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Effect of Scheduled Inspection and Preventive Maintenance on Exhaust Emissions and Fuel Economy

BY
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FEBRUARY, 2011

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EFFECT OF SCHEDULED INSPECTION AND PREVENTIVE MAINTENANCE ON EXHAUST EMISSIONS AND FUEL ECONOMY

By

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A thesis submitted to the Department of Materials Engineering of the College of Engineering, in partial fulfillment of the requirement for the degree of Master of Science, in Environmental Resources Management.

February, 2011

DECLARATION

I, Francis Akaboti Atibila, hereby declare that the submission is my own work towards the award of MSc. Environmental Resources Management and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The level of emissions and fuel economy at the maintenance stage of an automobile was studied on the DAF TB 2175 PE and YAXING JS 6120 GIH buses at the workshop of Metro Mass Transport Limited in Kumasi – Ashanti Region. The opacities of exhaust gases from the buses were measured with the OPUS 50 gas analyzer before and after servicing the buses. The buses were made to travel a total distance of 5000 km after which emission levels and fuel economy (distance travelled when 1 litre of fuel is consumed) were measured. Results indicated that emission levels reduced from 7.94% to 2.32% (a drop of 70.78%) for the DAF TB 2175 PE buses and from 5.27% to 3.20% (a drop of 58%) for the YAXING JS 6120 GIH buses over the study distance. These indicate that maintenance has great tendency to reduce emission levels, barring other factors such as driving pattern, fuel quality and traffic situation. Also the study revealed that after servicing the DAF TB 2175 PE buses could cover a distance of 2.775 km per litre of fuel instead of a shorter distance of 2.576 km with the same amount of fuel after 5,000 km (a drop of 7.2%). A similar observation was made for the YAXING JS 6120 GIH buses which covered 2.76 km after servicing and 2.55 km after 5,000 km, using one litre of fuel in each case. Additional 140 and 149 litres of diesel are needed to travel a distance of 5000 km by the DAF and YAXING buses respectively if preventive maintenance is ignored. These are at respective costs of GH¢241.36 and GH¢256.88 for the DAF TB 2175 PE and YAXING JS 6120 GIH buses, given the current price of diesel as GH¢ 1.724 per litre. Although other factors such as fuel quality could influence engine performance, the results suggest statistically significant improvement in exhaust emission reduction and fuel economy, calling for vehicle operators including governmental and non-governmental organizations to be well resourced and encouraged to undertake scheduled maintenance to save resources and reduce pollution.

ACKNOWLEDGEMENTS

The faith, wisdom, strength and determination that brought me to the successful completion of this MSc. Environmental Resources Management programme could only be by divine inspiration and grace, I am very grateful to the Almighty God. To God be all the Glory.

My special thanks go to my committed supervisors, Dr. A. A. Adjaottor and Mr. G. Owusu-Boateng, whose encouragement, advice and assistance aided the research, from conception of the topic to completion of the research report. Their schedules were visibly airtight, and in the scheme of managing their priorities, I was never second. I owe the successful completion of this thesis to their valuable time and experience. I indeed appreciate everything and wish them God's blessings.

My sincere thanks also go to all the lecturers who took us through the taught courses. Special mention goes to Professor F. W.Y. Momade, Professor K. Sraku-Lartey, Professor Kwadwo Yeboah-Gyan, Dr, Osei A. Kuffour, Dr. I.K. Dontwi, Dr. Bukari Ali and Dr. Simon K.Y. Gawu for their high sense of commitment, professional guidance and inspiration that enabled me to overcome the numerous challenges that I encountered throughout the entire programme.

The trust and confidence of my referees; Dr. Ruby Avotri, Assistant Director of Education, Ghana Education Service, Myelin Suarez Alvarez of the Consulate of the Republic of Cuba, Michael, Sandow Ali, District Director, Environmental Protection Agency (EPA), Tarkwa, is very much appreciated.

My gratitude also go to the regional management and staff of EPA, and Metro Mass Transit limited (MMT) both of Kumasi, especially Philomena Boakye Appiah (Mrs.), Ag Regional

Director (EPA) and Mr. Afful, Regional workshop manager of MMT for their wonderful support and cooperation during the project data collection.

The many colleagues and friends, whose counsel and technical expertise influenced my understanding of this study programme, are all acknowledged. Caroline Kumasi, Maxwell, Kyei Kwadwo and the rest of them, I will forever remember them.

My very special thanks go to my wife, Evelyn and my family for their understanding, and endurance during these long years of sacrifice. Your love, support and understanding were my source of inspiration which enabled me to carry on. I am grateful to God for your lives.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Medieval cities had no problems with air pollution. The environment naturally recycles itself if pollution levels do not exceed its assimilative capacity. However, population growth, urbanization and the advent of the Industrial Revolution, which replaced manpower with power-driven machinery as a mode of production, has resulted in a steady increase in emissions levels well beyond the environmental assimilative capacity in modern urban centers especially industrialized cities.

Vehicular emissions are gases and particles that are released into the air by motor vehicles. According to the United States Environmental Protection Agency (USEPA), driving a car is the single most polluting activity that most of us carry out (Anon, 1994). Emissions from an individual car are generally low, compared to the smokestack, which many associate with air pollution, but as motor vehicles multiply in numbers and emissions from millions of vehicles on the road add up; the automobile becomes the single greatest air polluter.

The power to move a car comes from burning fuel in an internal combustion engine. Pollution from cars comes from by-products of this combustion process, and from evaporation of the fuel itself. Motor vehicle exhaust emissions include nitrogen oxides (NOx), carbon oxides (COx), sulfur oxides (SO*x*), particulates and hydrocarbons. Evaporative emissions include hydrocarbons (HCs) and volatile organic compounds (VOCs).

These pollutants pose serious health and environmental hazards, including photochemical smog, reduced crop yields (limits solar energy for photosynthesis), increased incidence of chest infections and heart disorder. In addition, benzene VOCs are carcinogenic. Diesel engines discharge certain fine particulates, which can penetrate deep into the lung, increasing premature deaths among people already suffering from heart and lung diseases (Fairweather *et al*, 1999). Carbon dioxide (CO_2) is a greenhouse gas which contributes in causing regional and global climate change. A typical global climate change is the significant shrinking of the total mass of the Antarctic Ice Sheet, as well as the discovery of a "hole" in the stratospheric ozone shield over Antarctica in 1985 (Masters, 2001). NOx and SOx are major contributors to acid deposition (commonly called acid rain). Acid deposition kills aquatic organisms and corrodes metals and building materials (Masters, 2001).

Many urban areas in the world undergo episodes of air pollution (Baird, 1999). It is a general historical characteristic that once an undeveloped country starts industrial development; its air quality deteriorates significantly. The situation continues to deteriorate until a significant degree of affluence is attained, at which point emissions controls are enacted and enforced. Levels of pollutants in the ambient air of urban Singapore exceeded the World Health Organization (WHO) and the primary air standards of the United States Environmental Protection Agency (USEPA) in 1990.

To improve the situation, the Singapore Ministry of Environment, together with the Land Transport Authority, implemented a multi-pronged programme (mandatory periodic inspection and maintenance, the use of cleaner fuels and education), to control smoke emissions from motor vehicles. Survey results from the ministry have shown that the proportion of smoky Singapore-registered vehicles have decreased from about 8% in 1990 to about 2% by 2001 (Hong, 2001).

With the motor vehicle and for that matter the internal combustion engine at the center of these pollution incidents, amendments were made to National Air Quality Standards by many countries including Britain and the United States, aimed at minimizing motor vehicle emissions (USEPA, 1992).

For example the 1970 and 1990 amendments to the Clean Air Act introduced newemission control policies, which brought about fundamental improvements in engine design and source control systems in the USA. Charcoal canisters became part of engine design to collect hydrocarbon vapors as well as the introduction of exhaust gas recirculation valves to reduce nitrogenoxides (Fairweather*et al*., 1999; Enger and Smith, 1992).

The next major milestone in vehicle emission control technology came in 1980-81. In response to tighter standards, manufacturers equipped new cars with even more sophisticated emission control systems. These systems generally include a "three-way" catalyst, an on-board computer and an oxygen sensor. The catalyst converts carbon monoxide and hydrocarbons to carbon dioxide and water, and also helps reduce nitrogen oxides to elemental nitrogen and oxygen (Anon, 1994).

In Ghana, national ambient air quality monitoring results indicate that the air quality of Ghana's urban centers is generally good, as most monitoring stations do not capture any disturbing levels of gaseous emissions (Anon, 2001). However, the environmental challenges such as deforestation, desertification and land degradation continue to deplete the greenhouse gas sinks. Other factors such as industrialization, population and income growth, which result in increases in automobile ownership and use, are all indicators pointing to national air quality crisis if emission control measures are not put in place now. According to Agyemang-Bonsu *et al* (2007), Ghana Environmental Protection Agency has completed work on

Vehicular Emission Inventory, which is key for the promulgation of national Vehicular Emission Standards.

1.2. STATEMENT OF PROBLEM

The natural environment is a homeostatic system (i.e. a system which heals itself through cyclical processes). However, materials or substances in the atmosphere are considered innocuous at naturally occurring levels, but when human's activities add to these levels, overloading of natural cycles or disruption of finely tuned balances in the environment can occur (Cunningham and Saigo, 1990, 1992). Vehicular emission is one of such manmade disruptive factors which partly contribute to many public health problems, acid deposition, global climate change, ozone layer depletion and in some cases, generation of ground ozone. Also in the bid to economize fuel and hence financial resources, many vehicle operators either refuse to undertake periodic maintenance of their vehicles or delay the exercise.

