MEASUREMENT OF LIGHT –DUTY VEHICULAR EMISSIONS IN THE KUMASI METROPOLIS USING VALIDATED COPERT IV MODEL

By

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DEDICATION

This work is dedicated to the almighty God of whom strength, inspiration and life was given to me to undertake this task.

ACKNOWLEDEMENT

I give thanks to the almighty God my creator for his infinite mercies towards me. May him alone be glorified.

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CERTIFICATION

I hereby declare that this submission is my own work towards the award of the MSc and that to the best of my knowledge, it contains no material previously published by another person not material which had been accepted for the award of any other degree of the University, except where due acknowledgement had been made in the text.

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LIST OF ACRONYMS

CO_2	Carbon dioxide
CO	Carbon monoxide
O_2	Oxygen
SO_2	Sulfur dioxide
CH4	Methane
VOC	Volatile organic carbon
EPA	Environmental protection Agency
HC	Hydrocarbon
DVLA	Driver and Vehicle License Authority
NOx	Nitrogen oxides
HNO_3	Nitric acid
H_2SO_4	Sulfuric acid
O_3	Ozone
PAHs	Polycyclic Aromatic Hydrocarbons
WHO	World Health organization
BaP	Benzo[a]pyrene
PM	Particulate Matter
A/F	Air-fuel ratio
H_2O	water
COHb	Carboxyhaemoglobin
TEL	Tetra ethyl lead
FCCC	Framework Convention on Climate Change
LDV	Light duty vehicle
NDIR	Non Dispersive Infrared light
RPM	Revolution per minute
PPM	Parts per million
KNRMP	Kumasi Natural Resources Management Research Project
GHG	Green house gases
COPERT	Computer program to Estimate emissions from road transport

ABSTRACT

The effect of vehicular emission on both the environment and life forms is disastrous due to the respective undesirable effects of the components and their levels. In the bid to curb this, the levels of the various emissions and the causes including both human and vehicle factors need to be ascertained accurately for sound policy to be made. Various models including Copert IV emission models are available for estimation of emission levels. This study aims at bridging the gap between Copert IV-generated emission levels and that by real-life measurement to facilitate the determination of emission levels amidst scarcity of resources including time and financial resources, and to ascertain the driving patterns frequently employed by vehicle drivers in the Kumasi Metropolis which, in turn, bear relationship with levels of emission. In doing this, the Opus 40 device was used to determine the levels of carbon monoxide (CO), carbon dioxide (CO_2) and Hydrocarbon (HC) from sampled vehicles at the premises of the Kumasi office of the Driver's Vehicle Licensing Authority and the Copert IV emission model software also used to generate the levels of these gases. The difference was used to validate the Copert IV emission model. Administered questionnaires together with secondary data from the DVLA and EPA Ashanti region were used to assess the driving patterns and sources of emissions. Results indicated that Copert IV generates emission levels lesser than that liberated by vehicles, calling for addition of validation factor for the various gases (CO, CO_2 and HC). Also frequent gear changing behaviours, unstable and inconsistent speed profiles are the most common driving patterns in the Metropolis and together with vehicle age and maintenance schemes are the main causes of emissions necessitating intensified public education on vehicular emission issues especially the causes and preventive and mitigation measures.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Air is a rich resource which is vital for existence acting as an indispensable element for all living things. It covers every part of the 200 million square miles of the earth's surface (Owusu-Boateng, 2002). According to Woodworth and Cunningham (1992), in the course of a day, a single person breathes between 30 and 35 pounds of air in a constant automatic response to extract life-giving oxygen.

1.1.1 AIR QUALITY

The principal constituents of the atmosphere of the Earth are nitrogen (78 percent) and oxygen (21 percent). The remaining 1 percent gases are argon (0.9 percent), carbon dioxide (0.03 percent), varying amounts of water vapor and trace amounts of hydrogen, ozone, methane, carbon monoxide, helium, neon, krypton, and xenon (Encarta, 2005). These gases have their various uses. Nitrogen is used in the preparation of important chemical products such as fertilizers, nitric acid, urea etc. Oxygen is needed for respiration as well as combustion; Carbon dioxide is required by green plants for photosynthesis and also used in extinguishing fires. The presence of carbon dioxide in the blood stimulates breathing, for this reason carbon dioxide is added to oxygen or ordinary air in artificial respiration and to the gases used in anesthesia (Encarta, 2005). The various constituents of air play diverse roles to the advantage of man and the environment.

1.1.2 AIR POLLUTION

There are various gases absorbed into the atmosphere resulting from industrial activities and movement of automobiles. Most of these gases are usually the cause of air pollution in the environment. The environment is to act as a sink for this gaseous wastes, but the constant fuel combustion, dust released during industrial processes, other solids from accidental and deliberate burning of vegetation and other human activities tend to dissipate its effect. Seinfield and Pandis (1998) defined the condition of "air pollution" as a situation in which substances that result from anthropogenic activities are present in air at concentrations sufficiently high above their normal ambient levels to produce a measurable effect on humans, animals, vegetations or materials. Air pollution is viewed as a phenomenon characteristic of large urban centers and industrialized regions of the world. The increasing industrialization and urbanization have created growing demands to use the atmosphere, whether consciously or not, as a waste disposal medium.

The world's economy literally runs on fossil fuel to produce energy (Exxon Mobil energy report, 2007). This is to support the continued human progress for the world's growing population and therefore more energy will be needed. Even with significant improvements in energy efficiency, the world's total energy demand is expected to be approximately 40 percent higher by 2030 than it was in 2005 (Exxon Mobil energy report 2007). The vast majority of this demand increase will take place in developing countries, where economies are growing most rapidly and modern energy supplies are still a precious commodity for millions of people. Meeting higher energy requirements poses many challenges, including boosting efficiency, developing new supplies and managing environmental risks (Exxon Mobil energy report, 2007). These have given rise to more production as well as consumption. The transportation system in the world today is a major player in the energy sector. With the global transportation demand, it will be the fastest-growing energy-driven sector in few years to come with its attendant problems. This sector which can be broadly sub-divided into two major categories: commercial and private covers a variety of transport modes including road vehicles, ships, trains and aircrafts, all of which cause emission problems.

The need to control the emissions from automobiles gave rise to the computerization of the automobiles. Hydrocarbons, oxides of carbon and oxides of nitrogen are created during the combustion process and are emitted from the tail pipe posing threat to the environment and its inhabitants. There are also hydrocarbons emitted as a result of vaporization of gasoline and from the crankcase of the automobile.

1.2 STATEMENT OF PROBLEM

The importance of transport system for development of society cannot be underestimated. However the associated air pollution exerts damaging effect on the environment as well as human health and welfare which is expensive to curb. It attracts huge costs in medical expenses as well as absenteeism and loss of production the last two being are somewhat harder to quantify. Although the use of the air mostly remains free to each creature disposing waste into the environment, the social costs of poor air quality in the form of dangers to human health, agricultural damages; property destruction, and many other things accrued to society as a whole. When anything comes in contact with the atmosphere, it is exposed to pollutants.

According to Montgomery, (2000) reduction of air pollution levels by 50% in major urban areas would save more than $2 billion per year in health costs. Implicit decreased health cost is an increase in longevity and a decrease in illness among those now adversely affected by air pollution. The financial and human considerations together are powerful incentives for trying to limit air pollution.

1.3 JUSTIFICATION OF THE STUDY

The growing dissatisfaction of air quality in urban areas due to human interventions including development of transport systems is of much concern. In Ghana, especially in the major cities such as Accra and Kumasi, this has been aggravated by factors including daily influx of used vehicles, lack of knowledge on the contributory factors such as driving behaviour and maintenance schemes affecting emissions on the part of drivers and vehicle owners, etc.

Policies on vehicle emissions thrive on determined emission levels. However due to constrain in time, availability of funds and other logistic resources field measurement of vehicle emissions may be difficult. To solve this problem, models could be used. One of such models is the Copert IV Model which aims at predicting the levels of vehicle emission. However the levels of emissions recorded using the Copert IV model do not give the exact levels. It is therefore necessary to validate the model in other to improve on its predictive ability.

1.4 OBJECTIVES OF THE RESEARCH

The aim of this study is to develop a model for light duty Vehicular emissions in the Kumasi Metropolis. The specific objectives are:

- To validate the Copert IV emission model
- To determine the most common driving patterns of the drivers in the Metropolis
- To assess the quality of air emitted from vehicle exhausts.
- To determine the causes of vehicular emissions pollutions.

1.5 SCOPE OF THE STUDY

The scope of this work is limited to the Kumasi Metropolis. The study covers light duty automobile vehicles in the Kumasi Metropolis. Relevant data was obtained from the Vehicles at the Driver and Vehicle Licensing Authority (DVLA), and the KNUST campus.

CHAPTER TWO

LITERATURE REVIEW

2.1 AIR POLLUTION

Pollution occurs when there is an introduction of contaminants into an environment. These contaminants tend to cause disorder and harm to the physical systems or living organisms in that environment. Pollution can take the form of chemical substances, or energy, such as noise, heat, or light energy (Wikipedia, 2008). Elements of pollution can either be foreign substances, energies, or naturally occurring. When pollution occurs in the atmosphere, it is described as air pollution or atmospheric pollution. The substances that are liberated into the atmosphere to cause pollution are termed pollutants. They include; Carbon monoxide, sulphur oxides, Nitrogen oxides, particulate matter and volatile organic carbon. According to Smit (2006), this is not only because of the magnitude of its emissions, but also because pollutants are emitted in close proximity to human receptors which enhances exposure levels. There are various types and sources of air pollutants into the environment. The Principal gaseous pollutants are oxides of carbon, nitrogen and sulphur. They share some common sources but create distinctly different problems (Montgomery, 2000).

2.1.1 Carbon Gases

According to Montgomery, (2000) the main carbon gases in relation to humans are carbon dioxide and carbon monoxide. It is the main source of life to plants. It occurs as an end product of complete combustion of carbon-bearing fuels such as petrol, gas, oil and coal.

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

Carbon Oxygen carbon dioxide

Carbon dioxide (CO_2) is continually added to the atmosphere through fossil-fuel burning, as well as by natural processes, including respiration by all oxygen-breathing organisms (Montgomery 2000). According to Jacob, (1999) the current global rate of increase in atmospheric CO_2 is 1.8 ppm yr^{-1}, corresponding to 4.0 Pg C yr^{-1}.This increase is due mostly to fossil fuel combustion. When fuel is burned, almost all of the carbon in the fuel is oxidized to CO_2 and emitted to the atmosphere. Only half of the CO_2 emitted by fossil fuel combustion and deforestation actually accumulates in the atmosphere, the other half is transferred to other geochemical reservoirs (oceans, biosphere, and soils) (Jacob, 1999). It is a principal greenhouse gas. In high concentration it causes an increase in the breathing rate, unconsciousness and even death.

Carbon monoxide (CO) is produced during incomplete combustion of carbon-bearing materials, when less oxygen is available.

$$2C(s) + O_2(g) \longrightarrow 2CO(g)$$

Carbon Oxygen carbon monoxide

Carbon monoxide does not stay in the atmosphere for so long, after a few months, it reacts with more oxygen to create more carbon dioxide. It is toxic to humans when inhaled; it reacts with hemoglobin to form a stable compound thereby reducing the oxygen carrying capacity of the blood. It is produced from natural and synthetic products, such as cigarette smoke. High concentrations can be present in enclosed garages, poorly ventilated tunnels and along roadsides in heavy traffic (Pederson et al, 2003). The highest ambient levels generally occur during the colder months, when atmospheric temperature inversions are more common, trapping CO emissions near the surface under a layer of warmer air. The single largest source of carbon monoxide in the atmosphere is the automobile (Montgomery, 2000).

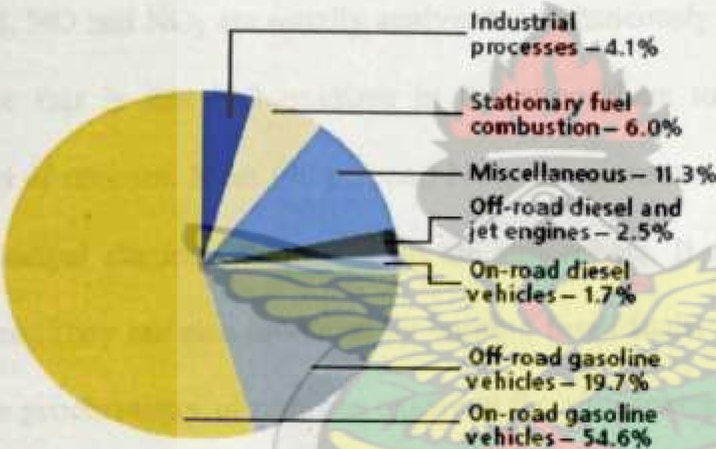


Fig. 2.1 1998 national man-made CO emissions

Source: US EPA Nation air pollution Emission Trends

2.1.2 Sulphur Gases:

The principal sulphur gas produced through human activities is sulphur dioxide (SO_2).It is a colourless corrosive gas, which is directly damaging to plant, animals and properties. To various degrees, all fossil fuels contain sulphur. When these fuels are burned, the sulphur produces sulphur dioxide and sulphur trioxide. The other sources are from coal combustion in factories-power-generating plants etc. Within a few days of its release into the atmosphere, sulphur dioxide reacts with water vapour and oxygen in the atmosphere to form Sulphuric acid (H_2SO_4) which is a strong and highly corrosive acid. Much of this is removed out of the atmosphere in the form of acid rain.

2.1.3 Nitrogen Gases

Nitrogen Oxides (NO_X) is the generic term for several reactive gases containing nitrogen and oxygen in various ratios. They form when fuel is burned at high temperatures. The air quality standard applies only to nitrogen dioxide (NO_2), but where emissions are concerned, NO and NO_2 are usually analyzed simultaneously and expressed as NO_x. The reason for this is that NO oxidizes in the atmosphere to form NO_2, which is the compound of concern. Most (90 percent) NO_X emissions are man-made. Nitrogen is one of the principal elements that make up the atmosphere. It comprises 76% of the total atmosphere. They are also produced by burning fossil fuels. According to (Montgomery 2000), the geochemistry of nitrogen oxides in the atmosphere is complex. Since nitrogen and oxygen are by far the most abundant elements in the air. Nitrogen monoxide behaves like carbon monoxide (CO) in the blood stream but hardly reaches the threshold level for toxicity. As time goes on, it reacts with oxygen to form nitrogen dioxide (NO_2). Nitrogen dioxide reacts with water vapor in the atmosphere to form nitric acid (HNO_3). This is one of the main contributors to smog and acid rain. Nitrogen oxides react to form smog. Smog in high dose harms humans by causing breathing difficulty for asthmatics, coughs in children, and general illness of the respiratory system. It also results in the formation of acid rain which can harm vegetation, run into lakes and rivers changing the chemistry of the water, and making it potentially uninhabitable for all but aid-tolerant bacteria (EHC, 2003). In addition, organic substances in the atmosphere combine photochemically with nitrogen oxides to create ozone, a bluish gas that has destructive effect on vegetation, causes rubber to deteriorate, and is responsible for a significant amount of other property damage. In this sense, it leads to the formation of single or atomic oxygen (O) by splitting either molecular oxygen (O_2) or Nitrogen dioxide (NO_2). The single oxygen then reacts with another O_2 to form ozone (O_3).

