SO_4. The enhancement of the pollutants effect by another is termed *synergism*. Synergism is common in all areas of environmental pollution. Inhaled particles may be toxic. Soot particles are known to contain benzopyrene, an organic compound which is cancer producing. Lead-containing particles from automobile exhausts may transmit toxic lead to the lungs and thence to the bloodstream. Lead is known to damage the brain, center nervous system (CNS), kidneys, liver and reproductive system.

4. CONTROL OF VEHICLE EMISSIONS

The carbon monoxide (CO) and volatile organic compounds (VOCs) are products of inefficient combustion, which would be eliminated by burning the fuel to carbon dioxide (CO_2) and water (H_2O) in the engine of the vehicle to produce power if possible. Most of the VOC emissions are from the tailpipe. These are controlled using catalytic reactors and by injecting air at the exhaust ports of the engine to burn emitted hydrocarbons in this high-temperature zone. Neither process recovers useful energy, so efforts to modify engine design have been intense. However, more than 20% of the uncontrolled vehicle engine VOC emissions are from the crankcase vent (blow-by and evaporating oil) and from the carburetor vent to the atmosphere. These emissions are controlled using a crankcase vent pipe to the engine intake duct (requiring a pollution control value or PCV) and a "carbon canister" absorption unit for evaporative losses. Fuel injection systems, with their advantage of providing much more precise metering of fuel to the cylinders, significantly reduces pollutant emissions, including further reduction of evaporative losses. Presently, use of oxygenated fuels is encouraged to reduce VOC emissions at the tail pipe (Henry and Heinke, 1996).

Researchers have found that it was necessary to reduce emissions of nitrogen oxides to reduce photochemical smog and rain precursor emissions. One of the most effective ways to reduce these oxides is by introduction of exhaust gas re-circulation (EGR), and by using two-stage combustion. High levels of lead emissions have been tackled by the introduction of lead-free gasoline, mandated in developed countries like USA but optional for developing countries like Nigeria. Driving behaviour and route driven (e.g. shifting gears and speedy accelerations) factors contribute to vehicle pollution. Control of emissions depends on several factors such as driver's experience, type of route used, and in-use factors such as wear, maintenance and malfunction conditions (Vesilind et al., 1993).

Vehicle pollution can also be reduced, partially or completely (zero emission) by using:

(i) lean-burn engines, i.e. engines that offer air/fuel ratios in the 22 – 23: 1 range, as opposed to conventional engines, which operate on stoichiometric ratio of 14.5:1;
(ii) intelligent transport systems (ITS) and
(iii) automatic pilot systems.

Also, vehicle emissions can be reduced through better routing of traffic to cut fuel consumption while at the same time reducing pollution and enhancing safety, or using other alternative types of vehicles such as hybrid or electric (Brisley et. al., 1996).

5. CONCLUSION

The dramatic increase in public awareness and concern about the state of the global and local environments, which has occurred in recent decades, has been accompanied and partly prompted by an ever-growing body of evidence on the extent to which pollution has caused severe environmental degradation. Considering all major anthropogenic source categories, with exception of agriculture, the transportation sector of our economy accounts for the major part of atmospheric pollution.

The vehicle exhaust emits volatile organic compounds, nitrogen oxides, leads and carbon monoxides into the atmosphere. These emissions are discussed in this paper. The introduction of vehicle pollutants into the environment has been shown to have many adverse effects on human health, agricultural productivity and natural ecosystems. It has also been shown that highest emissions occur in vehicle deceleration on a volumetric basis, which is due to low air-fuel ratio and low exhaust flow. Thermal air pollution, greenhouse effect, ozone depletion and other pollution resulting in disturbance of natural environment are discussed. Several methods of effective control of automobile emissions to meet current and future environmental demands are also analysed.

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