There is no single solution to this problem but it is believed that an effective method that ensures fuel economy and vehicular emission reduction includes scheduled inspection and preventive maintenance of the vehicles. It is however not certain as to what extent these measures improve environmental quality.

1.3 OBJECTIVES

The objectives of the study are:

1. to determine the effect of scheduled inspection and preventive maintenance on automobile exhaust emission
2. to determine the effect of scheduled inspection and preventive maintenance on diesel economy.

1.4 JUSTIFICATION

Vehicle operators choose to undertake the transportation venture in order to earn their living while contributing their quota towards national development and hence serving society. In order to remain in business all strategies are employed to minimize cost. The natural tendency associated with this is that, some of these strategies, including those linked to fuel economization efforts, are rather likely to result to loss unknowingly. A typical example is the perceived conservation of financial resources through delay or/and refusal to undertake periodic vehicle maintenance. Again, the likelihood that such practices contribute to environmental pollution particularly airpollution, a disturbing phenomenon cannot be over emphasized. There is therefore the need to estimate empirically the extent to which practices such as scheduled inspection and preventive maintenance which are usually delayed or/and avoided affect fuel economy and vehicular emission. This will serve as motivation and encouragement to vehicle operators to keep inspection and maintenance schedules which will in turn bring about greater economic benefit while striving for pollution-free environment.

1.5 HYPOTHESES:

This project seeks to investigate the following hypotheses:

i. Scheduled inspection and preventive maintenance reduce exhaust emissions to levels close to factory levels.

ii. Scheduled inspection and preventive maintenance improve engine efficiency, which in turn result in fuel economy.

1.6. SCOPE

Density of smoke particles (opacity) was the main emission parameter considered since it is the only technology available. The study is also limited to tailpipe emissions. All measurements were carried out under stationary conditions.

1.7. ASSUMPTIONS

For the purpose of studying the relationship between preventive maintenance of vehicles and the reduction in exhaust emissions and fuel consumption, the aggregation of other factors such as: air-fuel ratio, ignition timing, compression ratio, combustion chamber geometry, engine speed, type of fuel, mode of vehicle operation and traffic conditions, which also influence the parameters studied, shall be assumed constant, all things being equal. The reason for this assumption is that most of these aggregations of other factors are also greatly influenced by preventive maintenance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.2. FUNDAMENTAL CONCEPTS

The following are definitions of terms frequently used in the subject area, and which will be encountered frequently in the course of the thesis.

- **Aerosols:** Aerosol is a dispersion of solid or liquid particles of microscopic size in gaseous media, such as smoke, fog or mist (Kamala, A., Rao, D.L.K., 1988).
- **Dusts:** Dust is referred to solid particles larger than colloidal particles (Dp=>1.0μm) and capable of temporary suspension in air or other gases. Dusts do not tend to flocculate except under electrostatic forces; they do not diffuse but settle under the influence of gravity (Seinfeld, 1986).
- **Fume:** The solid particles (Dp 0.1 to 1μm), generated by condensation from the vapor state, generally after volatilization from melted substances. Fumes are often accompanied by a chemical reaction such as oxidation (Seinfeld, 1986).
- **Mist:** Mist is a term applied to dispersions of liquid particles (size 5-100μm) in the atmosphere (Kamala, A., Rao, D.L.K., 1988).
- **Fog:** This is referred to visible aerosols, in which the dispersed phase is liquid; usually a dispersion of water or ice (Seinfeld 1986). Or liquid dispersed aerosols in air by condensation (Kamala, A., Rao, D.L.K., 1988).
- **Smoke:** Small gas-borne particles (size: 0.01 to 1μm) resulting from incomplete combustion, consisting predominantly of carbon and other combustible material, and present in sufficient quantity to be observable independently of the presence of other solids (Seinfeld, 1986).
- **Soot:** This is formed by the agglomerations of particles of carbon impregnated with
- 'tar'. It is formed during incomplete combustion of carbonaceous material (Seinfeld, 1986)

- **Smog:** This is formed from the oxidation of volatile organic compounds (VOCs) found in solvents as well as the product of reactions between chemicals produced by burning fuel, gasoline, or other chemicals found in products such as paints and hair sprays. The oxidation readily occurs in the presence of sunlight (Seinfeld, 1986). It is also defined as air pollution that is localized in urban areas, where it reduces visibility.(Raven *et al* , 1993).
- **Photochemical Smog:** A brownish orange haze formed by chemical reactions between nitrogen oxides, volatile hydrocarbons, and oxygen, involving sunlight in the atmosphere (Raven *et al*, 1993).
- **Haze:** Haze is referred to a suspension in the atmosphere of minute dust or salt particles that are not individually seen but that nevertheless reduce visibility (Baird, 1999).
- **Ozone:** This is a form of molecular oxygen that consists of three oxygen atoms linked together. Ozone in the upper atmosphere, "ozone layer" occurs naturally and protects life on earth by filtering out ultraviolet radiation from the sun.
- **Ground-level ozone:** This is formed by the interaction of hydrocarbons (unburned or evaporated gasoline) and nitrogen oxides (NO_x) in the presence of sunlight.
- **Particle:** A particle (molecular dimensions > 0.001μm), consist of two or more unit structures held together by inter-particle adhesive forces such that it behaves as a single unit in suspension or upon deposit.
- **Particulate Matter:** This is defined as any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules (about 0.0002 µm in diameter), but smaller than about 500 µm. Examples include road dust, construction and other pollutants such as NOx and SOx, formed from incomplete combustion of fuel (Master, 2001; Air Resources Board, 2001,2005).

- **Emission Inventory:** An emission inventory is an accounting of all air pollutant emissions into the atmosphere. It forms the basis for air quality planning of any given area. (Hong, 2001).
- **Opacity:** Opacity is a measure of the smoke density on a scale from 0% to 100%. At 0% there are no smoke particles, at 100% the smoke is completely dense. (OPUS 50 Compact manual 44p).
- **K-value:** The k-value is calculated from the opacity value using a mathematical formula. The k-value is logarithmic and will increase more than the opacity value (OPUS 50 Compact manual 44p).

2.3.Sources of Auto Emissions

The power to move a car typically comes from burning fuel in an internal combustion engine. Pollution from cars comes as the by-products of this combustion process (exhaust) as well as the evaporation of the fuel (Makofske and Karlin, 1995). Whereas ships, locomotives, and aircraft are also included in the transportation sources category, it is highway vehicles that are by far the most important in terms of total emissions and location of the emissions relative to people (Masters, 2001). Gasoline and diesel fuels are mixtures of hydrocarbons, which are compounds that contain hydrogen and carbon atoms. In a perfect engine, oxygen in the air would convert all the hydrogen in the fuel to water and all the carbon in the fuel to carbon dioxide (CO_2). Nitrogen in the air would remain unaffected.

However, the combustion process is not perfect. As a result, automotive engines emit several types of pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (Makofske and Karlin, 1995). The total number of highway vehicles (excluding maritime transport, locomotives, and aircrafts) registered in 1986 in the United States as estimated by (Hill, 1999), was 186 million. These vehicles consumed a total of 1.3 billion gallons of fuels while emitting 58% of the nation's total CO, 38 percent of the lead, 34 percent of the nitrogen oxides (NO), 27 percent of the VOCs, and 16 percent of the particulates (USEIA, 1988, and USEPA, 1988).

Studies have revealed that, in São Paulo, one of the large cities in Brazil, private cars were responsible for approximately 75% of carbon monoxide (CO), 73% of hydrocarbons (HC), 23% of nitrogen oxides (NOx) and 10% of particulate matter (PM) emissions in 1997 (Claudio and Seroa da Motta, 1999). In the United Kingdom alone, estimates have been made that one-third of the population is at risk from traffic pollution, yet cars are predicted to increase in number from around 20 million in the early 1990s to 35 million by 2025 (The Open University 1993, 1996).

Pollution from such sources has a direct impact on the air that we breathe. Emissions from vehicles generate two of the worst air pollutants namely: ground-level ozone and carbon monoxide CO. Ground level ozone is formed when reactive organic gases (VOCs) and nitrogen oxides (NOx), reacts in the presence of heat and sunlight. Ground-level ozone irritates the lungs and eyes and can lead to permanent lung damage (De Nevers, 1995). Carbon monoxide also reduces the blood's ability to carry oxygen. When carbon monoxide comes into contact with hemoglobin contained in the blood in aveola, it disturbs the transportation of oxygen by the blood because carbon monoxide combines with hemoglobin more easily than oxygen. This affects the oxygen supply to the brain, resulting in impaired mental functions and visual perception. The effect can be deadly in high levels of CO.

2.2.1 Tailpipe emissions (Exhaust Emissions)

This is what most people think about vehicle’s air pollution; the products of burning fuel in vehicle's engine, emitted from the vehicle's exhaust system.The vast majority of gasoline is burned before combustion gases exit the engine inany properly operating vehicle, but a small fraction – typically 1 to 5 % – manages, for many reasons, to escape the combustion chamber unburned (Gasoline and Air quality, 2005). These VOC emissions consistprimarily of unburned hydrocarbons, but partially burned oxygen-containing compounds such asaldehydes 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 theengine and its controls, and the performance of the catalytic converter and driving pattern. If the vehicle has somesignificant malfunction that inhibits proper ignition or combustion, like a bad spark plug, VOCemissions can be many times higher than normal.