The photochemical equation may be summarized as follows:

$$NO_{2(g)} \rightarrow NO_{(g)} + \frac{1}{2}O_{2(g)}$$

$$\frac{1}{2}O_{2(g)} + O_{2(g)} \rightarrow O_{3(g)}$$

$$NO_{2(g)} \rightarrow NO_{(g)} + \frac{1}{2}O_{2(g)}$$

Leading to the photostationary state:

$$NO_{2(g} + O_{2(g)} \quad NO + O_{3(g)}$$

The NO combines with organic compounds generally represented by RO_2 to produce more ozone as follows:

$$RO_{2(g)} + NO_{(g)} \rightarrow RO_{(g)} + NO_{2(g)}$$

$$NO_{2(g)} + O_{2\,(g)} \quad NO_{(g)} + O_{3(g)}$$

The ozone (O_3) formed in the stratosphere provides valuable shield for the biosphere by absorbing in coming radiations. In ambient air, however, O_3 is a strong oxidizing agent with a devastating effect (Owusu-Boateng, 2002).

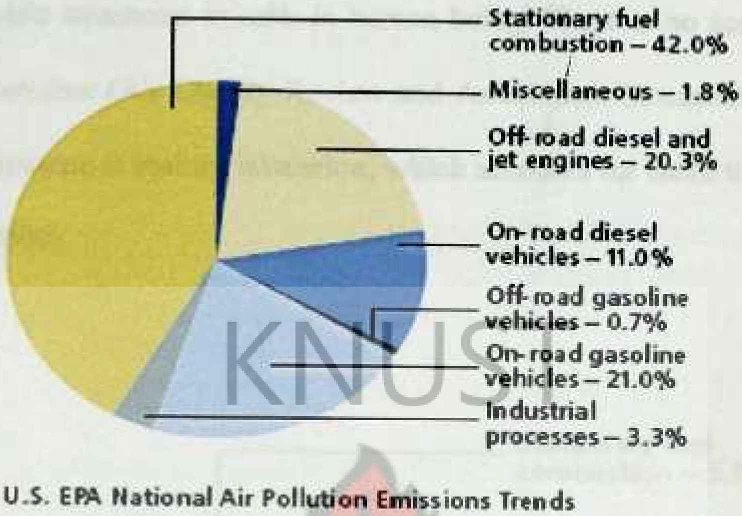


Fig. 2.2 1998 national man-made NOx emissions

Source: US EPA Nation air pollution Emission Trends

2.2 Hydrocarbons (HC)

These are emitted through incomplete gasoline combustion. They combine with nitrogen oxides in the presence of sunshine to form ozone (O_3) which has adverse health effects. There are two main groups of hydrocarbons of concern:

- Volatile Organic Compounds (VOCs)
- Polycyclic Aromatic Hydrocarbons (PAHs).

2.2.1 Volatile Organic Compounds (VOC)

The term volatile organic compound (VOCs) is used to denote the entire set of vapour-phase atmospheric organics excluding CO and CO_2 (Senfield & Pandis, 1998). They include petrol, benzene, toluene and many others. Volatile chemicals produce vapour easily. Vehicle emissions are a very important source of VOCs. Many VOCs are hazardous air pollutants. For example, benzene is a known human carcinogen and can cause damages to genetic structures in cells in human being. There is no accepted safe level of exposure to benzene (Air Quality Review and Assessment-Stockport, 2000). A route of exposure of benzene is mainly inhalation, which accounts for more than 99% of the exposure (WHO, 2000).

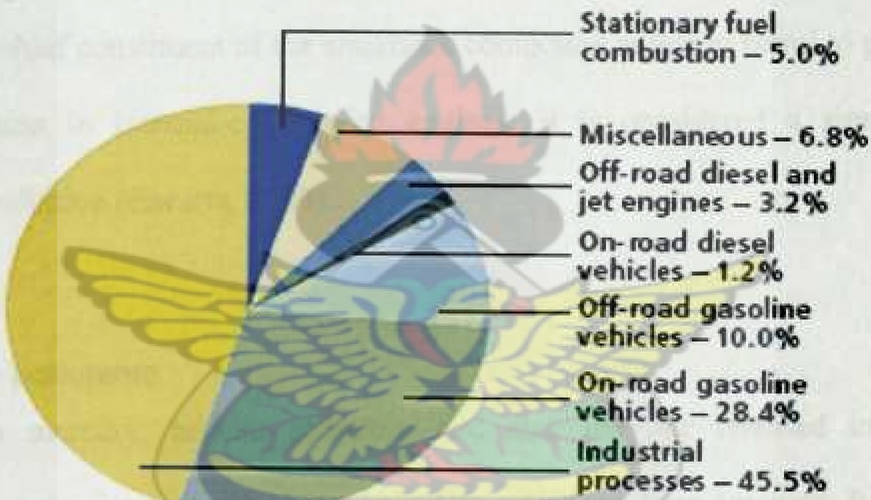


Fig. 2.3 1998 national man-made VOC emissions

Source: US EPA Nation air pollution Emission Trends

2.2.2 Polycyclic Aromatic Hydrocarbon (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds with two or more fused aromatic rings. Most of the PAHs with low vapour pressure in the air are adsorbed on particles. There are several hundred PAHs; the best known is benzo[a]pyrene (BaP). The emissions of BaP into the air from several sources in the

Federal Republic of Germany in 1981 were estimated to amount to 18 tonnes of which 13% by motor vehicles, however, the present contributions from the different important sources, such as vehicle exhausts and other, are very difficult to estimate (WHO, 2000).

2.2.3 Lead

Lead taken internally in any of its forms is highly toxic; the effects are usually felt after it has accumulated in the body over a period of time (Encarta, 2005). It is one air pollutant that has greatly been reduced. Most of the lead gas released into the atmosphere was emitted by automobile exhaust systems (Montgomery, 2000). Lead (IV)tetraethyl ($Pb(C_2H_5)_4$) is the chief constituent of the antiknock compound added to petrol to prevent premature detonation in internal-combustion engines; it is considered a significant contributor to air pollution (Encarta, 2005).

2.2.4 Metallic air pollutants

Elements such as mercury, arsenic cadmium and zinc may be released into the atmosphere either as vapors or attached to particulate emissions from smelters. But they are removed immediately by precipitation. These metals may accumulate in the soil. It can constitute a health hazard to the underground water as well as agricultural produce.

2.2.5 Particulate Matter (PM)

These different kinds of solid in the air in the form of smoke, dust, and vapour, which can remain suspended for extended periods. Microscopic particles can be in the air and can be breathed into lung tissue. After some time they become lodged and cause increased respiratory disease and lung damage. Particulates are also the main source of haze, which reduces visibility. There are many ways the particulates are produced into the environment. The main ones are burning of diesel fuel by trucks and bus engines, burning of fossil fuels and many other industrial ways, such as steel-making, mining, and also by agriculture burning (EHC, 2003).

2.3 CAUSES OF VEHICULAR EMISSIONS

Motor vehicle emissions consist of a large number of chemical species that primarily result from combustion within the engine and from fuel evaporation at various locations throughout the fuel delivery and storage system. When fuel is burned with the correct amount of air in a gasoline powered engine, the gases which are left are mostly water vapor, carbon dioxide and nitrogen (Anon, n.d). These are all favorable. A deviation from this baseline ideal combustion leads to the production of certain gases which are termed pollutants in the environment. They are CO, NO_X, Volatile organic compounds, Particulate matter etc. From the environment point of view; the emissions produced by a petrol vehicle fall into two basic categories: Tailpipe and Evaporative emissions.

2.3.1 Tailpipe emissions (Exhaust Emissions)

Vehicle's air pollution is viewed as the products of burning fuel in the vehicle's engine, emitted from the vehicle's exhaust system. The vast majority of gasoline is burned before combustion gases exit the engine in any properly operating vehicle, but a small fraction – typically 1 to 5 percent – manages, for a variety of reasons, to escape the combustion chamber unburned (Gasoline and Air quality 2005). These VOC emissions consist primarily of unburned hydrocarbons, but partially burned oxygen-containing compounds such as aldehydes are also present in small amounts. Most are removed by the vehicle's catalytic converter. The quantity of exhaust VOC emission is influenced by many factors, including engine design, operating temperature, air-fuel ratio (A/F), presence of fuel system deposits, the condition of the engine and its controls, and the performance of the catalytic converter and driving pattern. If the vehicle has some significant malfunction that inhibits proper ignition or combustion, like a bad spark plug, VOC emissions can be many times higher than normal (Gasoline and Air quality, 2005).

2.3.1.1 Cold Start

This is the process of starting an engine which has been turned off for some time and the catalytic converter (if the vehicle is so equipped) is cold. HC and CO emissions are higher when a cold engine is first started than after the vehicle is warmed up. This is because catalytic emission control systems do not provide full control until they reach operating temperature and a richer fuel air mixture must be provided to the cylinders under cold operating conditions to achieve satisfactory engine performance. The US EPA considers a cold start for a catalyst-equipped vehicle to occur after the engine has been turned off for one hour, while for non-catalyst vehicles, a four-hour engine-off period. Rich mixtures are necessary to achieve smooth combustion during warm up because gasoline does not fully vaporize and mix with the air in a cold engine. Extra fuel is added to ensure that an adequate amount of fuel is vaporized to achieve a combustible mixture. Complete vaporization eventually occurs in the engine cylinder as a result of the high temperatures created by combustion. However, the excess fuel that was needed to ensure adequate vaporization to start the combustion process cannot be completely burned due to a lack of sufficient oxygen in the cylinder. These results in partially burned fuel and unburned fuel are emitted in relatively high concentrations from a cold engine. Elevated emissions of these pollutants in this cold transient phase occur from the time a cold engine starts until it is fully warm. While engine-out NOx emissions tend to be low during rich operation of a cold engine, the lack of catalyst activity to control this pollutant results in elevated cold start NOx emissions as well.

2.3.1.2 Hot Starts

This is the process of starting an engine which has been switched off for a relatively short time. The catalyst has not had time to cool to ambient temperature. Thus, the warm-up period is shorter (if present at all) than that required under cold start conditions. Due to this, HC and CO hot start emissions will be significantly lower than under cold start operation. Under the standard test procedure used by EPA, a "hot start" is a test that begins exactly 10 minutes after a fully warmed up engine has been shut off. After only 10 minutes, no mixture enrichment is required to achieve a reliable re-start and the catalyst is usually still above its temperature.

2.3.2 Evaporative VOC

Exhaust gases are not the only source of VOC emissions from gasoline-fueled vehicles. In fact, US EPA estimated that in 1990, more than half the VOC emitted from gasoline vehicles resulted from evaporative-type processes (Gasoline and Air quality, 2005). Evaporative emissions consist entirely of hydrocarbon emissions. When a hot engine is turned off, fuel exposed to the engine (e.g., in carburetor float bowls or in fuel injectors) may evaporate and escape to the atmosphere. These are emissions of gasoline vapors that are generated due to heating of the fuel as a result of daily temperature variations and operation of the vehicle as well as leakage from the fuel system. Evaporative VOC emissions are different from exhaust VOC emissions. They contain no combustion products and their composition is weighted heavily toward the lowest boiling components of gasoline, because gasoline vapour is the main source. Gasoline vapour escapes from the typical vehicle from various locations on the vehicle, including the gasoline tank, carburetor (on vehicles that use them), and intake manifold. In addition, liquid gasoline can permeate through plastic fuel tanks and fuel hoses. It also can leak or seep from gasoline system components. Factors which influence the amount of evaporative emissions include fuel system design component integrity, ambient temperature, and gasoline vapour pressure and, of course, there is the amount lost during refueling, which may be collected by service station vapor recovery systems (Gasoline and Air quality, 2005). The volatility of the gasoline affects the VOC emission. As a fuel tank is being refueled, the incoming liquid fuel displaces gasoline vapor that has established a pseudo-equilibrium with the fuel in the tank, effectively "pushing' the vapor out of the tank. Spillage simply refers to a small amount of fuel that is assumed to drip on the ground and subsequently evaporate into the ambient air.

2.4 GREENHOUSE EMISSIONS

The atmosphere plays a role in helping to warm the earth's surface. The main source of heat to the earth is solar energy, which is transmitted from the sun to the earth (Jacob, 1999). It is largely transparent to incoming short-wave (or ultraviolet) solar radiation, which is absorbed by the earth's surface. Much of this radiation is then re-emitted as heat energy at long-wave, infrared wavelengths; some of this energy escapes back into space, but much of it is reflected back by gases such as carbon dioxide, methane, nitrous oxide, halocarbons, and ozone in the atmosphere. This heating effect is at the root of the theories concerning global warming. Under normal conditions the level of carbon dioxide in the atmosphere remains constant, and trees absorb the same amount of carbon dioxide that is produced into the atmosphere. But in recent decades, our planet has supported more people and fewer trees, leaving an excess of carbon dioxide in the atmosphere. The amount of carbon dioxide has been increasing by 0.4 per cent a year (Encarta,2005).; the use of fossil fuels such as oil, gas, and coal, and the slash-and-burn clearing of tropical forests have been contributing factors in the carbon cycle. Other gases that contribute to the greenhouse effect, such as methane and chlorofluorocarbons, are increasing even faster. The net effect of these increases could be a worldwide rise in temperature, estimated at 2° to 6° C (4° to 11° F) over the next 100 years (Encarta, 2005).

2.5 SMOG

The mixture of condensed water vapor suspended in atmosphere over the earth surface combined with smoke forms smog. This is often found in the urban cities. The Sage's English Dictionary and Thesaurus defines smog as "air pollution by a mixture of smoke and fog". Smog reduces natural visibility and hence increases the incidence of accidents on roads air and water bodies. Jacob, (1999) noted that the low visibility is due to scattering of solar radiation by high concentrations of anthropogenic aerosols. It also irritates the eyes and respiratory tract. In dense urban areas, the death rate may rise considerably during prolonged periods of smog, particularly when a process of heat inversion creates a smog-trapping ceiling over a city. It is only in recent years that the authorities concerned have kept records of the rise in the concentrations of pollutants in the air during smogs and of the effect on health, and even these records have not always been sufficiently detailed.

2.6 ACID RAIN

Acid rain was discovered in the nineteenth century by Robert Angus Smith, a pharmacist from Manchester (England), who measured high levels of acidity in rain falling over industrial regions of England and contrasted them to the much lower levels he observed in less polluted areas near the coast (Jacob, 1999).Little attention was paid to his work until the 1950's, when biologists noticed an alarming decline of fish populations in the lakes of southern Norway and traced the problem to acid rain (Jacob, 1999). It forms when oxides of sulphur or nitrogen combine with atmospheric moisture to yield sulphuric or nitric acids, which may then be carried long distances from their source before they are deposited by rain (Encarta, 2005).

$$H_20\ (l) \quad + \quad N0_2\ (g) \longrightarrow HN0_3\ (aq)$$

$$H_20\ (l) \quad + \quad S0_3\ (g) \longrightarrow H_2S0_4\ (aq)$$

This pollution may also take the form of snow or fog or be precipitated in dry forms. The term "acid rain" is been used ever since the scientific discovery was made. According to Encarta encyclopedia (2005), a more accurate scientific term would be "Acid deposition". Forests, lakes, ponds, and other terrestrial and aquatic environments throughout the world are being severely damaged by the effects of acid rain. Acid rain is caused by the combination of sulphur dioxide (SO_2) and nitrogen (NO_2) compounds with water (H_2O) in the atmosphere to produce rain with a very low pH. Normally, rainwater has a pH of 6.5, making it very slightly acidic. However, with the addition of sulphur and nitrogen compounds, the pH of rainwater may drop to as low as 2.0 or 3.0, similar to the acidity of vinegar. This forms sulfuric and nitric acid (H_2SO_4 and HNO_3). It has been known since 1960s that the high concentrations of $HN0_3$ and H_2S0_4 in acid rain are due to atmospheric oxidation of N0x and $S0_2$ (Jacob, 1999).In addition to chemically burning the leaves of plants, acid rain poisons lakewater, which kills most if not all of the aquatic inhabitants present in the system.