2.4.**The Internal Combustion Engine**

Seinfeld (1975) classifies the internal combustion engine intothree common types in wide use in the world. The most common is the four-stroke-cycle, spark-ignited internal combustion engine, commonly referred to as gasoline engine, used primarily for passenger cars and light-duty trucks.

The second most common is the four and two-stroke-cycle compression-ignition internal combustion engine, commonly referred to as a diesel engine. This is used for large trucks, buses, locomotives and ships. The third type of internal combustion engine is the aircraft gas-turbine engine, which is not the focus of this study.

2.3.1. The Gasoline Engine

The fuel-air mixture is prepared in the carburetor and then introduced into the combustion chamber. The mixture is characterized by the air-fuel ratio, the weight of air per weight of fuel. Ratios below 9 and above 20 are generally not combustible. Maximum power is obtained at a lower ratio rather than for minimum fuel consumption. Mixtures with low air-fuel ratios are referred to as rich, whereas those with high ratios are called lean. During acceleration when power is needed, a richer mixture is required than during cruising (Seinfeld, 1986). Modern engines use more of fuel injectors than carburetor. Mixture of air and fuel is controlled electronically allowing the right amount of air and fuel depending on the power demand.

2.3.3. **Diesel Engine**

In a diesel engine air and fuel are not mixed prior to being passed into the chamber. Air is drawn in through the intake valve, and while it is being compressed to a high temperature, fuel is injected into the chamber as a spray under pressure in precise quantities. As the piston nears the top position, the high temperature and pressure of compression cause ignition of the fuel without the aid of a spark. The timing of fuel injection into the combustion chamber during compression as the piston nears the top position is known as ignition timing. The power delivered is controlled by the amount of fuel injected in each cycle. The air-fuel mixture in a diesel engine is generally much leaner than that in a spark-ignition engine.

2.4 Types of Emissions

The following are the types of emissions from the internal combustion engine:

1. Crankcase Emissions
2. Evaporative Emissions
3. Exhaust Hydrocarbon Emission

4. Exhaust Particulate Emissions
5. Diurnal emissions
6. Running losses
7. Refueling losses

2.4.1 Crankcase Emissions

Crankcase emissions are caused by the escape of gases from the cylinder during the compression and power strokes. The gases escape between the sealing surfaces of the piston and cylinder wall into the crankcase. This leakage around the piston rings is commonly called *blow-by*. Emissions increase with increasing engine air flow and consist of a mixture of approximately 85 percent unburned fuel-air charge and 15 percent exhaust products. Hydrocarbon concentration in blow-by gases range from 6000 to 15,000 ppm. This type of emissions increases with increased wear of the seals between the piston and the cylinder wall (Seinfeld, 1986).

2.4.2 Evaporative Emissions

Evaporative emissions are from the fuel tank and the carburetor. Fuel tank losses result from the evaporation of fuel and the displacement of vapors when fuel is added to the tank. The amount of evaporation depends on the composition of the fuel and its temperature. Evaporation of fuel from the carburetor occurs primarily during the period just after the engine is turned off. During operation the carburetor and the fuel in the carburetor remain at about the temperature of the air under the hood. But the air flow ceases when the engine is stopped, and the carburetor bowl absorbs heat from the hot engine, causing fuel temperatures to rise above ambient. The vaporized gasoline leaves through the carburetor vents to the atmosphere; a condition called a *hot soak.* Fuel evaporation from both the fuel tank and the carburetor accounts for approximately 20 percent of hydrocarbon emissions from uncontrolled automobiles.

2.4.3. Exhaust Hydrocarbon Emissions

Ideal complete oxidation of hydrocarbon fuel yields only CO_2 and H_2O as combustion products. Unfortunately, under condition of combustion in an internal combustion engine, other products are formed, including CO. This gas is a product of incomplete combustion, which occurs when carbon in the fuel is partially oxidized rather than being fully oxidized to CO_2, H_2, and partially oxidized hydrocarbons, such as aldehydes. In addition, some of the gasoline remains unburned, while a fraction is thermally cracked to smaller hydrocarbon molecules.

Under the high pressure and temperature conditions in an engine, nitrogen and oxygen atoms in the air react to form various nitrogen oxides, collectively known as NOx. Finally, particulate matter consisting of carbon, metallic ash, and hydrocarbons accompanies the gaseous emissions. When sulfur compounds are present in the fuel, sulfur oxides (SOx) are also formed (Seinfeld, 1975).

2.4.4 Factors Influencing the Type and Quantity of Exhaust

2.4.4.1 Hydrocarbon Emissions

The exhaust hydrocarbon emissions discussed in the preceding section are controlled by and large by the following factors:

1. Air-fuel ratio
2. Engine Tune-up
3. Combustion chamber geometry
4. Ignition Timing
5. Composition of the fuel

2.4.4.2 Air-Fuel Ratio

In a modern combustion engine the air/fuel ratio of 14.7:1 represents the ideal performance versus emissions trade off. The air fuel ratio is important from both an economic and environmental point of view. The ideal ratio referred to as the stoichiometric (chemically correct) mixture corresponds to an air/fuel ratio combination during which, if combustion were perfect, all the hydrogen and carbon would be converted into harmless water (H_2O) and carbon dioxide (CO_2). The ratio of actual air/fuel mixture to the stoichiometric ratio is the equivalence ratio and is represented by the Greek letter Lamda (λ).

When the air/fuel ratio mixture is stoichiometric (14.7:1) the equivalence ratio is considered as 1. When this ratio is less than 1 the mixture is too rich. When the ratio is greater than 1 the mixture is lean. Maximum power requires a mixture richer than the stoichiometric, whereas best fuel economy is achieved with a mixture leaner than the stoichiometric (Seinfeld, 1986; De Nevers, 1995).

2.4.4.3 Engine Tune-Up

This is the setting of the engine to achieve rich, stoichiometric or lean mixture. The ideal engine tune-up, is the one that guarantees stoichiometric mixture, λ=1. Unfortunately, most mechanics have always known that an engine tuned for rich combustion starts and runs more smoothly than one tuned for lean combustion but with poorer fuel economy (De Nevers, 1995). Before the 1970s mechanics regularly changed the factory carburetor settings to make the combustion richer. Their customers liked the car's smooth performance, but these changes greatly increased the emissions. One of the early air pollution control steps was to modify the carburetors to make it much harder (and illegal) to change the factory settings.

2.4.4.4 Combustion Chamber Geometry

In the lean combustion mode, wall quenching of the ignition flame forms most of the hydrocarbon and carbon monoxide. Various techniques have been used to minimize this. The most effective way is to make the combustion chamber more nearly spherical, thus reducing the surface per unit volume. Reducing the size of crevices such as space between the piston rings and the cylinder wall associated with the head gasket, spark plug gasket, and piston rings also contributes to reducing flame quenching. Raising the temperature of the cylinder wall as well as that of the cylinder head lowers the thickness of the quench zone. Diesel engines do place the fuel in the middle of the combustion chamber leading to better combustion and lower CO and HC emissions (De Nevers, 1995).

2.4.4.5 Ignition Timing

The timing of fuel injection into the combustion chamber during compression as the piston nears the top position is known as ignition timing. Retarding the ignition timing decreases the exhaust hydrocarbon concentration as a result of decreases in the unburned fuel from the crevices. This result in decreases in the fraction of hydrocarbons not oxidized in the exhaust system.

2.4.4.6 Composition of the Fuel

The composition of the fuel, as being leaded or unleaded, having a high sulfur or low sulfur content, whether it is conventional petroleum or natural gas, all impact differently on the type and quantity of pollutants emitted. Hydrogen and methanol fuels have attractions as fuel for the future but may also have unknown environmental effects yet to be determined. Clean fuels for transport may be prohibitively expensive and choices will have to be made between environmental concerns and meeting the demand for transport.

2.4.5 Exhaust Particulate Emissions

Particulate matter, consisting of carbon, metallic ash, and hydrocarbons, is emitted in the exhaust and crank case blow-by gases of internal combustion engines. Metal-based particulates result from lead antiknock compounds in the fuel, metallic lubricating oil additives, and engine wear particles. Carbonaceous and hydrocarbon aerosol result from incomplete combustion of fuel and leakage of crankcase oil past the piston rings into the combustion chamber.

2.4.6 Diurnal Emissions

These emissions result from vented gasoline vapors due to temperature increases during the day. Gasoline evaporation increases as the temperature rises.

2.4.7 Running-Losses

Fuel vapours are lost to the atmosphere due to heat of the engine and exhaust system when the car is running.

2.4.8. Refueling-Losses

Gasoline vapors are always present in fuel tanks. These vapours are forced out when the tank is filled with liquid fuel.

2.5. AIR POLLUTANT EMISSIONS FROM DIESEL AND PETROL ENGINES

Studies carried out by The Open University (2000), has established that, if air pollutant emissions from diesel engines are compared with those from equivalent petrol engines, the diesel engines produce:

1. Fewer nitrogen oxides;
2. Considerably less carbon monoxides;
3. Fewer hydrocarbons, and
4. Much greater particulate emissions

While diesel emissions of NOx are less than that from an uncontrolled petrol engine, they are greater than from a petrol vehicle with a three- way catalyst. Hydrocarbons in the VOC context are less of a problem owing to the lower volatility of diesel fuel than petrol hydrocarbons, but are associated with carbonaceous particles formed by incomplete combustion.

2.6. EFFECTS OF VEHICULAR EMISSIONS

The combustion of fossil fuels and biomass results in the production of carbon dioxide (CO_2), carbon monoxide (CO), lead, nitrogenoxides (NO_x**),** ozone (O_3), particulate matter (PM), sulfur dioxide (SO_2), and volatile organic compounds (VOCs). These pollutants contribute directly and indirectly in a broad spectrum of environmental impacts (Makofke and Karlin, 1995). These include local and regional impacts (acid deposition, photochemical smog, industrial smog, haze), as well as global impacts (global warming, and stratospheric ozone loss).

2.6.1. Carbon Dioxide

Carbon dioxide does not directly impair human health, but it is a “greenhouse gas” that traps the earth’s heat and contributes to the potential for global warming. If inhaled in high concentrations, CO_2 can be toxic and cause an increase in the breathing rate, unconsciousness, and other serious health problems.

2.6.2. Carbon Monoxide

Carbon monoxide is an odorless, colorless gas. After being inhaled, CO molecules can enter the bloodstream through the lungs and forms carboxyhemoglobin, a compound that inhibits the adequate absorption of oxygen for delivery to organs and tissues. Low concentrations of this gas can cause dizziness, headaches, and fatigue. High concentrations on the other hand can be fatal. CO is produced by the incomplete burning of carbon-based fuels, including gasoline and oil. It can build up in high concentrations in enclosed areas such as garages, poorly ventilated tunnels, and even along roadsides in heavy traffic.

2.6.3. LEAD (Pb)

Historically, the primary source of lead emissions has been the result of tetraethyl lead additives to gasoline. Other sources include mining, smelting, waste incineration, iron and steel production, lead akyl manufacturing and battery manufacturing (Corbitt, 1990).Laad produces a range of adverse health effects, particularly in young children. Lead can cause nervous system damage and learning behavior problems. Lead can also harm wildlife. Legislative controls have contributed to reduce the impact of this source in countries like theUnited States (Corbitt, 1990).

2.6.4. MANGANESE (Mn)

Manganese is a naturally occurring metal that is necessary for children's growth and good health in small amounts. Everyone is exposed to manganese in air, water, food, and in new gasoline additive called methylcyclopentadienyl manganese tricarbonyl (MMT). However, when levels of manganese exceed what is considered safe, one’s health can be adversely affected. According to the Expert Group on Vitamins and Minerals (2003), World Health Organization (WHO) is yet to set a specific recommendation for manganese intake, however, the European Union (EU) Scientific Committee for Food (SCF) considered a ‘safe and adequate intake’ to be 1-10mg/person/day.

A greater likelihood of increased manganese in the environment is due to the new gasoline additive, MMT. Inhalation of Mn particulates by children could present new environmental risks. Chronic exposure to high levels of manganese can affect the central nervous system and is called manganism. Mothers exposed to high levels of manganese through drinking water while pregnant have alleged birth defects.

2.6.5. NITROGEN OXIDES (NO_x)

Nitrogen Oxides are major contributors to smog (smoke and fog) and acid rain. NO_xreacts with volatile organic compounds (VOCs) to form smog. In high doses, smog can harm humans by causing breathing difficulty for asthmatics, cough in children, and general illness of the respiratory system. Ground-level ozone is formed when NO_x combines with VOCs in the presence of heat and sunlight. Ground-level ozone can cause lung damage, chest pain, coughing, nausea, throat irritation, and congestion (Fairweather*et al*., 1999; Seinfeld, 1986). Acid rain can harm vegetation and has the potential to change the chemistry of lakes and rivers, making them uninhabitable for all but acid-tolerant bacteria. NO_x are produced from burning fuels, including gasoline and coal.

2.6.6. OZONE (O_3)

Ozone is a gas that consists of three oxygen atoms. Ozone forms naturally and is beneficial in the stratosphere (a layer of atmosphere high above earth) where it filters harmful ultraviolet (UV) rays. However, ozone that is close to the ground, called ground-level ozone can irritate the respiratory tract, and cause chest pain and persistent cough. This affects the ability of one to take a deep breath, and it increases one's susceptibility to lung infection. Ground level ozone can also damage trees and plants and reduce visibility. Motor vehicles and industries are major sources of ground-level ozone. Ground-level ozone comes from the oxidation (breakdown) of VOCs found in solvents. It is also a product of reactions between chemicals produced by burning coal, gasoline, and other fuels and chemicals found in paints and hair sprays. Oxidation occurs readily during hot weather.

2.6.6.1. Effects of Stratospheric Ozone Depletion

Stratospheric ozone depletion has a number of serious potential environmental effects including damage to the earth's food chains both on land and in the oceans. According to Raven *et al*. (1993), a study in 1992 confirmed that increased ultraviolet radiation is penetrating the surface waters around Antarctica and that as a result; the productivity of Antarctic phytoplankton has declined by at least 6 to 12 percent. If the phytoplankton continues to decline, the food chain of Antarctica, which includes fish, seals, penguins, whales, and vast populations of birds, will collapse. Excessive exposure to ultraviolet radiation due to ozone depletion is linked to a number of health problems in humans, including eye cataracts, skin cancer, and weakened immunity (Botkin and Keller, 1998).

2.6.7. Particulate Matter (PM)

These are different kindsof solid in the air in the form of smoke, dust, and vapour, which can remain suspended for extended periods. They are usually in the air. In addition to reducing visibility and soiling clothing, microscopic particles from the air can be breathed in and lodge in lung tissue, causing increased respiratory disease and lung damage. Particulates are also the main source of haze, which reduces visibility. Particulates are produced by many sources, including vehicles burning diesel fuels and other fossil fuels; the preparation and application of fertilizers and pesticides; road construction; industrial processes, such as steel making; mining; agricultural burning; and the operation of fireplaces and woodstoves.

2.6.8 Sulfur Dioxide (SO_2)

Sulfur dioxideis an odorless gas at low concentrations, but at high concentrations can have a very strong smell. Burning coal, most notably in power plants produces SO_2. Some industrial processes, such as paper production and metal smelting, produce SO_2. Like NO_2, SO_2 is a major contributor to smog and acid rain. It can harm vegetation and metals and can cause lung problems, including breathing problems and permanent lung damage.

2.6.9 Volatile Organic Compounds (VOCs)

Volatile organic compoundslike all organic compounds contain carbon. Organic chemicals are the basic chemicals found in all living organisms and all products derived from living organisms. Many organic compounds that we use do not occur in nature, but are synthesized by chemists in laboratories. Volatile chemicals easily produce vapours at room temperature. VOCs include gasoline, industrial chemicals, such as benzene, solvents, such as toluene and xylene, and perchloroethylene (the principal dry cleaning solvent). VOCs are released from burning fuel, such as gasoline, wood, coal (natural gas), and from solvents, paints, glues, and other products used at home or work. Vehicle emissions are an important source of VOCs.

2.7.Emission Control for Internal Combustion Engine

Auto emission controls are mandated by legislations. The legislative history of motor vehicle control began in California, United States, in 1959 (Cunningham and Saigo, 1999). At the time, typical new cars were emitting nearly 13 grams per mile hydrocarbons (HC), 3.6 grams per mile nitrogen oxides (NO_x), and 87 grams per mile carbon monoxide (CO), (USEPA, 1992). Since then, the Federal government of the United States has set standards to bring down levels of these pollutants. The current Federal certification standards for exhaust emissions from cars are 0.25 gram per mile HC, 0.4 gram per mile NO_x, and 3.4 grams per mile CO. The standard for evaporative HC emissions is 2 grams per test (USEPA, 1992).

The current European Union (EU) exhaust emission requirements regulate four groups of compounds: nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM). For light vehicles (under 3.5 tons) the emission standards differ depending on the engine type (petrol or diesel). Emissions of the greenhouse gas carbon dioxide are not currently regulated for any type of vehicle. Emission standards for light and heavy road vehicles in the EU have been stiffened over the years (Tables 1 and 2).

Table 1 USEPA Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr

Year	HC	CO	NO_x	PM
Heavy-Duty Diesel Truck Engines				
1988	1.3	15.5	10.7	0.60
1990	1.3	15.5	6.0	0.60
1991	1.3	15.5	5.0	0.25
1994	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10
Urban Bus Engines				
1991	1.3	15.5	5.0	0.25
1993	1.3	15.5	5.0	0.10
1994	1.3	15.5	5.0	0.07
1996	1.3	15.5	5.0	0.05*
1998	1.3	15.5	4.0	0.05*
* - in-use PM standard 0.07				

Source: Dieselnet, US emission standards, model year 1987-2003

Table 2: EU Emission Standards for HD Diesel Engines, g/kWh (smoke in m^{-1})

Tier	Date	Test	CO	HC	NOx	PM	Smoke
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	*1999.10, EEVs only*	*ESC&ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC&ELR	2.1	0.66	5.0	0.10 0.13[a]	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5
Euro VI	2013.01		1.5	0.13	0.4	0.01	

a - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

Source: Dieselnet (2000)

The auto industry has responded to the progressive stiffening of these standards by developing new emission control technologies to meet specific emission levels per standard requirements. In response to tighter standards in the 1990 Clean Air Act amendment, manufacturers equipped new cars with sophisticated emission control systems.

Mobile source provisions include even tighter tailpipe standards, increased durability of emission control systems, improved control of evaporative emissions, and computerized diagnostic systems that identify malfunctioning emission controls (Enger and Smith, 1992). Manufacturers have also introduced engine management systems. These systems help the operator to monitor performance of the various units of the engine and also help in the diagnosis of faults through error codes displayed on an instruments panel. An example of this are the 20 Dutch- made DAF buses used for this study.