2.7 MEDICAL PROBLEMS ASSOCIATED WITH ATMOSPHERIC POLLUTION

The total exposure of an individual to a specific pollutant is determined by the concentration of contaminant and the duration of exposure (Spengler and Dockery 1981). The exposures to indoor and outdoor air qualities are different because they always vary with the time and the diurnal pattern (TERI 1995). The health status and the exposure level of a typical population which is homogenous in terms of habitat, drinking water source, indoor microclimate, domestic fuel consumption, movement pattern, overall living standards, general sense of health and hygiene, literacy and interaction with locality, and work place are reported (CPCB 1997). In many urban cities the air is already so polluted that it has been causing illness and premature deaths among people who are living in the city. Most of the ambient air pollution in urban areas comes from motor vehicles, fossil fuels industry, heating and electricity generation. But Enemari, (2001) reported that vehicular emissions in typical urban centre constitute over 60% of total pollutants emission.

The number of motorized vehicles and the distances driven are constantly increased, which has raised the use of gasoline and increased greenhouse gas emissions. This explosive growth in the number of road vehicles is a big problem in many cities, while many cities centers have major difficulties trying to cope with the chaotic automobile traffic. The traffic jams are extremely bad in many cities and transport traffic in the city area during the rush hours is really slow. The pollution is high due to constant traffic and causes many diseases to city inhabitants (Pederson *et al*, 2001). In the daily graphic of 5^{th} December 11, 2007, it was reported that a transportation crisis beyond Lagos and Beijing proportions are been predicted in Ghana if the prevailing ratio of vehicles to motorable roads should continue into 2015.

Table 2.1 Atmospheric Effects of Trace Gases

Gas	Urban Air Pollution	Acid Deposition	Visibility Impairment	Greenhouse Effect	Stratospheric O_3 Depletion	Decreased Self-cleaning of Atmosphere (Decreases OH)
CO_2				+	+/-	
CH_4				+	+/-	+/-
CO	+					+
N_2O				+	+/-	
NO_X $(NO+NO_2)$	+	+	+		+/-	-
SO_2	+	+	+	-		
CFCs				+	+	
O_3	+	+		+		-

Source: Graedel and Crutzen (1989)

From table 2, The Positive signs (+) indicates a contribution to the effect; negative signs (-) indicates amelioration. Dual signs (+/-) indicate that the effect of the gas can vary. For example, CO_2, N_2O and NOx can either enhance or deplete stratospheric O_3 depending on the altitude.CH_4 generally ameliorates stratospheric O_3 depletion, except in the polar ozone hole. The tendency of CH_4 to diminish the self-cleaning of the atmosphere by reducing OH abundance is different in the Northern (NH) and Southern Hemispheres (SH); CH_4 diminishes self cleaning in the SH but has the opposite effect in the NH.

2.7.1 Carbon Monoxide

Carbon monoxide (CO) is one of the most common and widely distributed air pollutants (EIWD, 2003). Emissions are dominated by road transport particularly petrol engines which are idling or decelerating (Air Quality and Assessment-Stockport, 2000).

2.7.1.1 Routes of Exposure and Metabolism

Carbon monoxide is a rather stable gas in the atmosphere; the lungs are practically the only significant routes for environmental exposures. Carbon monoxide binds readily with haemoglobin to form a respiratory poison called carboxyhaemoglobin (COHb), which can be measured in a blood sample by specific spectrophotometer or gas chromatographic methods. After reaching the lungs, carbon monoxide diffuses rapidly across the alveolar and capillary membranes. It also readily crosses the placental membranes. Carbon monoxide binds reversibly to one of the haem proteins (Pederson *et al*, 2001). Approximately 80–90% of the absorbed carbon monoxide binds with haemoglobin; this causes a severe reduction in the oxygen-carrying capacity of the blood (WHO, 2000). Carbon monoxide is eliminated unchanged via the lungs.

2.7.1.2 Health Effects

The organs and tissues that are mostly affected include the brain, the cardiovascular system, exercising skeletal muscle and the developing foetus. The health effects are dose dependent, as illustrated in figure 4 below. At a COHb level of about 10%, carbon monoxide is likely to cause headache, and at somewhat higher levels there will be also dizziness, nausea and vomiting. At a COHb level of about 40%, carbon monoxide starts to cause coma and collapse, and at 50–60% the poisonings are often lethal. The neurobehavioral effects include impaired co-ordination, tracking, driving ability, vigilance and cognitive performance at COHb levels as low as 5.1–8.2% (WHO, 2000). The carbon monoxide at high level could involve angina, with increased electrocardiographic changes and with impaired left ventricular function. In the case of pregnant mother, the foetus in uterus and the new-born infant are at high risk of adverse health effects like low birth weight (WHO, 2000).

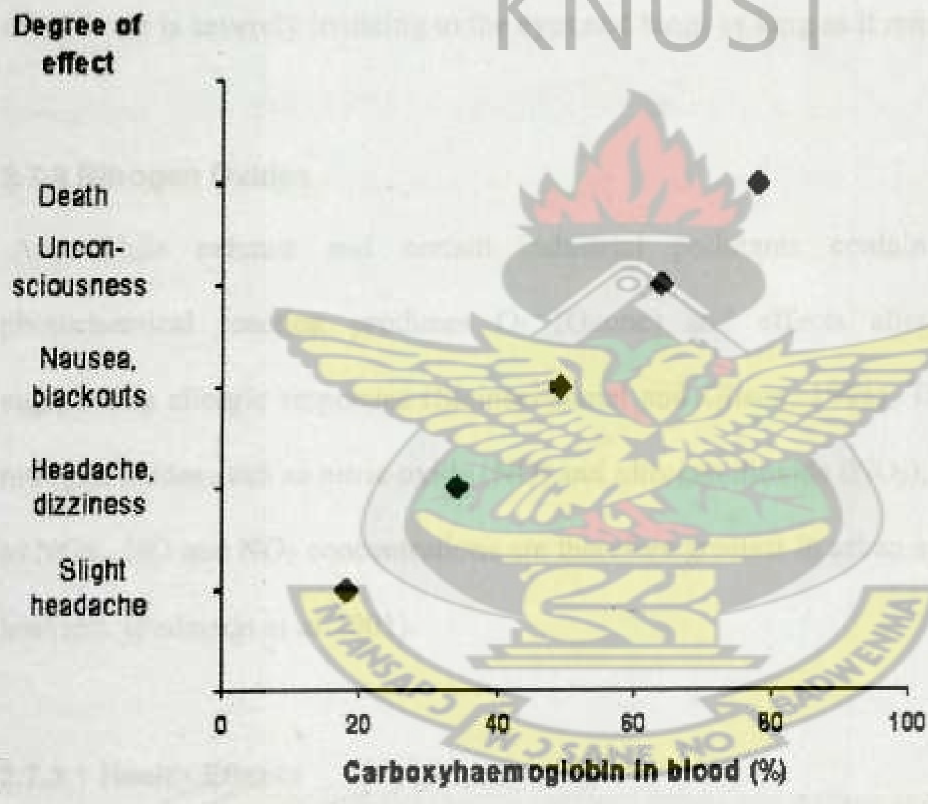


Figure 2.4: Dose-effect relationship of carbon monoxide (Beaglehole *et al,* 1993)

2.7.2 Sulphur Dioxide

Sulphur dioxide is a corrosive acid gas, which combines with water vapour in the atmosphere to produce acid rain. Road transport is a minor source of sulphur dioxide, in some urban areas it can be important. SO_2 emissions have diminished steadily and, in most European countries, they are no longer considered to pose a significant threat to health (Pederson *et al*, 2001).

2.7.2.1 Health Effects

Sulphur dioxide (SO_2) in ambient air is also associated with asthma and chronic bronchitis (choking effect on small concentrations). Sulphuric acid (H_2SO_4) in the form of acid rain is severely irritating to the eyes and lungs as long as it remains in the air.

2.7.3 Nitrogen Oxides

Automobile exhaust and certain industrial pollutants contain NO_2, which by photochemical reaction produces O_3 (Ozone) and effects allergic asthmatics by augmenting allergic responses (SteinbergJanel and Gilson, 1991). The main sources of nitrogen oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2), collectively known as NOx. NO and NO_2 concentrations are therefore greatest in urban areas where traffic is heaviest. (Pederson *et al* 2001).

2.7.3.1 Health Effects

Nitrogen dioxide has a variety of health impacts:

- It is a respiratory irritant, may exacerbate asthma and possibly increase susceptibility to infections.
- He causes lung damage: penetrates deeply into smaller airways and lung parenchyma, causes pulmonary oedema at high concentration.
- Damage to blood vessel

- It is a photochemical smog which causes headaches, eyes, and nose and throat irritations.
- Affect the pulmonary function and cause inflammation of the bronchial mucus (Karen and Michak 1991).

2.7.4 LEAD

Lead has been a gasoline additive since the 1940s as an antiknock agent to improve engine performance. In order to raise the octane number in petrol the compound of lead called tetra ethyl lead (TEL) is used. The introduction of lead into gasoline raises the octane number and functions as lubricant for valve seats. The use of leaded petrol has contributed to approximately 90% of lead in air pollution worldwide; it is still like those in developing countries where the leaded petrol is used (Household, 1998). The combustion of petrol is inefficient in most cases and gases and particulate are emitted as exhaust particulate. One of the perturbing ones is lead particulate matter, which has detrimental physiological affects. Exposure to lead involves several physiological disorders in man.

2.7.4.1 Toxicokinetic and Metabolism

The lead once inhaled it is distributed rapidly into soft tissues (blood, kidney, and liver) as well as bone and teeth. It is eliminated in urine and faeces and a variety of these tissues and exeretion products have been used in attempts to assess exposure, although whole blood is most widely used for this purpose (Andrew Wadge, 1999).

2.7.4.2 Health Effects

- The most sensitive parts of the body are the kidneys, the blood and the central nervous system. Because children are developing, they are more susceptible to the effects of even low levels, once thought to be safe (Household, 1998).
- It causes brain damage in high concentrations

2.8 ENVIRONMENTAL TREATIES

In 1992 the United Nations Conference on Environment and Development (Earth Summit) held in Rio de Janeiro. Two important international conventions were agreed at the conference;

- the Framework Convention on Climate Change, and the
- Convention on Biological Diversity.

A decade later, the 2002 World Summit, held in Johannesburg, again sought agreement on environmental policies. In view of all these, very little impact has been made to achieve the set target. The Kyoto Protocol, which emerged from the 1997 conference, is the first agreement under the FCCC with greenhouse gas emission reduction targets that will be binding in international law. The FCCC itself set voluntary targets for industrialized nations such that their CO_2 emissions should be no higher in 2000 than they were in 1990. Developing countries argued that they had no responsibilities to cut emissions because the industrialized countries were the main emitters of greenhouse gases. Unsurprisingly, not many nations met their voluntary targets. The Kyoto Protocol sought a 5.2 per cent reduction in overall (carbon-equivalent) greenhouse gas emissions by about 2010 relative to 1990. This target applies collectively to industrialized economies only. Once again, developing countries have no mandatory targets. The target is differentiated between industrialized countries.

2.9 LIGHT- DUTY VEHICLES

Vehicles are divided into two main categories. They are heavy and light duty vehicles. Heavy duty vehicles are defined as vehicles with more than two axles or with dual tyres on the rear axle. The US highway capacity manual defines a heavy vehicle as "a vehicle with more than four wheels touching the pavement during normal operation" (TRB, 2000). Thus, buses, trucks, semi-trailers (articulated vehicles), cars towing trailers or caravans, tractors and other slow-moving vehicles are classified as Heavy vehicles. All other vehicles are defined as Light duty vehicles (cars, vans, small trucks) (CAITR, 2003). They are Passenger cars, small truck or multi-purpose vehicles weighing less than 6,000 pounds GVWR.

Table 2.2 FTP EMISSION STANDARDS

Federal Test Procedure (FTP 75) test and expressed in g/mile.

Table 1

EPA Tier 1 Emission Standards for Passenger Cars and Light-Duty Trucks, FTP 75, g/mi

ategory	50,000 miles/5 years						100,000 miles/10 years[1]					
	TH (total hydrocarbons)	NMHC (non-methane hydrocarbons)	CO	NOx† diesel	*NOx gasoline*	PM	THC	NMHC	CO	NOx† diesel	*NOx gasoline*	PM
er cars	0.41	0.25	3.4	1.0	*0.4*	0.08	-	0.31	4.2	1.25	*0.6*	0.10
.VW <3,750 lbs	-	0.25	3.4	1.0	*0.4*	0.08	0.80	0.31	4.2	1.25	*0.6*	0.10
.VW >3,750 lbs	-	0.32	4.4	-	*0.7*	0.08	0.80	0.40	5.5	0.97	*0.97*	0.10
ALVW <5,750 lbs	0.32	-	4.4	-	*0.7*	-	0.80	0.46	6.4	0.98	*0.98*	0.10
ALVW > 5,750	0.39	-	5.0	-	*1.1*	-	0.80	0.56	7.3	1.53	*1.53*	0.12

l life 120,000 miles/11 years for all HLDT standards and for THC standards for LDT
relaxed NOx limits for diesels applicable to vehicles through 2003 model year

ations:
oaded vehicle weight (curb weight + 300 lbs)
adjusted LVW (the numerical average of the curb weight and the GVWR)
light light-duty truck (below 6,000 lbs GVWR)
heavy light-duty truck (above 6,000 lbs GVWR)

2.10 DRIVING PATTERNS

In urban areas driving patterns vary a great deal. However, the knowledge of those characteristics of driving patterns that causes increased environmental effects is limited. It is well known that driving patterns, i.e. vehicle speed profile, affect the fuel consumption and vehicle exhaust emissions (Ma *et al*, 1999). In urban areas, driving patterns vary a great deal at any time and several studies have been performed to create typical driving cycles for urban driving (Ma *et al*, 1999). Driving disorder, such as having difficulty in staying in the lane, abrupt lane changes and driving on the shoulder are typical consequences of many dangerous driving circumstances, and can be grouped under the heading of "lateral discipline of driving". It is based on establishing certain threshold values for normal driving (lateral) patterns and by checking given traffic instances against these criteria. Driving patterns such as speed, acceleration and choice of gears greatly influence exhaust emissions and fuel consumption. Real world driving has frequent speed fluctuations and sharp acceleration and deceleration. According to Guensler, (1993) sharp acceleration could increase emission rates by increasing the air to fuel ratio. This might be due to a number of factors such as variation in road characteristics, traffic characteristics and roadway environment. Nesamani *et al* (2006) noted that with the increase in traffic volume and change in travel-related characteristics, vehicular emissions and energy consumption have increased significantly.

2.11 MODEL

A model is a description of a physical system that maybe used to predict or explain the behavior of the original system. Microsoft works dictionary defines a model as a simplified version of something complex used in analyzing and solving problems or making predictions. One fundamental principle is to use a simple model that captures the important behaviors of the system, under which the conditions in which the model will be used. In modeling, a real world problem must envisage.

2.11.1 Mathematical modeling

Mathematical modeling is the use of a simplified mathematical representation of a real system, process, or theory. Mathematical models are developed in order to enhance our ability to understand, predict and possibly control the behaviour of the system being modeled. Mathematical models are symbolic and help to express ideas and problems clearly. They may use equations such as:

$$V = f\lambda \qquad \text{...Eqn 1}$$

Where V = Velocity, f = frequency, and λ = Wavelength

Mathematical models may also use diagrams and groups such as electronic computers, circuit diagrams, or stock – market index performance charts. With the advent of technology and its associated increasing growth rate it has become inevitable that analytical procedures for solving difference and differential equations also be pursued vigorously. When dealing with events or consequences (e.g. discharge of pollutants into the atmosphere which occur at discrete - time periods such as hourly, daily, monthly or yearly periods). It is convenient to use difference equations.

Mathematical modeling technique has been employed as an essential part in the bid to achieve the said goal. However, selecting a model depends on the following factors:

1. The depth of understanding needed at a particular stage of the problem study.
2. The application to which the model will be put.

2.12 EMISSION TESTING

2.12.1 Types of Emission testing

There are various types and forms in testing vehicular emissions. They appear in different forms, different manufacturers and type of equipment. The most common type of test is the one that measure exhaust gas content with the engine idling. The test is based on what is known as a Four Gas Analyzer. This machine tests for carbon dioxide (combustion efficiency), carbon monoxide (incomplete combustion), oxygen content and unburned hydrocarbons.

Fig 2.5 AN OPUS 40 GAS ANALYZER INTERFACE

(Source: Opus 40 Analyzer manual)

Figure 2.6: A SET OF OPUS 40 GAS ANALYZER

(Source: Opus 40 Analyzer manual)

Figure 2.7: The metal hose and the metal sample probe of the OPUS 40 gas analyzer (Source: Opus 40 Analyzer manual)

The tester is usually combined with a computer or other operator interface so that test parameters such as vehicle year, test limits etc can be set.

The OPUS 40 gas analyzer (fig 2.6) is equipped with the following components

- RPM pickup or battery type
- Oil temperature probe
- Sample probe with a 7 meter hose
- Power supply cable,5 meter
- Manual in English
- Remote control with wire

2.12.2 PRINCIPLE OF THE OPUS 40 GAS MEASUREMENTS

The measuring of CO, CO_2 and HC is done using a technique called NDIR (Non Dispersive Infrared light). Parts of the vehicles exhaust fumes are pumped into a sample cell where it is lit through by an infrared light originating from one side of the sample cell. On the opposite side of the chamber a detector reads the amount of infrared light passing through the chamber. Different gases absorb or reduce infrared light at different wavelength. When filtering these wavelengths by applying an optical filter in front of the detector, reading the amount of infrared light passing through the sample cell, the gas concentration can be defined. The gas levels and relationship between the gases indicates to the operator what is happening during the power stroke. Once the operator recognizes causes of abnormal gas readings, a quick accurate diagnosis can be made.

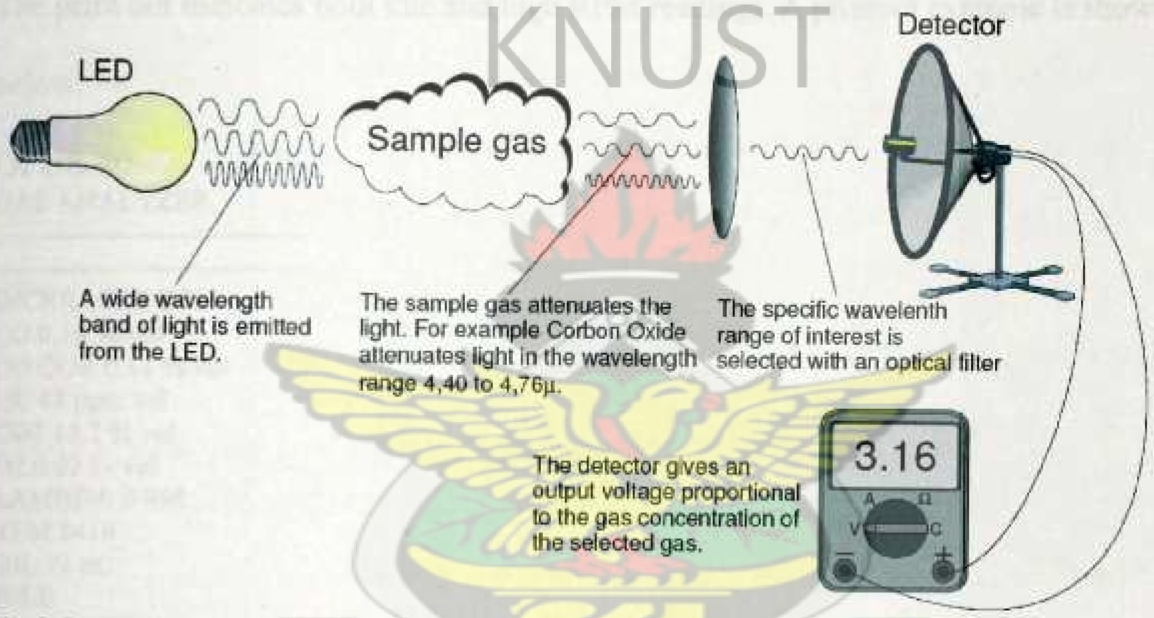


Fig 2.8 OPUS 40 Sample Transducer

(Source: Opus 40 Analyzer manual)

During sampling, the OPUS 40 will continuously pump exhaust gas through the measuring cell and show all readings on corresponding displays.

ppm vol. HC	-	Hydrocarbon, measured as hexane in parts per million
% vol. C O	-	Carbon Monoxide, measured in volume percentage
% vol. CO_2	-	Carbon Dioxide, measured in volume percentage
% vol. O_2	.	Oxygen measured in volume percentage
`Lambda (γ)	-	Air/Fuel ratio

RPM and oil temperatures etc

To perform gas sampling on a vehicle, the following activities are carried out.

- Start the vehicle and make sure it is warmed up
- Press the remote control until ''HI'' is displayed
- Increase the RPM to 2000-2500 r/m and wait until the values have stabilized
- Press the remote control till ''LO'' is displayed.
- Let the engine drop to idle and wait until the values have stabilized.
- Press the key of the remote control until ''P'' displays and a print out is done.

The print out indicates both idle and high RPM readings. A printout example is shown below:

OPUS 40
GAS ANALYZER

INCREASED RPM
CO 0.14 % vol
CO COR 0.13 % vol
HC 48 ppm vol
CO2 15.2 % vol
O2 0.03 % vol
LAMBDA 0.998
RPM 2416
OIL 71 oC
IDLE
CO 0.21 % vol
CO COR 0.21 % vol
HC 76 ppm vol
CO2 14.8 % vol
O2 0.18 % vol
LAMBDA 0.995
RPM 762
OIL 71 oC
Date: 2005-01-16 13:22
Order.no:…………………
Chass.no:………………..
Reg.no:…………………..
Km: …………………..
Sign: ……………………

Fig 2.9 : A print out indicating Idle and High RPM readings of the Opus 40 Analyzer

(Source: Opus 40 Analyzer manual)

2.13 Evaluating Vehicle Emissions

Reading HC and CO at the tailpipe to diagnose emission problems may not give you the complete picture because the catalytic converter "masks" many problems by significantly lowering HC and CO in the exhaust. That is where a three- or four-gas analyzer comes in handy (Carley, 2005). The relative proportions of carbon dioxide and oxygen in the exhaust can divulge whether the air/fuel ratio is correct or not in addition to other problems that affect engine performance and emissions. As combustion efficiency decreases, the oxygen content in the exhaust rises and carbon dioxide falls. An engine that is running at a nearly ideal air/fuel ratio of 14.5:1 will show about 14.5 percent carbon dioxide and 2.5 percent oxygen in the exhaust. Carbon dioxide readings of less than about 13 percent and oxygen readings greater than about 4 or 5 percent indicate poor combustion efficiency. This translates to over-rich or over-lean air/fuel ratio, poor compression, or an ignition problem.

2.14 GASEOUS EMISSIONS OF OPUS 40 GAS ANALYZER

2.14.1 Carbon Monoxide

This is measured in percent. It is the result of incomplete combustion. This is when the fuel mixture has been compressed and ignited, but could not complete the combustion process due to lack of oxygen. This failure is always a mixture or ignition timing related. The ideal reading for CO is 0%. A normal reading for CO is usually around 0.25% to 0.75% with 1.2% being the failure mark in most areas for vehicles of 1984 and newer. Earlier cars are allowed higher readings. Any car running equipped with an oxygen sensor will try to run under 1.0% as measured before the catalytic converter. A vehicle with a CAT, O_2 sensors and an AIR system (Air Injection Reaction) will read almost 0% with everything working properly.

2.14.2 Carbon Dioxide

Carbon dioxide is the end product of fossil fuel combustion. It is also measured in percent which is an indication of engine combustion efficiency. The ideal is 14%.CO_2 is affected by timing (valve and ignition), compression, mixture, engine condition and temperature. Changes to tire sizes and gear ratios will affect this test.

2.14.3 Hydrocarbons

This is Measured in PPM (parts per million). It is the result of unburned fuel making it out the tailpipe. This is different from CO problem in the sense that the fuel has not started combustion at all. This failure is usually caused by an ignition (misfire), or an engine problem such as a bad valve. An engine running too lean will often have excessive HC due to what is called a "lean misfire". Any leaks in the intake valve system or bad injectors will also cause excessive HC due to uneven fuel distribution. The ideal reading is 0 PPM. Most late model cars run under 100 PPM with readings between 10 and 50 PPM being typical and a reading of over 220 PPM being the failure mark for most inspection program.

2.14.4 Oxygen

This is also measured in percent. It is actually excess oxygen left over from the combustion process. If this reading is very low, then there will be an occurrence of high CO. In automobiles 18% will be ideal but a normal atmosphere is 21%. This is controlled in late model vehicles by the Oxygen sensor circuit. The O_2 sensor actually measures the difference in O_2 content of the atmosphere and the exhaust. When the atmosphere has more O_2 than the exhaust, a small positive voltage is generated.

2.14.5 LAMBDA (λ)

This is the air to fuel ratio. It is how much air is present in the fuel mixture that is being burnt. According to Guensler, (1993) sharp acceleration could increase emission rates by increasing the air to fuel ratio.

λ -1.00 ⟶ Enough for complete combustion of fuel and no excess Oxygen.

$\lambda > 1.00$ ⟶ Excess air (Lean mixture)

$\lambda < 1.00$ ⟶ Insufficient air (Rich mixture)

2.15 CATALYTIC CONVERTERS

This is a pollution control device fitted to cars. Its function is to convert carbon monoxide to carbon dioxide. This entails reduction from the toxicity of emissions emanating from internal combustion engines. Although this pollution control device called catalytic converter is fitted in many cars, it does not work efficiently to remove pollutants from the exhaust emissions until it is warmed to working temperature. Vehicle manufacturers such as Ford motor company indicated that during cold starts, catalytic emissions control systems do not provide full control until they reach operation temperatures and richer mixtures. This is the main reason for the emissions encountered due to cold and hot starts. The heating can take several kilometres depending on the car. It depends on the length of the journey. The catalytic converter may not be eliminating exhaust emissions during short trips such as driving within the vicinity or neighbourhood. Safonov (2000) stated that Catalytic converts increases fuel consumption and therefore carbon dioxide emissions by 3 to 10%. He further stated that in cities, catalytic converters are of little effect as most journeys are below 5 km. This is due to fact that catalytic converters are not effective until the exhausts have warmed up.

2.16 FUEL ECONOMY IN RELATION TO AUTOMOBILE EMISSIONS

Fossil fuels more often than not contain hydrocarbons (compounds containing Hydrogen and carbon). In the combustion process, these fuels are oxidized to generate heat. In an ideal combustion, oxygen (O_2) in the air combines with all of the carbon (C) in the fuel to form carbon dioxide (CO_2) and all of the hydrogen (H) in the fuel to form water (H_2O). The combustion of gasoline produces CO_2 in amounts that can be readily calculated. From basic organic chemistry of hydrocarbons, the burning of a gallon of gasoline produces about 20 pounds of CO_2 (www.fueleconomy.gov/feg/CO₂.shtml). Most of this mass comes from the oxygen in the atmosphere. A carbon atom has an atomic weight of 12, and each oxygen atom has an atomic weight of 16, giving each single molecule of CO_2 an atomic weight of 12 + (16 x 2) or 44. To calculate the weight of the CO_2 produced from a gallon of gasoline, the weight of the carbon in the gasoline is multiplied by 44/12 or 3.7. Since gasoline is about 87% carbon and 13% hydrogen by weight, and since a gallon of gasoline weighs about 6.3 pounds, the carbon in a gallon of gasoline weighs (6.3 lbs. x .87) or 5.5 pounds. If the weight of the carbon (5.5 pounds) is then multiplied by 3.7, this is approximately 20 pounds. Hence, the weight of carbon dioxide emitted from one gallon of gasoline is given as,

$$\mathbf{5.5 * 3.7 = 20\,pounds\left(20lbs\right).}$$

Density of CO_2 = 1.98 kg

Mass of 20 pounds of CO_2 = 9.1 kg

Volume of CO_2 from one gallon of gasoline =?

$$\mathbf{Density = \frac{mass}{volume}}$$

$$\text{Volume} = \frac{\text{mass (m)}}{\text{density}\ (\rho)}$$

$$\text{Volume} = \frac{9.1\,\text{kg}}{1.98\,\text{kg}/\text{m}^3}$$

Volume of CO_2 = 4.58 m^3

Volume of CO_2 emitted from one gallon of gasoline is 4.58 m^3.

However in practice, the combustion process is not 100 percent efficient. Automobile engines produce different types of emissions as combustion by-product or as a result of incomplete combustion. For an internal combustion engine, these include nitrogen oxides (NOx) (from nitrogen and oxygen in the atmosphere), carbon monoxide (CO) and hydrocarbons (HC), including methane. These emissions do not change the fact that burning of gasoline produces CO_2. Furthermore, the amounts of CO_2 emitted per mile are far greater than the amounts of HC, CO, and NOx, singly or combined (US EPA, 2000). CO_2 emissions are always and directly associated with fuel consumption because CO2 is the ultimate end product of fossil fuel combustion. The more gasoline a vehicle consumes, the more CO_2 it emits. Vehicles with lower fuel economy burn more fuel, creating more CO_2. Your vehicle creates about 20 pounds of CO_2 (170 cu. ft.) per gallon of gasoline it consumes (Fuel economy guide, 2006). Therefore, by choosing a vehicle with higher fuel economy global climate change can be reduced. By choosing a vehicle that achieves 25 miles per gallon rather than 20, the release of about 17 (260 thousand cu. ft.) tons of greenhouse gases over the lifetime of the vehicle can be avoided (Fuel economy guide, 2006). Thus, fuel economy is directly related to emissions of greenhouse gases such as CO_2. Fuel consumption and CO_2 emissions from vehicles are two inseparable parameters.