2.7.1. EMISSION CONTROL EFFORTS IN GHANA

A focused approach to the control and reduction of air pollution (while avoiding larger- scale damage to economic development) in Ghana has been first to compile emission inventories to provide policy makers and the public with an understanding of the key polluting sources and determine how these sources have developed with economic growth. The emission inventories helps policy makers to know how they are likely to contribute to pollution in the future and thus implement measures to meet the demands of sustainable development. EPA of Ghana conducted the emission inventories with support from the DANIDA Transport Sector Programme support to Ghana (Agyemang-Bonsu *et al* 2007).

Available statistics at the Driver and Vehicle Licensing Authority (DVLA) and Ghana Statistical Service, shows that between 2000 and 2005, vehicle fleet population increased from 382,261 to 624,783 (63%) with a corresponding human population growth from 18.845 million to 21.694 million (15%), indicating an increasing trend of the pressures that drive the pollution sources. According to Agyeman-Bonsu *et.al*, 2007, Ghana, the growth rate of Ghana’s population is 2.7 percent, and is projected to double after 26 years. Ghana’s population is predominantly rural. According to the 1984 population census, Ghana had over 47,000 human settlements, for the 12 million people.

The population increased by nearly 50 percent between 1984 and 2000, with rural/urban ratio also increasing in line with the general global trend. There is about 50,000 km of road network and road transport accounts for about 94 percent of freight and 97 percent of traffic movement. About 9,486 km of the road are paved with about 40,555.5 km unpaved. Ghana road map is attached in Figure 2.1 below (Agyemang-Bonsu *et al* 2007)

Figure 2.1: Road Network in Ghana

Source: Agyemang-Bonsu *et al* 2007

The rapid expansion of the vehicle fleet (6.9 percent per annum between 2000 and 2005) has resulted in increased traffic congestion and fuel use. Recent studies by EPA Ghana, predict the complete saturation of the road network before the year 2015 especially in the Ghanaian capital. Statistics available at Driver Vehicle Licensing Authority (DVLA) show that the fleet population (road transport vehicles) increases between 2000 and 2005 was at a yearly average growth rate of 6.9%. Table 3 below represents fleet numbers between year 2000 and 2005.

Table 3: National Fleet Statistics, Ghana

YEARS	**FLEET POPULATION**
2000	382,261
2001	420,343
2002	461,457
2003	507,222
2004	563,513
2005	624,783

Source: DVLA, Ghanaian Vehicular Emission Compliers, 2006

2.7.2. Output of Emission Inventories

Results of the emission inventories form the basis for air quality planning, which will be used subsequently to prepare an emission policy strategy for the transport sector in Ghana. An example of the outputs of the study is the Heavy-duty (HD) Vehicle Emission by year of production, shown in Table 4 below. The emission level for vehicles of Euro III Technologies as indicated in the table shall constitute the baseline figure for analysis of this study.

Table 4: Heavy-duty vehicle emission by year of production

Years	2000	2001	2002	2003	2004	2005	Av	
Heavy-duty Emission Levels								
HD	548.18	602.77	662.05	727.63	808.12	896.13	707.48	
% HD Emission	2.00	2.00	2.00	2.00	2.00	2.00	2.00	% Emission
Conventional	428.41	471.11	517.48	568.72	631.59	700.40	552.95	78.16
Euro I	84.87	93.30	102.45	112.60	125.09	138.70	109.50	15.4755
Euro II	24.20	26.59	29.21	32.11	35.68	39.54	31.22	1.55799
Euro III	10.70	11.76	12.91	14.20	15.77	17.49	13.81	1.95136

Source:Agyemang-Bonsu *et al* 2007

Note: Conventional vehicles are those without special emission control systems fitted on them. Euro Technology vehicles are those designed with special emission control systems to enable them meet the requirements of European commission emission standards I, II and III. Emission from heavy-duty vehicles averagely constituted 2 percent of the total fleet emission in the country during the study period. Of the two percent, 78.16 percent and 15.4 percent were respectively attributed to conventional and Euro 1 vehicles. 1.6% and 1.9 % were from Euro 2 and Euro 3 respectively.

2.8. 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/CO_2.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 2.86 kg, the carbon in a gallon of gasoline weighs (2.86kg. x .87) or 2.49kg. If the weight of the carbon (2.49kg) is then multiplied by 3.7, this is approximately9.1kg.Hence, the weight of carbon dioxide emitted from one gallon of gasoline is given as,

$$2.49\text{kg} \times 3.7 \approx 9.1\text{kg}$$

Density of CO_2 = 1.98 kg

Mass of CO_2 = 9.1 kg

Volume of CO_2 from one gallon of gasoline =?

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

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

$$\text{volume} = \frac{9.1\text{ kg}}{1.98\text{kg/m}^3} = 4.6\text{ m}^3.$$

Volume of CO_2 = 4.6 m^3.

Thus, volume of CO_2 emitted from one gallon of gasoline is 4.6 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 CO_2 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 9.1kg ofCO_2 per gallon of gasoline it consumes (Fuel economy guide, 2006). Therefore, by choosing a vehicle with higher fuel economy global climatechange can be reduced. By choosing a vehicle that achieves 40.2 km per gallonrather than 32.2, the release of about 17 tons of greenhouse gases over thelifetime of your 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 a vehicle are two inseparable parameters.

2.9 EXHAUST EMISSION CONTROL METHODOLOGIES

Many of the steps being taken to reduce motor vehicle pollution are mandated by air quality legislations around the world, since these legislations are progressively being made even more stringent, so are efforts by vehicle makers and operators to meet standard requirements. Air quality standards are location-based, however, to achieve both local and global objectives, the most frequently used reference guidelines are those of the World Health Organization (WHO), the European Union (EU), and the standards of the United States Environment Protection Agency (U.S. EPA)

The World Health Organization (WHO) and U.S. EPA guidelines/standards have been set based on clinical, toxicological, and epidemiological evidence. Whereas the EU standards as shown on Tables 1 and 2 earlier are based on consultation and legislative decision-making processes that took into account the environmental conditions and the economic and social development of the various regions. It therefore acknowledged a phased approach to compliance to the standards (European Community, 1992).

2.9.1 TECHNOLOGIES AND METHODS

Reduction in vehicular tail pipe emissions can be achieved through interventions at three major stages of the automobile's live cycle namely: the design, operation and maintenance stages. The following are widely used technologies and methods used at these stages to help meet the requirements of air quality legislations:

2.9.1.1 Design

Emission control systems at the design stage of automobiles vary between manufacturers and vehicles, and include: On board computers (O B C), Catalytic Converters, Exhaust Gas Re-circulation (EGR), and Positive Crankcase Ventilation (PCV).

2.9.1.2 On Board Computers

These are computers added to the ignition systems, which allows the engine to monitor and adjust itself continuously. This helps to ensure complete combustion, and can reduce carbon monoxide and hydrocarbon emission by about ninety-six percent from pre-control vehicles. Anon (2008) eg Dutch buses

2.9.1.3 Catalytic Converters

Catalytic converters are similar to the catalyst used for catalytic incinerators but are smaller. The modern catalyst is contained in a steel box, similar to an exhaust silencer. A ceramic bloc within the box has a large surface area, such as a honeycomb. A coating of precious metal on this large surface area serves as the catalyst, which bring about the oxidation of hydrocarbons and carbon monoxides, while simultaneously promoting the reduction of nitrogen oxides. The simplest catalysts capable of being fitted to existing cars are not controlled by an engine management system, and have no link to the air-fuel ratio. Consequently it may remove only up to 50% of the pollutants (CO, HC, NO_x), since there is no engine management system to optimize the engine efficiency (The Open University,1993).

2.9.1.3.1 Three–Way Catalyst

Three-way catalysts, achieve the cleanest exhaust emissions when they operate with an engine management system. A ‘lambda (λ) probe’ is located between the engine and the catalyst and measures the level of oxygen in the exhaust gases. The air-fuel mixture may then be adjusted appropriately to ensure most efficient operation of the catalyst, see the location of a catalytic converter (Figure 2.2).

Figure 2.2: Location of catalytic converter in the exhaust system

Source: Wikipedia, the free encyclopedia

2.9.1.3.2How Catalytic Converters Reduce Pollution

In chemistry, a catalyst is a substance that causes or accelerates a chemical reaction without itself being affected. Catalysts participate in the reactions, but are neither reactants nor products of the reaction they catalyze. In the human body, enzymes are naturally occurring catalysts responsible for many essential biochemical reactions (Anon, 1998-2007). In the catalytic converter, there are two different types of catalysts at work, a reduction catalyst and an oxidation catalyst. Both types consist of a ceramic structure coated with a metal catalyst, usually platinum, rhodium and/or palladium. The idea is to create a structure that exposes the maximum surface area of catalyst to the exhaust stream, while also minimizing the amount of catalyst required, as the materials are extremely expensive. Some of the newest converters have even started to use gold mixed with the more traditional catalysts. Gold is cheaper than the other materials and could increase oxidation, the chemical reaction that reduces pollutants, by up to 40 percent (Anon, 1998-2007).Most modern cars are equipped with three-way catalytic converters(Figure 2.3). This refers to the three regulated emissions it helps to reduce.

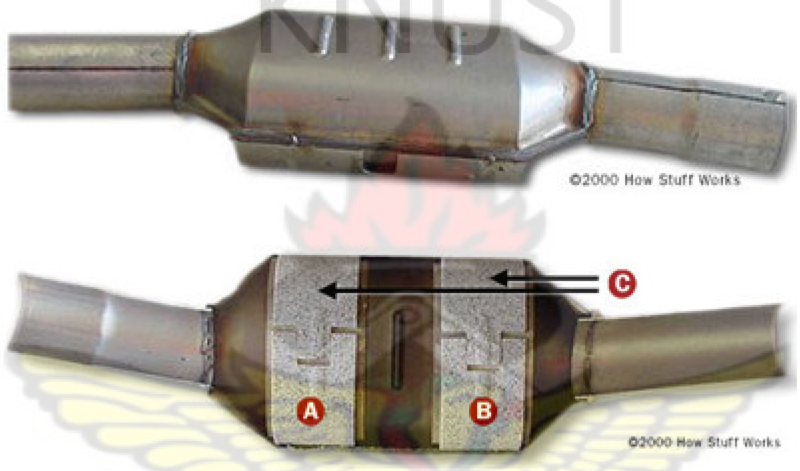

Figure 2.3: Three-way catalytic converters

Source: Anon, 1998-2007.

The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to help reduce the NOx emissions. When an NO or NO_2 molecule contacts the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form of O_2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2. For example:

$$\mathbf{2NO \Leftrightarrow N_2 + O_2} \text{ or } \mathbf{2NO_2 \Leftrightarrow N_2 + 2O_2}$$

The **oxidation catalyst** is the second stage of the catalytic converter. It reduces the unburned hydrocarbons and carbon monoxide by burning (oxidizing) them over a platinum and palladium catalyst. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas. For example:

$$\mathbf{2CO + O_2 \rightarrow 2CO_2}$$

There are two main types of structures used in catalytic converters -- honeycomb (Figure 4) and ceramic beads. Most cars today use a honeycomb structure.

Figure 2.4: Ceramic honeycomb catalytic structure
Source: Anon, 1998-2007

2.9.1.3.3. Disadvantages of Catalytic Converters.

Catalysts are not necessarily the panacea that they may appear to be. Unfortunately, while three way catalysts eliminate 90% of CO, HC, and NOx, it is reported that they make the engine 7% less efficient. Thus carbon dioxide emissions increase. Catalysts also need to reach a temperature of 300 ^{o}C in order for them to become active, and since many journeys are over short distances, the catalyst may not be performing optimally since it requires time to warm up. Leaded additive also poisons the catalyst (The Open University, 1993).

2.9.1.4Exhaust Gas Recycle (EGR)

The Exhaust Gas Recycle (EGR) valve is used to send some of the exhaust gas back into the cylinders to reduce combustion temperature. Nitrous oxides (NO) form when the temperature gets above 1371 ^{o}C. This happens because at such temperatures, the nitrogen in the air mixes with the oxygen to create nitrous oxides. When it is sunny, the nitrous oxides from the exhaust also combine with the hydrocarbons in the air to form smog. (Anon. 2008)

The advantage of EGR results mainly from the fact that the air-fuel mixture can be diluted without addition of excess oxygen (from which NO is formed), and that dilution with exhaust gas results in the introduction into the chamber of species such as CO_2 and H_2O, with higher heat capacities than nitrogen (N_2)(Seinfeld, 1986).

2.9.1.5Positive Crankcase Ventilation (PCV)

The process of combustion forms several gases and vapors; many of them quite corrosive. Some of these gases get past the piston rings and into the crankcase. If these substances are left in the crankcase, they would cause rust, corrosion and formation of sludge. In the past, they were removed and dumped into the atmosphere through a tube resulting in pollution problems in the sixties. (Anon, 2008). The PCV system replaces the old "dump tube". It uses a hose connected between the engine and the intake manifold to draw these gases out of the engine's crankcase and back into the cylinders to burn with the regular fuel. Anon (2008).

2.9.2Operation

At the operation stage, emission control interventions include: the use of alternative cleaner fuels, modification in vehicular operations and change in gasoline composition.

2.9.2.1 AlternativeCleaner Fuels

There are a number of alternatives to gasoline that are being investigated as possible fuels for the future. These include methanol, ethanol, compressed natural gas, propane, and hydrogen. Conversion of a vehicle to enable it use some of these fuels, such as propane, according to Hill (Hill, 1997) and Fairweather (Fairweather, 1999), cost $1,000-2,000 per vehicle in the United States, however, the lower cost of propane as vehicular fuel results in fuel savings which may pay for the cost of conversion within a year. Vehicles maintenance cost and engine wear are also reduced because propane is clean-burning and leaves no lead, varnish, or carbon deposits.

2.9.2.2Modification in Vehicular Operations

This modification comprises of changes, which can be done to the vehicle without the need for engine redesign e.g. modifying air-fuel ratios and/or ignition timing.

2.9.2.3Change in gasoline composition

Changing gasoline compositions is a means to reducing exhaust emission. Oxygen-containing chemicals, such as ethanol, methanol, and methyl tertiary butylether (M T B E) are added to gasoline to make it burn more cleanly and thus reduce carbon monoxide emissions. Cars, trucks, and other vehicles, including tractors and agricultural equipment can use reformulated gasoline, which cost more per gallon than conventional gasoline. MTBE has proved to be a controversial additive because there have been reports from consumers that the odor makes them ill. Potential health effects of MTBE and other oxygenated fuels are being further studied (Hill, 1997).

2.10INSPECTION AND MAINTENANCE (I/M) STAGE

Scheduled inspection and preventive maintenance is that maintenance recommended by a vehicle manufacturer, which encompasses a range of services, such as changing the oil and the oil filter, fuel filters, air cleaners and identifying failures that may cause inefficient engine and vehicle operation.

Periodic inspections and maintenance covers all sorts of vehicle components not strictly that for emissions. This ensures that vehicle components and equipment remain rightly fitted and are functioning properly. This is of central importance if durability requirements and efficiency of all other control systems are to have the intended effect.

In vehicle combustion trouble shooting, the objective is to determine whether the air fuel ratio is stoichiometric (chemically correct). Stoichiometric (14.7:1) mixture corresponds to an air/fuel ratio combination during which, if combustion were perfect, all the hydrogen and carbon would be converted into harmless water H_2O and CO_2. The ratio of actual air/fuel mixture to the stoichiometric ratio is the equivalence ratio and is represented by the Greek letter Lambda (λ).

During vehicle inspection and combustion troubleshooting, Lambda is determined through the use of Gas and Smoke Analyzers. Interpretation of the various gas concentrations in conjunction with the Lambda value allows the technician to accurately diagnose faults including the following:

- Detecting exhaust leaks
- Troubleshooting periodic misfire/fault ignition
- Timing problems
- Detecting rich air/fuel ratio

- Detecting lean air/fuel ratio
- Testing for combustion leaks into cooling systems
- Detecting blown, damaged cylinder head gaskets/cracked head
- Detecting worn piston rings
- Detecting leaking injectors and
- Troubleshooting oil consumption problems

According to *McGinn*(2003) of the Noranda Technology Center, a case study, which used an Undiluted Gas Analysis System (UGAS) and an Undiluted Particulate Sampling System (UPSS) to investigate the relationship between, improved diesel engine maintenance and associated reductions in emissions, produced the following results:

- Gaseous and particulate emissions could be reduced significantly depending on engine design technology and condition.
- Gaseous emissions reductions (carbon monoxide) as high as 65% were proven and
- Particulate emissions reductions as high as 55% were seen as well.

A study on the effects of maintenance on fuel efficiency of a fleet of public buses by Ang and Deng (1990) showed a significant improvement in fuel efficiency each time major maintenance is applied. The relationship between fuel efficiency and vehicle mileage after the application of major maintenance was found to be non-linear. Fuel efficiency dropped, by 2.8 and 3.4% as the mileage reaches 3500 and 7000 km respectively. The study however, fell short in addressing the impact of major preventive maintenance

When national exhaust emission standards and guidelines are finally in place with compliance testing programs to identify offending vehicles, inspection and maintenance will be vital for emission reduction in Ghana. Vehicles with emission levels above standards must be repaired or taken off the road. Maintenance option makes vehicles more fuel-efficient resulting in lesser levels of emissions per kilometer driven.

2.11 DAF TB 2175 PE BUS

The DAF TB 2175 PE buses are of Dutch origin and are powered with a four stroke six cylinder 9.2 litre EURO 3 technology compliant diesel engine, with an engine management system called UPEC (unit pump electronically controlled) system. This system controls the various components of the engine to ensure efficiency and minimize emissions among other things. The sample vehicles were all put in operation in July 2005 and their mileages range from 89,879 to 198,683 km.

2.12 The UPEC System

This consists of a number of electronic units, centrally controllingelements of the injection and other systems used in DAF engines. The functions of the UPEC system can be sub-divided into engine functions, vehicle functions and a diagnostic function. Engine functions include: full-load limitations, smoke limitation, and determination of timing and duration of injection, injection quantity correction, cold start, and boost pressure control.Vehicle functions include: Engine speed control using steering column switch, engine speed control via application connector, vehicle speed limiter, variable vehicle speed limiter, and cruise control.

The unit requires different input signals for the control of the engine and vehicle functions. The various components are activated via output signals. Diagnostic function: The UPEC electronic unitcommunicates with other electronic systems inthe vehicle to enable a display of output signals. For example depending on the reading of various inputsignals, the designated electronic unit calculates the desired injection timing and the desired injectionquantity. In this regard, thestarting point is to reduce the emission of harmful gases ($NO_x$and HC) as much as possible (UPEC system manual).