CHAPTER THREE

METHODOLOGY

3.1 Location/Project Site

In line with the study of light–duty vehicular emissions in the Kumasi Metropolis through the Transport Sector Programme Support (TSPS) Phase II, vehicles within the Kumasi Metropolis were considered. The vehicles considered were from KNUST and Driver and Vehicles Licensing Authority (DVLA).

The DVLA is an institution where drivers of different automobiles come to license their new cars and renew their expired old road worthy licenses, while KNUST being an academic institution where lots of activities including those that are commercial in nature. All these call for the use of transport in one way or the other. Also the EPA, which is the custodian of the sampling device (Opus 40 gas analyzer) was undertaking similar survey towards the Transport Sector Programme Support Phase II therefore making accessibility of the device easier and convenient.

3.2 Characteristics of the Kumasi City

Kumasi is the second largest city in Ghana. The city has a total area of 89.68 kilometers. The built up area is about 25.6km^2, about 25% of the total area (KNRMP, 2000). The city has a population of 1.2 million with an annual growth rate of 3.4% suggesting increasing need and use of vehicle transport for daily activities (KNRMP, 2000). With the presence of a university, forests, art works, Banks, shops etc, Majority of the trips undertaken includes education trips, business trips, shopping and recreational activities. It has many arterial streets connecting the Central Business District (C.B.D) at Adum with outlying residential and industrial suburbs of the city. The inhabitants Kumasi do not depend on railway transport but on road network for intra-city commuting.

3.3 SOURCES OF DATA USED

3.3.1 Primary Sources of Data

a) Questionnaire

A set of questionnaires were administered to 30 vehicle drivers (respondents) in the Kumasi Metropolis. The questionnaire focused on information relating to driving pattern, car fleet and circulation evaporation, fuel and climate data and other information required in the COPERT IV model (Appendix A).

b) Sampling of Real life emissions

This was carried out using the OPUS 40 (fig 2.6), a device designed to meet the high demands of a modern gas analyzer. It was carried out at the premises of the DVLA and KNUST campus where each vehicle that attended for inspection was sampled. Both high *rpm* and *idle* states of vehicles were considered. The device which has an exhaust probe attached was inserted into the exhaust hole of the selected light duty vehicles and a computerized interface and readings noted and printed out. The print out indicates both high Revolution per minute (RPM) and idle Revolution per minute readings. The readings indicates the concentrations of CO (carbon monoxide), CO_2 (carbon dioxide), HC (hydrocarbons), O_2 (oxygen) and NOx (nitrous oxides) in the fumes from the selected motor vehicles.

High Revolution per Minute Reading: This was obtained during acceleration test. The acceleration pedal was pressed when the vehicle was in neutral gear. The sound of the engine changed and the readings were taken.

Idle Revolution Per Minute Readings: The vehicle was left to steam on its own and readings taken.

Precautions taken

1) The mouth of the probe was covered with the thumb during each acceleration test on each vehicle to prevent entry of gases.
2) At the end of every test, the probe was taken away from the vehicle and any remaining gas in the hose removed by shaking for two to three minutes.

The values of various concentrations of sampled gases recorded were grouped according to the year of manufacture of the vehicles and their engine capacities. Their mean values were also noted.

c) Interviews

Drivers and vehicle owners were interviewed to obtain information that could not be captured by the sampling and questionnaire.

d) Observations

A direct inspection of trends in vehicle driving patterns such as cold and hot starts, types of vehicles within the metropolis was done. This was to ascertain the conditions under which light duty vehicle emissions was modelled using the Copert IV.

3.4 Secondary Sources of Data

Materials and facilities which served as secondary sources of data included journals, published and unpublished works, transport related policy document of Ghana, library/desk researches, magazines , national dailies, libraries and the use of internet were explored.

3.5 TECHNIQUE OF DATA COLLECTION

In the process of administering the questionnaires, both purposive and simple random sampling techniques were adopted to collect thirty samples from vehicle owners within the Kumasi Metropolis. In checking for the real life emissions from the Opus 40 gas analyzer, 109 vehicles were sampled. The choice of vehicle and the drivers were at randomly done.

3.6 ANALYTICAL TECHNIQUE

Based on the responses from vehicle owners, a database was created and the Statistical Package for Social Sciences (SPSS) used to analyze the relationships among different parameters related to the driving patterns of vehicle emissions.

3.7 Validation of Copert IV

In the bid to address the short falls of Copert IV in estimating the vehicular emission models, the levels recorded by Copert IV was compared with those from real live emissions. The difference in levels of emissions between the two categories (table 4.9) was found and used to validate the Copert IV model according to the following procedure);

Results from real live emission measurements (R) - Results from copert IV emission measurements (C) = a Validation factor (x)

ie $R - C = x \Rightarrow R = C + x$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 MODELLING AND DATA ANALYSIS

This chapter involves the difference between the emission levels as generated by Copert IV model and real life emission, identification of driving patterns, quality of gases emitted from vehicle exhaust and emission model for CO, CO_2, and VOC. Acceleration and deceleration profiles, car fleet and circulation data obtained from the questionnaire were organized using SPSS and the data fed into the COPERT 1V model software.