2.13 YAXING JS6120G1H Bus

YAXINGJS6120G1H BUS buses are of Chinese origin and are powered with a four stroke six cylinder 8.6litre conventional diesel engine. They are about a year newer than the DAF buses. They were put in operation in May 2006 and their mileage ranged from 42,136 to 71658 km.

2.14. The OPUS 50 Smoke Analyzer

The OPUS 50 compact smoke analyzer has been developed to meet the high demands laid on a modern smoke analyzer. It has easily read large 1 inch LED displays as well as a hand held LCD remote control. It is of a robust professional design and very easy to use with many automatic functions, such as auto zeroing, automatic gas calibration, leak test, HC residual test and electronic linearity test.

OPUS 50 is made in Sweden, based on best available components of industrial quality for testing diesel vehicles, as well as trucks and buses at Vehicle Inspections and Professional Workshops. Figure 2.5 below shows an OPUS 40/50 with an LCD remote control.

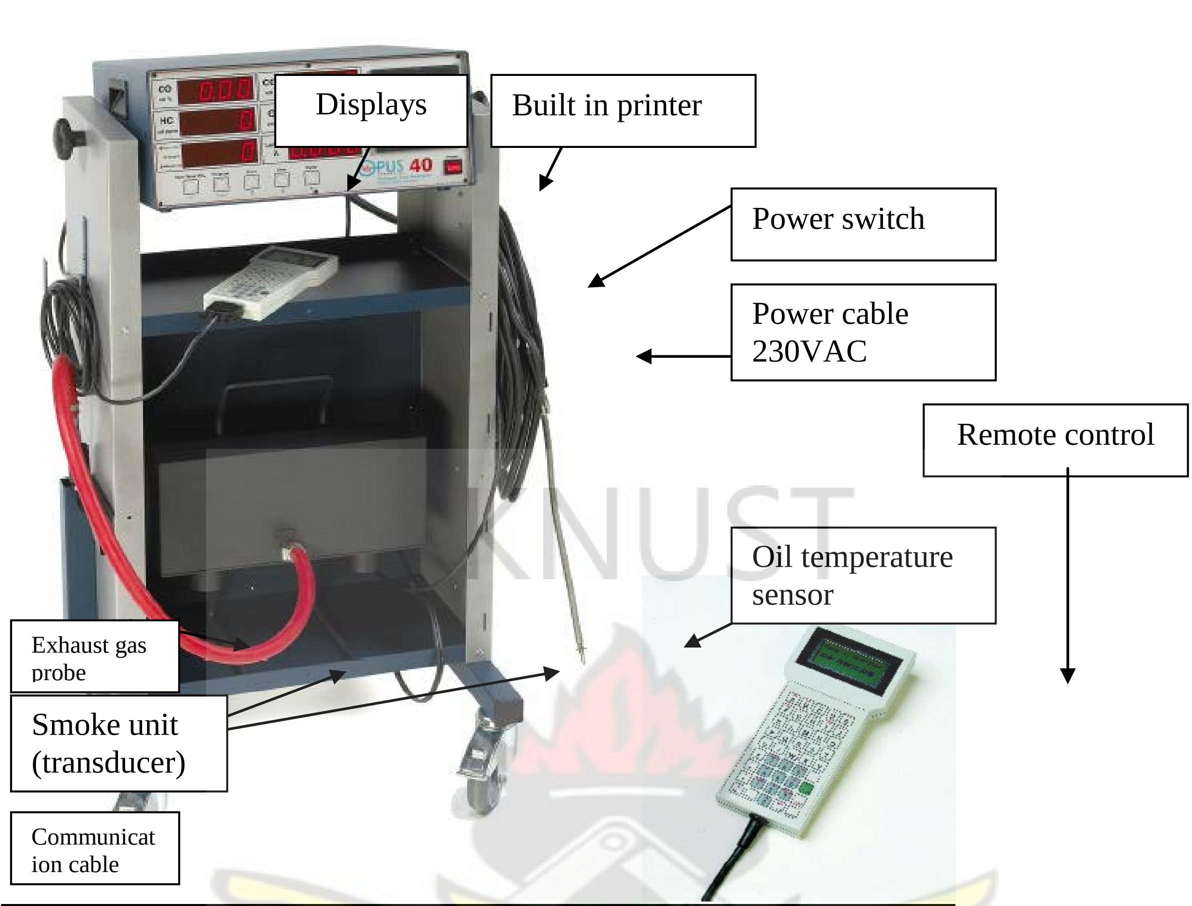

Figure 2.5: An OPUS 50 smoke analyzer mounted on a mobile stand and an LCD remote control

(*Source*: Opus 50 Compact Smoke Analyzer manual)

Figure 2.6: 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 2.5 and 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 meters
- Manual in English
- Remote control with wire

2.15 Principle of the OPUS 40 Gas Measurements

The measuring of CO, HC and CO_2 is done using a technique called NDIR (Non Dispersive Infrared light). Parts ofthe vehicles exhaust fumes are pumped into a sample cell where it is lit through by an infrared light originating fromone side of the sample cell. On the opposite side of the chamber a detector reads the amount of infrared lightpassing through the chamber.Different gases absorb or reduce infrared light at different wavelength. When filtering these wavelengths by applyingan 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 tells the technician what is happening during the power stroke. Once the technician recognizes causes of abnormal gas readings, a quick accurate diagnosis can be made.

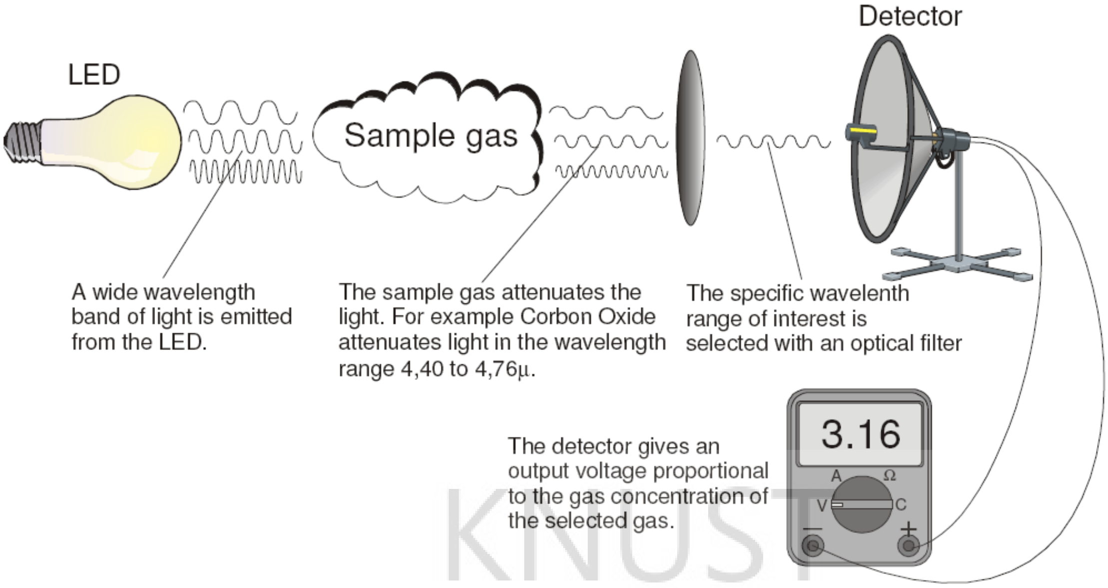

Figure 2.7:Measuring Exhaust gases with OPUS 40, the NDIR technique

The readings are presented on 5 display windowsnamelyopacity, k value, rpm, oil temperature, and status information. The displays are also used to present warning and error codes. Below is the technical information of the diesel smoke analyzer:

2.16TECHNICAL DATA DIESEL SMOKE

	Range	Resolution	Accuracy*
Opacity	0 - 100 %	0,1 %	2 %
k	0 - 99,99 m-1	0,01 m-1	2 %
Rpm	0 - 9999 r/m	1 1/m	
Temp	0 - 160 °C	1 °C	
Pressure range: 0-10 kPa		*Or 5 % of reading	

Warm-up time:	Approx. 3 minutes
Measuring chamber:	Heated controlled to 75 ^{o}C
Optical path length:	215 mm.
Source light:	Green LED (560 nm)
Detector:	Silicon photo diode
Externals:	RS232 (Optional: OPUS DSS PC management SW for storing test data)
Hose:	1,4 m with stainless steel Probe
Optionals:	
RPM:	Piezo Electric System, including 6 mm clamp or Battery voltage measuring system
Oil temperature:	Sensor for oil dip-stick or IR Temp
Power supply:	12 VDC, 6 A and 220 VAC. 50 Hz. 0,3 A, 10 meter power supply cable.
Size (WxHxD):	
Measuring unit	375 x 180 x 75 mm.
Weight:	
Measuring unit	approx. 5,5 kg incl. stand

2.17 SAFETY CONSIDERATIONS

The following safety measures must be kept in mind when using the equipment.

- Exhaust gases can reach temperatures of more than 100 ^{o}C at the tail pipe. Use extreme caution when handling the exhaust probe after a test has been completed, as the probe can get very hot.
- To avoid electrical failure, always protect the equipment from rain and dirt.
- Protect the cable from excessive heat generated from the manifold and from damage by rotating parts like fans and belts.
- Never try to open a unit if you are not specifically asked to do so by manual.