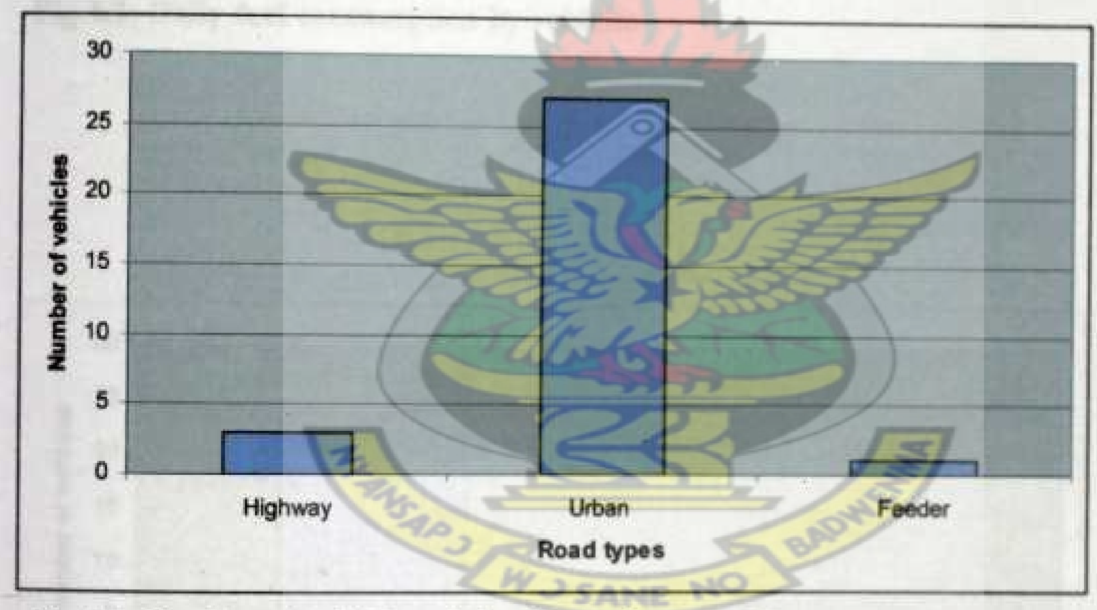


Fig 4.1: Number of vehicles plying the various road types

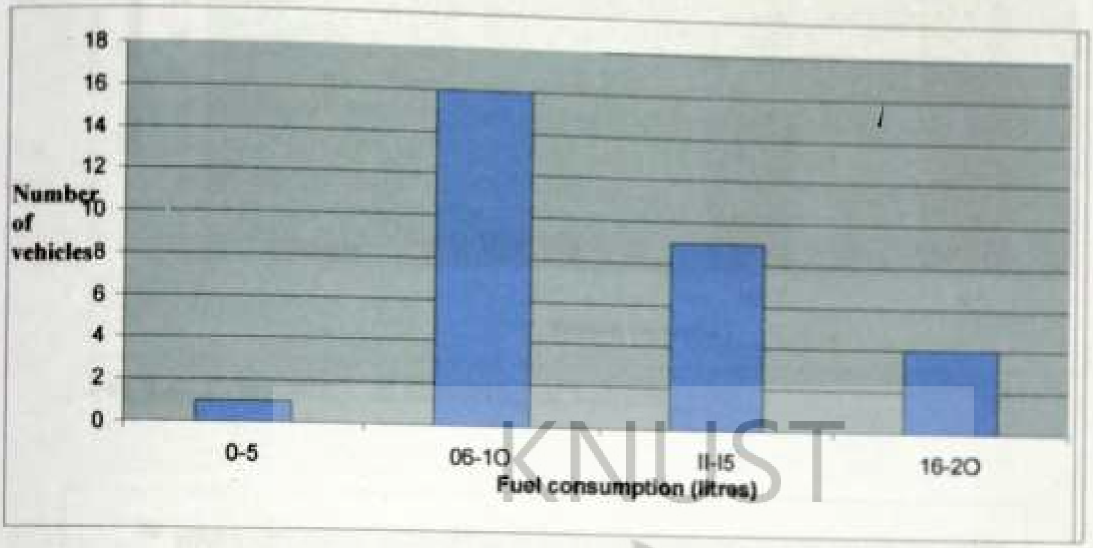


Fig 4.2: Daily fuel consumption by vehicles

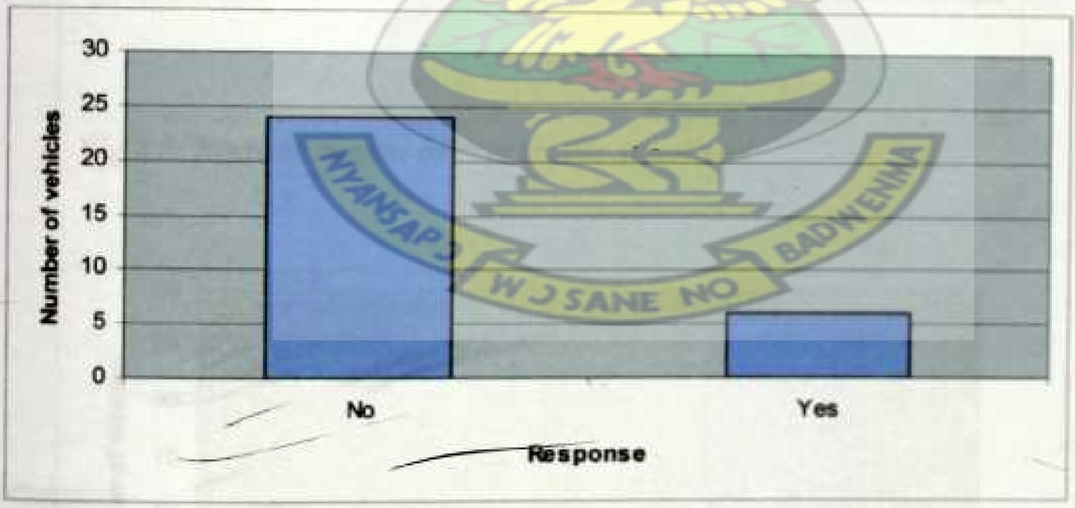


Fig 4.3: Observation of rules on sitting capacity by vehicle drivers

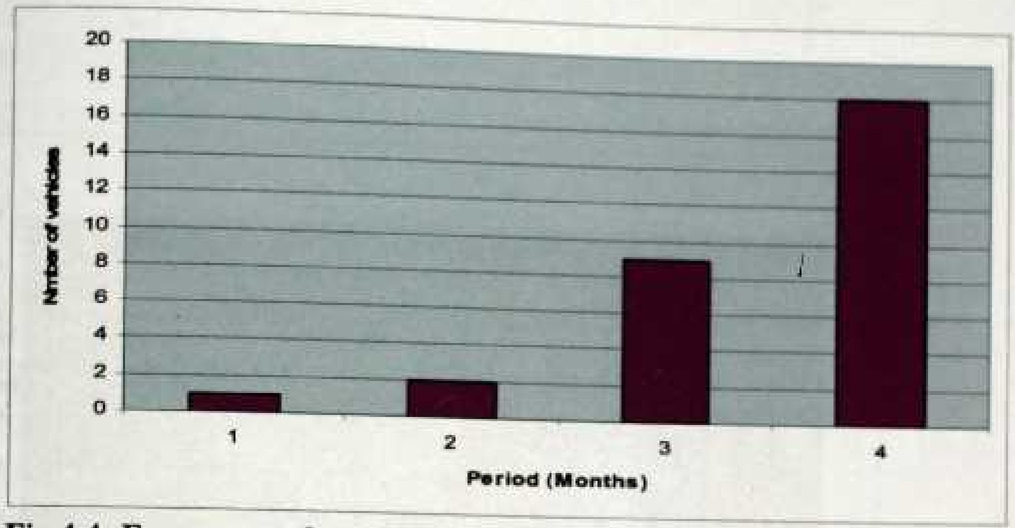


Fig 4.4: Frequency of servicing of vehicle

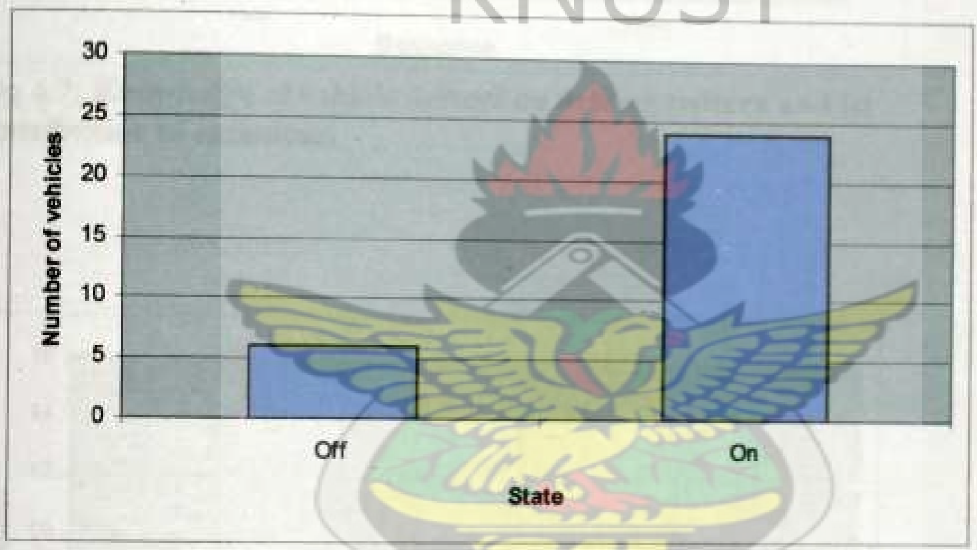


Fig 4.5: State of engine during traffic situations

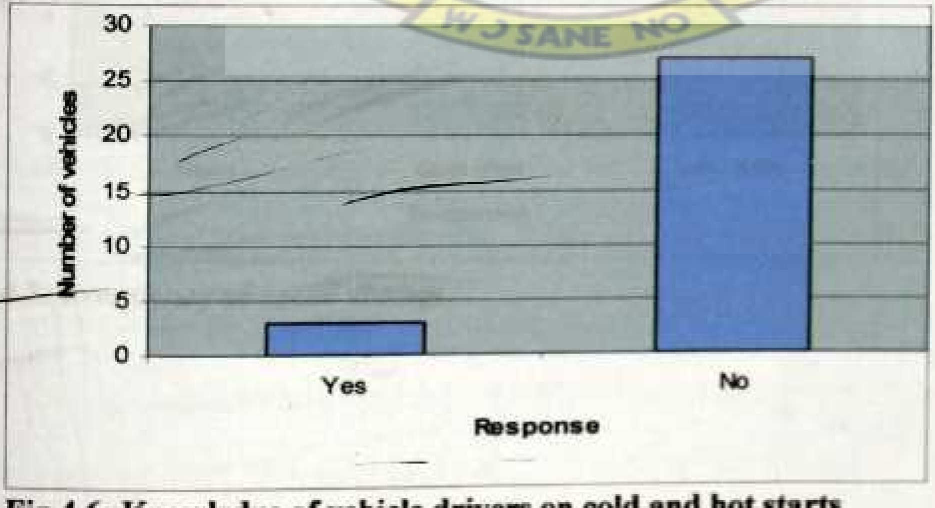


Fig 4.6: Knowledge of vehicle drivers on cold and hot starts

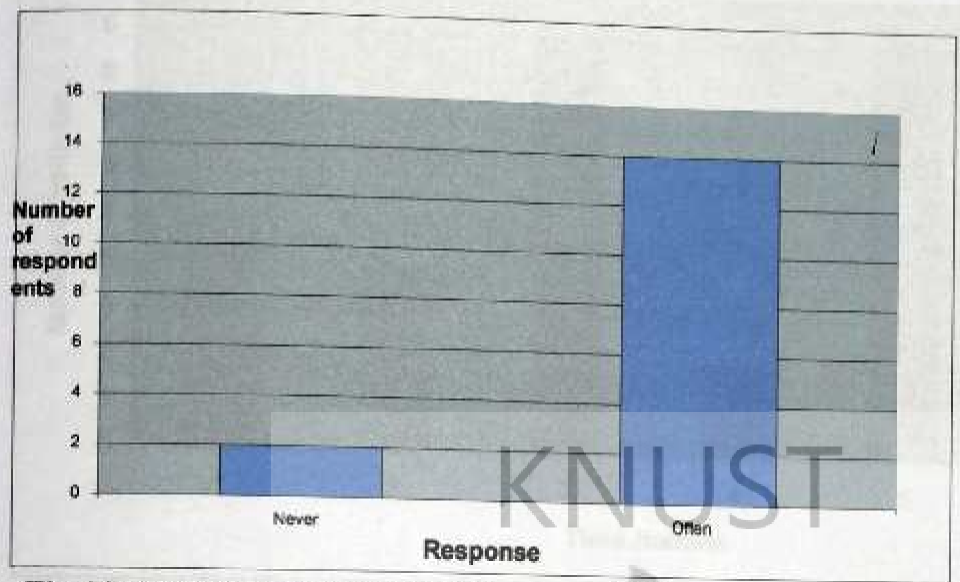


Fig 4.7: Knowledge of vehicle drivers on driving pattern and its contribution to emissions.

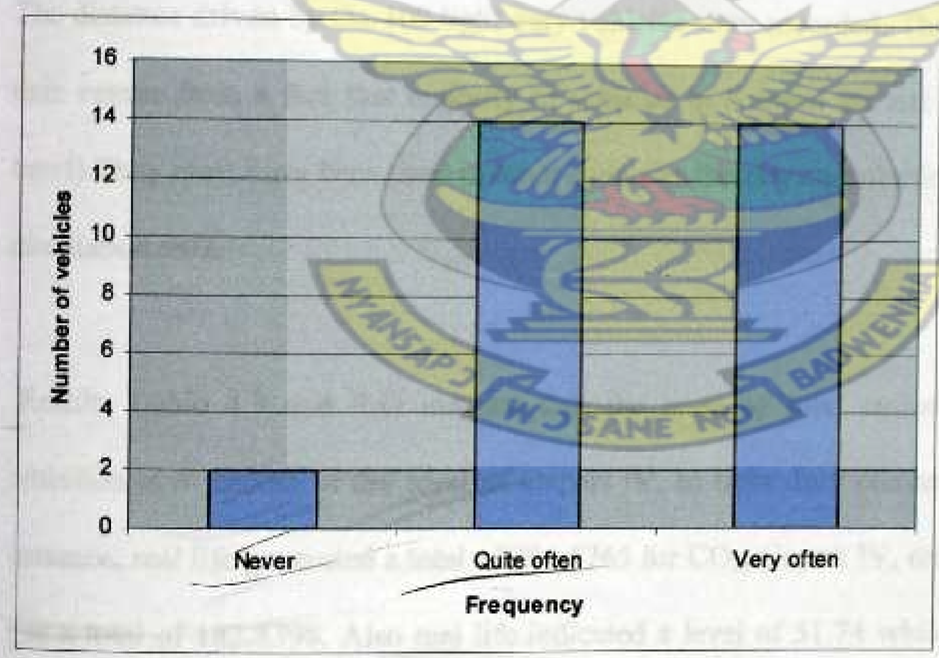
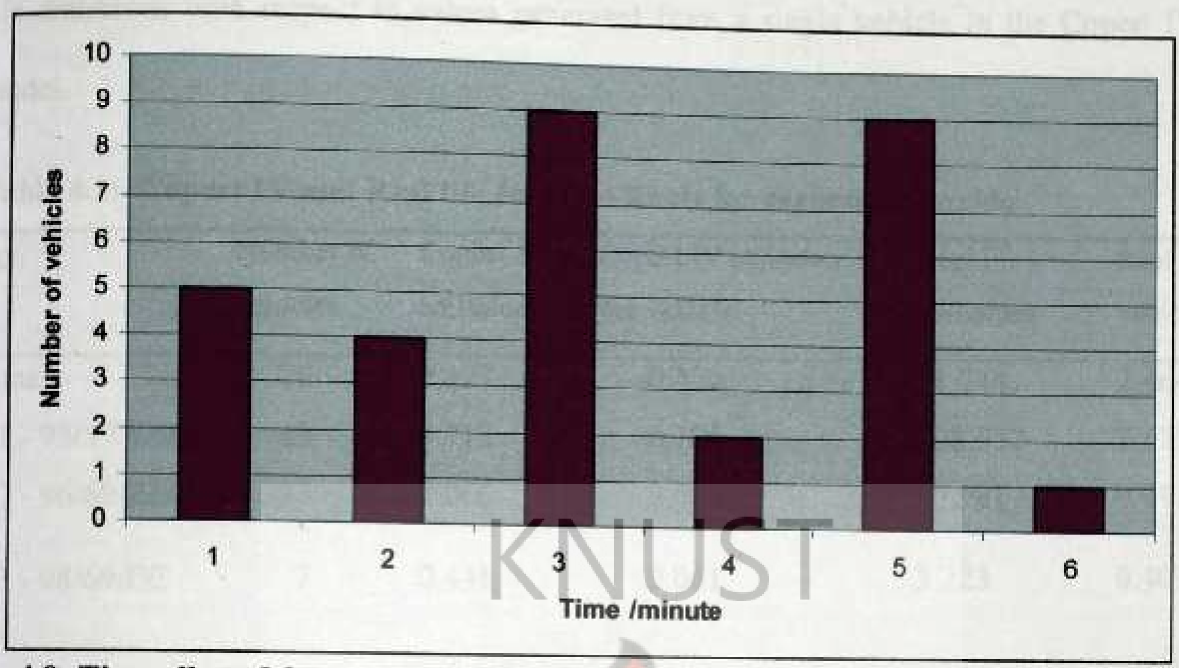


Fig 4.8: Frequency of speed change



4.9: Time allowed for engine stabilization

4.2 Circulation Data

The distance driven by the 109 light duty vehicles were recorded. The uncertainty of this data comes from a fact that majority of vehicles in Kumasi are not brand new (second hand).They must have been used in other countries thereby contributing an increase to the circulation data.

Results (table 4.3 and 4.4) indicate that the level of total emissions from real life emission is in excess of the level of Copert IV. In light duty conventional vehicles for instance, real life generated a total of 204.6765 for CO_2, Copert IV, recorded for the same gas a total of 182.8398. Also real life indicated a level of 51.74 while Copert IV gave a total of 8.377.Carbon dioxide emissions for Euro 1 vehicles indicated 521.2265 for real life emissions while Copert recorded 503.9327. Carbon monoxide recorded 108.63 for real life while Copert IV recorded 5.11 etc.

Each vehicular class is being considered for a single vehicle. The mean values of the real life emissions with respect to values generated from a single vehicle in the Copert IV model.

Table 4.1: Copert IV and Real life emission levels for carbon monoxide

Technology	Number of vehicles	Copert IV emissions	Copert IV emission per vehicle	Real life emissions	Real life emission per vehicle
Conventional	20	8.377	0.420	51.744	2.464
LD Euro 1 - 93/59/EEC	49	5.113	0.105	108.632	2.173
LD Euro 2 - 96/69/EEC	33	2.066	0.062	30.981	0.911
LD Euro 3 - 98/69/EC Stage2000	7	0.431	0.061	3.223	0.403

Table 4.2: Copert IV and Real life emission levels for carbon dioxide

Technology	Number of vehicles	Copert IV emissions	Copert IV emission per vehicle	Real life emissions	Real life emission vehicle
Conventional	20	182.8398	9.1400	204.6765	10.2300
LD Euro 1 - 93/59/EEC	49	503.9327	10.2800	521.2265	10.6300
LD Euro 2 - 96/69/EEC	33	358.1695	10.8500	387.9091	11.7500
LD Euro 3 - 98/69/EC Stage2000	7	77.7585	11.1000	102.5486	14.6500

Table 4.3: Copert IV and Real life emission levels for hydrocarbon

Technology	Number of vehicles	Copert IV emissions	Copert IV model for one vehicle	Real life emissions	Real life emission per vehicle
Conventional	20	0.8710	0.0436	0.9770	0.0488
LD Euro 1 - 93/59/EEC	49	0.3230	0.0066	1.8850	0.0375
LD Euro 2 - 96/69/EEC	33	0.0630	0.0019	0.8480	0.0256
LD Euro 3 - 98/69/EC Stage2000	7	0.0085	0.0012	0.0635	0.0090

Table 4.4 Differences between Real life emissions levels and Copert IV model emissions levels for Carbon dioxide, Carbon monoxide and Hydrocarbon

Technology	*Carbon dioxide*	*Carbon monoxide*	*Hydrocarbon*
Conventional	1.0900	2.0400	0.0052
LD Euro 1 - 93/59/EEC	0.3500	2.0600	0.0309
LD Euro 2 - 96/69/EEC	0.9000	0.8500	0.0237
LD Euro 3 - 98/69/EC	3.3500	0.3400	0.0005

4.5: Validated Copert IV model for emission levels of Carbon monoxide for the various vehicle types

Technology class	*Validated Copert IV model*	*Percentage Error*
Conventional	Copert IV emissions + 2.044	82.7
LD Euro 1 - 93/59/EEC	Copert IV emissions + 2.060	94.8
LD Euro 2 - 96/69/EEC	Copert IV emissions + 0.849	93.3
LD Euro 3 - 98/69/EC	Copert IV emissions + 0.342	84.4

4.6: Validated Copert IV model for emission levels of Carbon dioxide for the various vehicle types

Technology class	*Validated Copert IV model*	*Percentage Error*
Conventional	Copert IV emissions + 1.09	10.7
LD Euro 1 - 93/59/EEC	Copert IV emissions + 0.35	3.30
LD Euro 2 - 96/69/EEC	Copert IV emissions + 0.90	7.70
LD Euro 3 - 98/69/EC	Copert IV emissions + 3.35	23.0

4.7: Validated Copert IV model for emission levels of Hydrocarbon for the various vehicle types

Technology class	*Validated Copert IV model*	*Percentage Error*
Conventional	Copert IV emissions + 0.0052	10.7
LD Euro 1 - 93/59/EEC	Copert IV emissions + 0.0309	82.4
LD Euro 2 - 96/69/EEC	Copert IV emissions + 0.0237	92.6
LD Euro 3 - 98/69/EC	Copert IV emissions + 0.0005	5.60

4.3 SAMPLING RESULTS

The data describes the level of the following pollutants liberated into the atmosphere: Carbon dioxide (CO_2), Carbon monoxide dioxide (CO) and (HC). It also shows the percentage of Excess oxygen left from the combustion process (02 %) and air/ fuel ratio (λ). (Table 4.9 and 4.10)

Vehicles sampled have been divided into various technology classes using the EU legislation improvement years. This is used as a guide in the classification of vehicle under technology class as demanded by COPERT model. They are Conventional, Euro 1, Euro 2 and Euro 3.

Table 4.8: Technological classification of vehicles

Technology Class	**Year of manufacture**
Conventional	Before 1992
Euro 1	> 1992 - 1996
Euro 2	> 1996 - 2000
Euro 3	> 2000 - date

Table 4.9 Mean values of emissions based on the year of manufacture at Increased RPM

Emission Characteristics	*Conventional*	*Euro 1*	*Euro 2*	*Euro 3*
Carbon Monoxide	2.464	2.172653	0.911212	0.402857
Carbon dioxide	10.23	10.63000	11.75000	14.65000
Hydrocarbon	0.0488	0.0375	0.0256	0.0091
Percentage Oxygen	4.8035	4.876531	4.4712	2.3957
Lambda (λ)	0.9956	0.955	1.038	0.8889

Table 4.10 Mean value of emissions based on the year of manufacture at idle mode

Emission characteristics	*Conventional*	*Euro 1*	*Euro 2*	*Euro 3*
Carbon Monoxide	3.844	2.553878	1.703462	0.625714
Carbon dioxide	9.515	9.990816	11.11939	11.17
Hydrocarbon	0.0724	0.0539	0.0418	0.0778
Percentage Oxygen	4.526	3.65	3.1160	1.5714
Lambda (λ)	1.0089	1.067	1.1036	1.08

Table 4.11 VEHICLE TYPES WITH PETROL ENGINES SAMPLED AT DVLA

Year of manufacture	*Frequency*	*Percentage %*	*Cumulative frequency*
Conventional	20	18.34	20
Euro 1	49	45	69
Euro 2	33	30.3	102
Euro 3	7	6.4	109

From (Table 4.11), the frequency of Euro 1 is the highest. This forms 45% of the vehicles sampled. It is been shown to an extent that the percentage of vehicles in Kumasi is within the period of Euro 1.While about 6.4% of the vehicles sampled are Belongs to Euro 3.

Table 4.12 Mean values of engine capacities based on the year of manufacture

Technology class	***Engine capacities***
Conventional	1649.22
Euro 1	1600.58
Euro 2	1888.61
Euro 3	1966.67

From table 4.12, vehicles manufactured during the conventional period have an average of 1649.22, while Euro 3 has an average engine capacity of 1966.67 indicating a progress increase in engine capacities.

Table 4.13 Mileage distribution among technology class

Technology Class	*Mean Mileage (Km)*	*Total Mileage (km)*
Conventional	206162	4123240
Euro 1	207050.8	10145491
Euro 2	162215.1	5353098
Euro 3	63814.86	446704

4.4 INTERVIEWS AND OBSERVATION

Personal observations and interviews made indicate that most of the vehicles are not properly maintained. Also, at lower speeds (i.e., below 20 mph) results in higher emissions because it takes a longer time to cover the same distance). At high speeds (above 50 mph) emissions are also predicted to increase.

4.5 DISCUSSIONS

4.5.1 Driving Patterns and sources of emissions

Driving pattern including the speed profiles affect fuel consumption as well as total emissions. In urban areas driving patterns vary greatly, affecting the amount of exhaust emission and fuel consumption (Ma *et al*, 1999). From the emission data (Table 4.2), carbon dioxide had the greatest emission value. This may be attributed to the carbon bearing fuels which all contain fossil fuels. Jacob (1999) noted that the current global rate of increase in atmospheric CO_2 is 1.8ppm/yr corresponding to 4.0 PgC/yr and attributed the increase mainly to combustion of fossil fuel. When fuel is burned nearly all the carbon in the fuel is oxidized to CO_2 and emitted to the atmosphere.

The data on driving patterns obtained for this study indicate majority (90%) of light duty vehicle drivers and / or owners of vehicle that ply the three road types; highway, urban and feeder roads daily. They have no knowledge about the contribution of their driving patterns to increased vehicular emissions (Fig 4.6) e. g. the effect of their gear changing attitude, preferred state of engine in traffic situations. There was also lack of knowledge on the effect and contribution of idle and hot emissions (Fig 4.7). As a result 96.3% of the respondents (drivers) do not allow their vehicles to stabilize for times longer than 5 minutes (Fig 4.9). This has had a profound effect on emission rates. The effect may include weakening of the engine and also the performance of the catalysts in those engines that use such catalytic converters. This compares favourably with an observation made by vehicle manufacturers such as Ford motor company that during cold starts, catalytic emissions control systems do not provide full control until they reach operational temperature and a richer mixture.

Deducing from the fact that only 20% of drivers put off their engines when stuck in dense traffic (Fig 4.5), the contribution of cold start emissions to the total emissions is likely to be relatively less. However, conscious of the traffic build-ups tendencies from mornings, drivers in their bid to avoid being caught up in such traffic situations hurriedly move their vehicles without allowing enough time for initial warm up. This therefore explains the increased cold start emissions. According to the USEPA, hot start test begins exactly 10 minutes after a fully warmed up when there is no requirement of mixture enrichment to achieve this. The extremely high level of CO_2 may be attributed to oxidation of CO as they are liberated from the exhaust. This observation conforms to that of Owusu-Boateng (2003) that CO is unstable and is oxidized at lower levels where oxygen concentration is high.

Vehicle age is one of the major factors that contribute to emissions into the atmosphere. This is based on year of manufacture as noted during registration at the DVLA. Most of the vehicles imported into the country are already more than 10 years old. This study reveals that there is a general decline in the concentration of the various emission characteristics for both increased RPM (Table 4.9) and idle mode (Table 4.10) with vehicles in the manufacturing class of Euro 3 to date experiencing the highest decline. The concentrations of these are within the USEPA limit. For example, limit of 0.25 to 0.41 (HC) and 3.4 to 5.0 (CO) for an average of 50,000 miles/year (Table 2.2). The decline may be attributed to technological improvement.

Majority of the vehicles considered in this study do not speed much due to intermittent traffic lights, existence of intersections, roundabouts and vehicle traffic congestions. This may explain the difficulty in maintaining constant speed and therefore force drivers to exhibit frequent gear-changing behaviours, unstable and inconsistent speed profiles as the most common driving patterns and hence the high levels of emissions. This observation is similar to that of Nesamani *et al* (2006) who noted that with increase in traffic volume and change in travel-related characteristics, vehicular emission and energy assumption have increased significantly. Also when a vehicle is at high speed the emission tends to be lower than when the vehicle moves at snail speed.

4.5.2 Quality of Emissions

Estimation of emissions from on-road motor vehicles is important since it is used to develop regional emission inventories which in turn give indication of progress made toward and maintenance of compliance of ambient air quality standards, indicates where efforts should be placed to control air pollution in a community and also determines the consistency and conformity of state implementation Plans.

According to Singer *et al* (1999), hydrocarbons and Carbon monoxide emissions are higher when an engine is started than after the vehicle is warmed up. This may explain the higher levels of hydrocarbons and carbon monoxide recorded in the study. Also during cold start, extra fuel is added to ensure that adequate amount of fuel is vaporized to achieve a combustible mixture. This therefore supports the fact that the few drivers who put off their engines do not in the end save fuel. Vehicles of technological class Euro

1, in this study have the highest frequency (table 4.11) are not environmentally friendly in terms of atmospheric emissions as viewed against the US EPA standards.

Engine capacity also affects the emission levels of vehicles. The lower the engine capacity, the higher the concentration of emissions liberated. Also the higher the engine capacity, the lower the level of emissions. A vehicle manufactured within the technological class of Euro 1 has lower average engine capacity than that manufactured in Euro 2. This may be attributed to improved technology with the passage of time. A good example is the introduction of catalytic converters in modern vehicles. It is therefore a sound policy (holding other factors constant) that importation of older vehicles attract, higher duty charges.

Other factors which affect quality and quantity of emissions include engine design, operating temperature, air fuel ratio, presence of fuel system deposits, the condition of the engine and its control. Taking into consideration the economy of towns and landlocked cities such as the Kumasi Metropolis, which has relatively high population of older vehicles than newer ones, the commensurate relatively higher emissions levels recorded in this study is therefore not surprising.

4.5.3 The Model

From the results, it could be deduced that Copert IV recorded lesser levels of total emissions than total real life emissions. For example results show 9.14 and 10.23 for Copert IV and real life measurement respectively in the case of CO_2 and 0.42 and 2.464

for Copert IV and real life measurement respectively in the case of CO (table 4.1 and 4.2) for conventional vehicles. This could be attributed to circulation, which has the tendency to limit the amount of emissions that was captured by the device (Opus 40) (fig 2.7) used for measuring the gases emitted. From table 4.1, 4.2 and 4.3, there is an increment in carbon dioxide and a reduction in carbon monoxide and hydrocarbon as one moves from conventional vehicular class to Euro 3 class. This could be attributed to technological advancement including addition of catalytic converters which converts CO to CO_2. Safonov (2000) reported that Catalytic converters increases fuel consumption and therefore carbon dioxide emissions by 3 to 10% supporting this observation.

Vehicles of technological class Euro I which are the classes of vehicles manufactured between 1992 to 1996 form the majority (45%) of vehicles that showed up at the premises of the DVLA and KNUST. The observation by Luca *et al* (2007) that emissions from road traffic show an increase in trends from 1990 onwards, due to an increase in fuel consumption.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

1. More accurate emission levels of CO, CO_2 and HC emissions could be obtained with a validated Copert IV model.

2. Light duty vehicle drivers and / or owners of vehicle that ply the three road types; highway, urban and feeder roads daily have no knowledge about their contribution of driving patterns. Frequent gear-changing behaviors, unstable and inconsistent speed profiles due to intermittent traffic lights, intersections, roundabouts and vehicle population congestions are the most common driving patterns.

3. With the exception of vehicles of technological class Euro 3, emissions from vehicles of technological classes especially the Euro 1 technology class (the most abundant), were higher than the US EPA standards. Emissions from vehicles tend to have a reduction in carbon monoxide and an increment in carbon dioxide due to technological advancement.

4. Vehicles with lower the engine capacities produce higher concentration of emissions than those with higher engine capacities. Vehicles with older manufacturing age produce higher amount of emissions levels than newer vehicles.

5.2 RECOMMENDATIONS

In an attempt to improvements to local air quality and for that matter avert problems such as in premature deaths and morbidity due to air pollution, reduce fuel consumption and greenhouse gas (CO_2) emissions, certain measures ought to be put in place. These include:

1. Public education campaign on the effect of driving pattern, and maintenance habits should be intensified. This will enable vehicle drivers and owners to be abreast with issues concerning driving pattern and emission levels and hence contribute their quota towards reduction of vehicle emission. Also the use efficient fuels should be encouraged

2. Laws on imported vehicle specification standards should be enforced.

3. Relevant institutions including the DVLA, EPA, Ghana Standards Board and Motor Traffic Transport Union, should expedite action on the development of emissions standards for the country.

4. The use of other transport alternatives such as cycling should be encouraged and electric trains should be explored.

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APPENDICES

Appendix A

QUESTIONAIRES TO CAPTURE DATA ON DRIVING PATTERNS FOR LIGHT-DUTY VEHICLES IN KUMASI METROPOLIS

1. Type of vehicle?..
2. How old is your vehicle?...
3. What is the engine capacity of the vehicle?...
4. What is the odometer reading of the vehicle?...
5. What is the average speed per vehicle trip?...............................
6. How often is the car used? Tick appropriately. a) Daily ☐

b) Weekly ☐ If others specify ....

7. Which is your vehicle road type? Please tick appropriately

a) Highway ☐ b) Urban ☐ c) Feeder ☐

8. How much litres of petrol does your car consume in a daily?...............................
9. What is the sitting capacity of the car?..
10. Do you exceed the sitting capacity? ....
11. How often is the vehicle serviced?...
12. Do you put of the engine when you are stuck in the traffic?
13. Do you have any knowledge on cold and hot starts?
14. Do you have any knowledge on contribution of driving patterns to increased vehicular emissions? a) Yes ☐ b) No ☐

If yes explain ....

15. For how long do you allow the started engine to stabilize before moving in the morning?..

16. Is there any means by which you can improve your driving pattern?...

Appendix B

Data on driving patterns

Car Fleet Data

Table 1: Frequency of Vehicle Usage

	Frequency	Percent	Valid Percent	Cumulative Percent
daily	30	100.0	100.0	100.0

Table 1 shows us that 90% of vehicles ply urban roads, 6.7%; highways and just about 3.3% ply the feeder roads.

Table 2: Vehicle road type

	Frequency	Percent	Valid Percent	Cumulative Percent
highway	2	6.7	6.7	6.7
urban	27	90.0	90.0	96.7
feeder	1	3.3	3.3	100.0
Total	30	100.0	100.0	

Table 3: Number of litres consumed by car

	Frequency	Percent	Valid Percent	Cumulative Percent
0-5	1	3.3	3.3	3.3
6-10	16	53.3	53.3	56.7
11-15	9	30.0	30.0	86.7
16-20	4	13.3	13.3	100.0
Total	30	100.0	100.0	

Table 3 gives us the daily gasoline consumption of respondents. It has 3.3% for 0-5 litres, 53% 6-10 litres, 30% for 11-15 litres and 13.3% for 16-20 litres.

Table 4: Sitting capacity of car

	Frequency	Percent	Valid Percent	Cumulative Percent
0-5	30	100.0	100.0	100.0

Table 4 tells us the discipline nature of vehicle owners. The sitting capacities of vehicles where not exceeded.

Table 5: Do you exceed the sitting capacity?

	Frequency	Percent	Valid Percent	Cumulative Percent
no	24	80.0	80.0	80.0
yes	6	20.0	20.0	100.0
Total	30	100.0	100.0	

Table6: How often is your vehicle serviced?

	Frequency	Percent	Valid Percent	Cumulative Percent
monthly	18	60.0	60.0	60.0
2 months	9	30.0	30.0	90.0
3 months	2	6.7	6.7	96.7
4 months	1	3.3	3.3	100.0
Total	30	100.0	100.0	

From Table 6: Servicing of vehicles differs. 60% of respondents service their vehicles monthly, 30%; every 2 months, 6.7%; every 3 months and 3.3%; every 4 months

Table 7: Do your engine off when stuck in traffic

	Frequency	Percent	Valid Percent	Cumulative Percent
yes	6	20.0	20.0	20.0
no	24	80.0	80.0	100.0
Total	30	100.0	100.0	

Table 8: Do you have knowledge on cold and hot starts?

	Frequency	Percent	Valid Percent	Cumulative Percent
yes	3	10.0	10.0	10.0
no	27	90.0	90.0	100.0
Total	30	100.0	100.0	

Table 8 tells that 90% of respondents have no knowledge on either hot or cold starts emissions

Table 9: Do you have knowledge on contribution of driving patterns to increased vehicular emissions

	Frequency	Percent	Valid Percent	Cumulative Percent
yes	3	10.0	10.0	10.0
no	27	90.0	90.0	100.0
Total	30	100.0	100.0	

Table 10 How long does your engine stabilize before moving in the morning

	Frequency	Percent	Valid Percent	Cumulative Percent
1	5	16.7	16.7	16.7
2	4	13.3	13.3	30.0
3	9	30.0	30.0	60.0
4	2	6.7	6.7	66.7
5	9	30.0	30.0	96.7
6	1	3.3	3.3	100.0
Total	30	100.0	100.0	

From Table 10, there is a variation on the timing of started engine before proceeding on motion. 16% leave their cars to warm for a minute, 13.3% for 2minutes,30% for 3 minuts,6.7%for 4 minutes 30%for 5 minutes and 3.3% leave their vehicles to steam for just 6 minutes before proceeding on motion.

Appendix C

Table 11: Mileage of vehicle technology class

	Conventional	*Euro 1*	*Euro 2*	*Euro 3*
	251468	174209	23613	9372
	406982	129095	95620	46807
	254961	335086	91609	24833
	152952	199243	83025	153550
	305357	281306	114097	59892
	278816	292544	63601	106023
	129121	244452	1221413	46227
	386547	180051	214960	
	215801	248944	147258	
	198850	64518	168573	
	9180	191096	64233	
	249091	206548	116693	
	135084	142854	90103	
	59620	164574	247424	
	131990	102185	103500	
	187690	216091	133995	
	23358	205775	122468	
	362786	189807	172601	
	196275	180707	103808	
	187311	218515	59485	
		397891	147459	
		173073	108676	
		278823	137760	
		243595	115286	
		97215	96826	
		130711	187298	
		216860	263569	
		202208	136590	
		210931	134257	
		163184	204455	
		176490	179932	
		120169	179298	
		171548	23613	
		171870		
		177576		
		406883		
		248028		
		213879		
		248719		
		269325		
		169876		
		397399		
		50147		
		161910		
		175463		
		228423		

		289301		
		210931		
		175463		
	206162	207050.8	162215.1	63814.86
Average				
Total	4329402	10352542	5515313	510518.9

Table 12: Carbon monoxide Emission data from opus 40 gas analyzer at increased RPM

	Conventional	*Euro 1*	*Euro 2*	*Euro 3*
	0.42	0.91	0.48	0.66
	1.06	1.36	0.38	0.08
	0.64	0.38	0.43	0.11
	4.17	0.1	3.09	0.1
	2.5	0.11	0.1	1.75
	0.11	0.01	0.37	0.12
	8.78	0.04	0.21	0
	0.12	0.12	0.02	
	5.45	0.11	0.03	
	5.32	3.82	0.05	
	0.42	7.39	4.97	
	3.46	4.16	0.11	
	0.13	1.33	1.41	
	4.16	7.71	0.28	
	0.31	1.29	0.95	
	0.1	3.33	0.01	
	4.41	1.96	6	
	0.14	4.94	0.87	
	2.59	8.32	0.01	
	4.99	0.19	2.06	
		0.87	0.28	
		0.34	0.35	
		1.51	0.61	
		0.29	0.23	
		1.46	1.05	
		8.12	0.43	
		4.28	0.19	
		0.74	2.08	
		0.15	0	
		4.47	0.81	
		0.93	0.8	
		1.99	1.01	
		0.44	0.4	
		0.04		
		0.71		
		0.11		
		0.78		

		2.96		
		1.87		
		0.34		
		0.03		
		0.1		
		3.95		
		10.19		
		0.66		
		0		
		11.5		
		0.03		
		0.02		
Mean	2.464	2.172653	0.911212	0.402857
Total	51.744	108.6327	30.98121	3.222857

Table 13: Carbon dioxide emission data from opus 40 analyzer at increased RPM

Conventional	*Euro 1*	*Euro 2*	*Euro 3*
9.1	8.5	11.7	14.2
12.1	5.3	13.2	11.12
8.2	9.1	12.1	13
9.3	7.9	11.9	10.21
9	8.1	10.6	13.5
8.8	10.9	13.7	14.1
11.4	13.1	13.2	13.6
8.1	11.4	12.9	
4.5	8.3	12.3	
13.4	13.9	12.5	
9.8	9.6	12.4	
10.7	12.2	12.9	
4.23	12.1	13.8	
4.9	7.2	13.5	
12.8	8.4	9.9	
9.3	7.1	7	
9.3	8.9	12.7	
13.6	8	12.2	
12.2	9.1	11.8	
14.2	13.5	12.1	
	12.2	8.3	
	13.4	10.3	
	12.6	12.9	
	13.5	13.1	
	11.5	13	
	9.5	11.4	
	11.7	11.7	
	11.4	9.4	
	13.2	12.2	
	8.3	12.8	

		12.9	7	
		13.1	4.9	
		10.2	7.1	
		9.7		
		11.2		
		11.7		
		13.7		
		5		
		5.9		
		14.1		
		13.1		
		7.5		
		11.4		
		4.3		
		11.8		
		8.6		
		13.1		
		9.5		
		14.2		
Average	10.2300	10.63012	11.7511	14.65023
Total	204.6765	521.3265	387.9091	102.5486

Table 14: Carbon monoxide Emission data from opus 40 gas analyzer at idle mode

Conventional	Euro 1	Euro 2	Euro 3
1.88	1.26	3.06	0.03
5.11	2.31	0.89	0.04
8.29	3.42	1.17	1.81
1.84	0.08	0.51	0
0.16	10.37	2.66	0.84
6.55	6.46	0.25	0.96
0.41	3.67	0.22	0.7
0.46	0.62	2.18	
1.79	0.72	0.11	
5.32	1.07	8.29	
3.51	1.36	0	
1.18	2.72	1.21	
6.55	0.76	3	
4.02	1.47	0.23	
1.46	10.45	0.63	
0.46	0.03	1.26	
4.44	0.78	1.71	
10.15	1.69	7.46	
5.95	0.03	0.45	
7.35	4.72	1.09	
	0.68	0.92	
	3.27	3.72	

		0.83	0.14	
		3.41	0.03	
		0.57	1.83	
		0.3	1.27	
		5.85		
		1.54		
		1.13		
		1.12		
		6.77		
		2.35		
		0.03		
		5.63		
		4.02		
		6.07		
		0.61		
		0.63		
		1.01		
		1.13		
		7.37		
		0.97		
		2.45		
		0.34		
		4.21		
		6.21		
		0.57		
		2.05		
		0.03		
Average	3.844	2.553878	1.703462	0.625714
Total	80.724	127.6939	45.99346	5.005714

Table 15: Carbon dioxide Emission data from opus 40 gas analyzer at idle mode

Conventional	Euro 1	Euro 2	Euro 3
10	12.2	11.5	14.1
9.1	10.9	13.3	14.2
7.8	6.1	12.5	12.8
11.3	12.1	11.3	13
7.5	12.8	13.2	4.31
5.6	7.1	12.3	9.46
13.8	4.3	12.6	10.32
10	11.6	8.2	
9	8.3	9.9	
9.2	8.4	11	
10.3	6.9	5.2	
6.9	10.9	11.9	
8.1	12.4	10.5	
8.8	12.4	13.5	
12.3	12.1	13.1	
9.9	12.3	12.9	
6	9.1	10.3	
8.1	10.9	7.3	

	12.9	14.1	11.9	
	13.7	12.6	12.7	
		9	9.1	
		8.3	10.7	
		13.4	13.7	
		12.3	13.2	
		9.1	12.4	
		11.3	11.8	
		12	12.34	
		11.6	9.3	
		12.7	13.1	
		9.8	6.1	
		12.8	8.3	
		9.3	9.5	
		13.9	12.3	
		12.3		
		3.1		
		4.8		
		10.6		
		10.6		
		10.7		
		9.3		
		10.5		
		6.1		
		10.2		
		12.5		
		13.1		
		6.2		
		7.4		
		8.3		
		0.85		
Average	9.515	9.990816	11.11939	11.17
Total	199.815	499.5408	378.0594	89.36

Table 16: Air to fuel ratio (Lambda) at high RPM

	Conventional	*Euro 1*	*Euro 2*	*Euro 3*
	0.94	1.034	0.985	1.099
	1.671	1.348	1.444	1.038
	1.018	0.831	1.111	1.041
	1.022	0.889	0.852	1.003
	0	1.145	1.042	1.033
	0.968	0	1.124	0
	1.053	1.282	0	1.008
	1.517	0	1.064	
	0.923	1.498	1.179	
	1.152	1.103	1.208	
	1.05	0.799	1.661	
	0.994	0.978	1.132	
	1.189	0.98	1.158	
	0	1.058	1.167	

	1.203	1.108	0.992	
	1.122	1.219	1.267	
	1.005	0.959	1.181	
	0.922	0.755	1.419	
	0.9	1.058	1.122	
	1.263	0.744	1.225	
		0.829	0	
		0.994	0	
		0.909	1.269	
		1.296	1.037	
		0	1.052	
		1.516	1.329	
		1.614	1.181	
		1.108	0.987	
		1.304	0.914	
		0.701	1.196	
		0	1.004	
		1.079	0.939	
		1.05	1.037	
		1.05		
		0		
		0		
		1.175		
		1.479		
		0		
		1.274		
		1.423		
		1.005		
		0.902		
		1.179		
		1.071		
		0.998		
		0.807		
		1.539		
		1.082		
		1.346		
		1.225		
Mean	0.9956	0.955745	1.038727	0.888857

Table 17: Air to fuel ratio (Lambda) at idle mode

Conventional	*Euro 1*	*Euro 2*	*Euro 3*
0.916	1.242	1.031	1.039
1.209	1.148	0.997	1.026
1.158	0.74	1.069	1
1.031	1.095	0.954	1.053
0	1.063	1.387	1.27
0.914	1.111	1.123	1.129
0.99	1.449	1.241	1.043
1.414	1.238	0.902	

	1.009	1.56	1.177	
	1.171	1.327	1.052	
	1.214	0.935	1.097	
	0.91	1.165	1.067	
	0.824	1.064	0.945	
	1.418	1.088	1.113	
	1.167	1.129	0.825	
	0.923	1.091	1.369	
	1.267	0.946	1.4	
	0.884	0.858	1.506	
	0.701	1.046	1.123	
	1.058	0.962	1.162	
		0.838	1.067	
		1.465	1.189	
		1.003	0.95	
		1.035	1.026	
		0.998	1.017	
		1.212	1.339	
		1.151	1.125	
		0.939	0.98	
		1.053	1.034	
		1.049	1	
		1.095	1.12	
		0.991	0.984	
		1.065	1.049	
		1.065		
		0		
		0.868		
		1.152		
		1.237		
		1.037		
		1.309		
		1.32		
		0.895		
		0.966		
		1.108		
		1.066		
		1.106		
		0.741		
		1.259		
		1.014		
Mean	1.0089	1.067224	1.103636	1.08

Table 18: Hydrocarbon content at high RPM

Conventional	Euro 1	Euro 2	Euro 3
233	1991	355	66
331	580	145	10
144	68	126	172
215	334	45	1
1077	379	84	193

	439	801	172	92
	96	155	156	101
	2270	188	507	
	313	227	94	
	342	372	32	
	152	133	308	
	775	649	515	
	683	37	200	
	483	155	46	
	345	397	62	
	682	150	104	
	450	4	93	
	129	152	503	
	383	32	14	
	227	132	77	
		32	137	
		1899	612	
		136	37	
		102	223	
		54	258	
		999	27	
		290	2270	
		229	64	
		202	115	
		92	253	
		820	203	
		903	192	
		20	447	
		934		
		385		
		169		
		147		
		194		
		243		
		540		
		453		
		454		
		264		
		254		
		178		
		352		
		95		
		492		
		510		
Mean	488.45	375.0612	256.8485	90.71429

Table 19: Hydrocarbon content at idle mode

Conventional	Euro 1	Euro 2	Euro 3
1222	1735	465	43
131	360	140	10
108	312	219	182
365	341	69	1
557	306	161	152
807	964	139	75
570	118	126	82
3130	185	714	
1697	1003	337	
192	2850	6	
236	89	3550	
1364	419	664	
479	364	2220	
214	195	98	
1662	1057	469	
32	930	116	
156	6	394	
654	504	449	
548	20	39	
358	688	428	
	253	184	
	637	829	
	922	150	
	163	164	
	69	333	
	443	91	
	294	152	
	572	93	
	115	188	
	122	327	
	355	138	
	375	273	
	20	89	
	443		
	256		
	148		
	638		
	299		
	180		
	149		
	1008		
	410		
	285		
	195		
	4300		
	342		
	182		
	163		
	648		

Mean	724.1	539.4286	418.6061	77.85714

Table 20: Percentage oxygen at high RPM

Conventional	Euro 1	Euro 2	Euro 3
1.75	5.32	1.23	1.41
10.43	8.43	5.97	0.89
3.28	1.87	1.57	2.01
0.73	8.37	1.12	0.67
11.39	1.46	1.54	1.35
3.05	3.56	2.22	9.58
1.41	1.49	11.2	0.86
10.15	3.54	5	
1.66	0.86	3.11	
2.79	1.71	2.98	
2.86	7.04	9.86	
3.87	5.61	2.53	
5.48	2.91	3.31	
7.73	6.96	3.79	
2.69	3.99	2.13	
6.06	21.29	4.59	
5.79	20.33	3.49	
3.59	1.63	5.55	
6.23	1.03	2.69	
5.13	2.09	4.17	
	19.07	12.2	
	2.19	14.16	
	5.88	5.43	
	2.44	1.39	
	8.88	2.69	
	7.99	4.01	
	10.06	3.91	
	5.16	3.27	
	0.67	5.72	
	0.96	6.97	
	1.77	3.11	
	2.29	4.86	
	1.2	1.78	
	1.68		
	2		
	4.18		
	2.34		
	1.87		
	3.07		
	2.12		
	1.44		
	3.13		
	8.09		
	9		
	5.33		
	10.05		
	2.83		
	2.33		

		1.44		
Mean	4.8035	4.876531	4.471212	2.395714

Table 21: Percentage oxygen at idle mode

Conventional	*Euro 1*	*Euro 2*	*Euro 3*
2.45	2.09	1.7	1.31
4.93	4.88	0.97	0.59
4.21	1.14	1.13	0.84
0.74	5.78	2.17	4.31
10.26	0.96	6.35	1.71
3.73	6.86	2.54	1.71
2.57	1.36	4.56	0.53
9.29	2.59	3.46	
4.44	2.55	3.26	
4.34	5.13	1.45	
5.07	6.06	2.74	
2.65	6.02	1.55	
2.09	2.79	2.68	
5.06	4.52	3.52	
6.06	4.6	5.13	
	5.58	5.79	
	16.83	6.53	
	2.17	6.99	
	1.34	2.51	
	3.53	3.19	
	2.5	1.78	
	3.61	4.17	
	2.39	1.05	
	1.04	1.21	
	3.13	2.46	
	4.15	4.11	
	3.08	5	
	2.13	4.27	
	0.89	3.36	
	7.1	1.22	
	1.01	2.23	
	1.02	1.98	
	0.98	1.77	
	0.72		
	1.86		
	2.24		
	2.38		
	2.31		
	2.03		
	3.69		
	4.63		
	7.1		
	8.38		
	3.16		
	9.67		

		4.82		
		1.73		
		2.48		
		1.84		
Mean	4.526	3.65	3.116061	1.571429

Appendix D

INPUT DATA FOR COPERT IV ANALYSIS

Table 22:Vehicle population

Sector	*Subsector*	*Technology*	
Light Duty Vehicles	Gasoline <3,5t	Conventional	20
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	49
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	33
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	7

Table 23: Mileage kilometer per year

Sector	*Subsector*	*Technology*	
Light Duty Vehicles	Gasoline <3,5t	Conventional	37800
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	36540
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	41580
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	45360

Table 24: Mean fleet mileage

Sector	*Subsector*	*Technology*	
Light Duty Vehicles	Gasoline <3,5t	Conventional	206162
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	207050.8
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	162215.1
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	63814.86

RESULTS

Table 25: Total CO emissions

Sector	*Subsector*	*Technology*	
Light Duty Vehicles	Gasoline <3,5t	Conventional	8.377246
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	5.113418
Light Duty	Gasoline	LD Euro 2 - 96/69/EEC	2.065925

Vehicles	<3,5t		
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	0.430625

Table 26: Total CO_2 emissions

Sector	*Subsector*	*Technology*	
Light Duty Vehicles	Gasoline <3,5t	Conventional	182.8398
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	503.9327
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	358.1695
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	77.75851

Total VOC emissions

Sector	Subsector	Technology	2008
Light Duty Vehicles	Gasoline <3,5t	Conventional	0.871054
Light Duty Vehicles	Gasoline <3,5t	LD Euro 1 - 93/59/EEC	0.322964
Light Duty Vehicles	Gasoline <3,5t	LD Euro 2 - 96/69/EEC	0.063232
Light Duty Vehicles	Gasoline <3,5t	LD Euro 3 - 98/69/EC Stage2000	0.00851

Table 27 **Copert IV and real-life emission levels Compared**

	Parameter	Real-Life levels	Copert IV Levels	Difference (x)
Conventional	CO	2.4640	0.4200	2.0400
	CO_2	10.230	9.1400	1.0900
	HC	0.0488	0.0436	0.0052
Euro I	CO	2.1730	0.1050	2.0600
	CO_2	10.630	10.280	0.3500
	HC	0.0488	0.0066	0.0309
Euro II	CO	0.9110	0.0620	0.8500
	CO_2	11.750	10.850	0.9000
	HC	0.0256	0.0019	0.2370
Euro III	CO	0.4030	0.0610	0.3400
	CO_2	14.650	11.100	3.3500
	HC	0.009	0.0012	0.0005