CHARPTER THREE

3.0 METHODOLOGY

3.1 Project Site Description

The project data collection was carried out at Metro Mass Transport Limited (MMT) regional workshop in Kumasi. The workshop is located at Bantama, a suburb of Kumasi, near AbrepoJunction and adjacent to NEOPLAN Limited, Kumasi. Metro Mass Transport started operation on a pilot basis in Accra in 2002, and was later incorporated on 3rd March 2003 as a private limited liability company formed under Ghana companies code, Act 179 1963. The share-holding standing of the company is the order of 45% for Ghana Government and 55% for the consortium of companies (Ghana Oil Company, Prudential Bank, State Insurance Company, Agricultural Development Bank, Social Security and National Insurance Trust, and National Investment Bank).

The operation of MMT, seen by many as a noble initiative to help address the public transportation needs has since been extended to all the ten regions of Ghana with a nation-wide total fleet of 642 buses as of May 2007 (MMT Accra). Metro Mass Transport commenced operation in Kumasi on the same day that it was incorporated, with 32 buses. Over the years, the regional fleet has increased to 130 buses as of 1st May 2007. Below is the model breakdown for the Ashanti Region:

Table 5: Status of buses at the Kumasi Metro Mass Transport Limited

NUMBER	MAKE	ORIGIN	QUANTITY	STATUS	
				Operational	Grounded
1	YAXING	China	52	34	18 engine fault
2	YAXING D. DECK	China	18	18	0
3	DAF	Holland	20	18	2 engine fault
4	DAF-VDL	Holland	40	40	0
Total			130	110	20

Source: MMTL Kumasi (May 2007)

3.2 SOURCES OF DATA

Two categories of data namely primary and secondary data were collected for the study.

3.2.1. PRIMARY DATA

An attempt was made to conduct the project investigation in three organizations namely Kwame Nkruma University of Science and Technology (KNUST), the Forestry Commission and Metro Mass Transport Limited (MMTL) Kumasi. However, only MMTL complied with their inspections and maintenance scheduled, hence, the choice of MMTL. Fuel consumption and exhaust emission data were obtained from field measurements and records, while inspection and preventive maintenance schedule compliance records were obtained from fleet work orders and computerized database of MMT workshop. General information about Metro Mass Transport Limited was obtained by interviewing the Kumasi Workshop manager of the Company. Technical and operational data such as; vehicle registration numbers, year of manufacture, vehicle type, make/model, max loading capacity, odometer readings, engine type, engine capacity, and seating capacity, were obtained through physical inspection of the vehicles, document review (vehicle operating manuals, fleetpreventive maintenance work orders, maintenance log books) and interviewing of workshop personnel.

3.2.2. SECONDARY DATA

Websites and published data at the libraries of Kwame Nkrumah University of Science and Technology (KNUST), University of Ghana, (Legon), the EPA Ghana, Statistical Service Department and MMT Accra and Kumasi were the sources of secondary data which created a framework within which the research was conducted.

3.3 DATA COLLECTION

Prior to commencement of the study, a visit was paid to the study site, the Ashanti regional workshop of the Metro Mass Transport Limited (MMT) in Kumasi to establish the initial contacts and also the needed rapport with the management including the EPA-Ashanti and staff of the company. The initial visit was also to get familiarized with the study environment. In the process, the consent of the EPA- Ashanti was sought for the use of the Opus 50 Gas Analyzer. With the help of the EPA- Ashanti, proper handling of the measuring equipment to be used was learned. An orientation course on data collection protocols was also organized for the supporting staff.

A brief review of MMT workshop maintenance plan was carried out together with the workshop manager. Preventive maintenance follows the manufacturer's recommendations in the vehicles operation manuals, and product specifications. At Metro Mass Transport, there are two separate maintenance plans, one for the DAF (VDL) buses and another for old DAF and the YAXING buses (Appendix I, Tables 1and 2)

Preventive maintenance schedules are grouped into four categories:

1. P = maintenance performed at every 1000 Km,
2. A = maintenance performed at every 5,000 km,
3. B = maintenance performed at every 10,000 km and
4. C = maintenance performed at every 15.000 km of distance traveled.

Category ‘A’ was selected for the study based on the potential it has to influence directly, the fuel system, air supply, lubrication and other components that affect engine efficiency and exhaust emission. Other consideration was the limited period of access to the measuring equipment as it was needed for other projects at EPA Kumasi. The sample vehicles were identified and 2nd May 2007 was agreed for the data collection process to start.

3.3.1 Sampling

Two main categories of buses were considered for the study. These were

DAF TB 2175 PE buses (20 buses available) and YAXING JS6120G1H buses (10 buses available).

Figure 3.1: A DAF TB 2175 PE bus parked on a ramp ready for emission measurements

Figure 3.2: YAXING Buses parked behind Researcher and staff of EPA and MMTL in front with the OPUS 50 smoke analyzer

The following were used to carry out every measurement for the required data: The OPUS 50 smoke analyzer for diesel engines (for detection of emission levels), disposable latex medical examination gloves and dust and filter masks (for safety of personnel), printing paper for smoke analyzer, tissue paper for cleaning oil temperature and exhaust smoke probes and forms (for recording of exhaust emission and fuel consumption data).

3.3.1.1 Exhaust Emission Measurement

The opacity of the exhaust gas was measured at the servicing bay where the buses were usually parked for scheduled inspection and preventive maintenance. In the process, **t**he OPUS 50 smoke analyzer was strategically positioned to enable attachments of all sensing units (RPM battery adapter, oil temperature probe, and smoke probe) to the vehicle to be made (Figures 3.3, 3.4, 3.5and 3.6.

The transducer uses a technique called partial flow. The unit was connected to the vehicle's tail pipe via a probe. The exhaust gas flowed through the probe into the transducers sample tube and out under the transducer. The transducer is very light and can be placed on the vehicle's roof or hung on the side of the vehicle if the tail pipe is mounted high up. It has two connectors on the rear panel, one for communication with the control box and the other for power supply.

Emission measurement was begun with vehicles for category 'A' servicing, where opacities were measured before and after servicing of vehicles. This provided data on how servicing affects its opacity. The monitoring and measurement was repeated for vehicles of category 'A' after they had travelled an average distance 2,000 km each. When the sample vehicles had covered an average of 5,000 km of distance traveled after the initial category 'A' servicing, the next scheduled category 'A' maintenance was performed to complete a cycle of servicing at 5,000 km. Opacities were measured again before and after servicing was carried out. With the help of a computerized interface, readings were noted and printed out. All opacity measurements were done in triplicates to improve precision. The essence was to establish the trendof variation of the opacities within one cycle of preventive maintenance. In all cases,triplicate measurements of opacity were obtained and their mean values estimated. This was to reduce errors and hence promote precision.

3.3.1.2 RPM Measurement

The process of RPM measurement was initiated as follows:

It was first ensured that the vehicles were in the idle state. Once this was attained, the adapter. was connected to the "smoke rpm" connector on the OPUS 50's rear panel. This was followed by connection of the power clamps to the battery, with red to the positive terminal and black to the negative terminal(Figure 3.3). The RPM battery adapter can be used on every vehicle that has a 12V system.

Figure 3.3: The researcher connecting the RPM battery adapter to a 12 V power supply

The function key marked ‘setup cylinders’ was pressed and held for a few seconds until the display showed a digit. This was maintained until number of cylinders was indicated in the display. The ‘up’ or ‘down’ key was then used to select the actual number of cylinders for the DAF TB 2175 PE and YAXING JS6120G1H buses (thevehicles of interest). After the correct number of cylinders had been selected, the function key ‘Rpm/Temp’ was released. After a few seconds the adapter initialized and the engine’s rpm was displayed.

The temperature probe was placed into the dipstick holder pipe, after removing the dipstick (Figures 3,4 and 3.5). The probe was then connected to the “Smoke RPM” input on the rear panel of the display unit.

Figure 3.4: Insertion of oil temperature probe into the oil sump of a DAF vehicle

Figure 3.5: Connection of oil temperature probe into the oil sump of a YAXING vehicle

The exhaust probe was connected to the sample unit made of stainless steel. The probe hose is insulated to prevent the exhaust gas from cooling off before it reaches the transducer. In order to achieve a good flow of smoke through the probe, it was ascertained that the inlet of the probe is not placed near any curves or bends in the tailpipe. The probe was inserted correctly by adjusting the length of the probe.

Figure 3.6: Smoke probe being connected into the tail pipe

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.

3.3.1.3 Acceleration Tests

The essence of acceleration tests was to determine the opacities of the exhaust gas of the vehicles at high and low accelerations. The gear box was kept at the neutral position and the rpm slowly increased to its maximum to enable one check whether or not the vehicle's rpm cut-off was functioning. It was then checked against the engine manufacturer's specification. Threerapid accelerations were performed in order to ensure that the exhaust system was clean from smoke particles. While the probe was out of the exhaust pipe three zeroing procedures were performed by pressing the "zero" key on the display unit on each occasion.

When the displays of CAL had ceased, the probe was inserted into the exhaust pipe and the 'Acc' key on the remote control pressed to start the acceleration test. The accelerator pedal was pressed harder to maximum and held at cut-off rpm for approximately 1-2 seconds after which it was completely released. The “Print” button, on the remote control was activatedfor computerized interface to produce a ‘print out’ of the readings. The process was repeated until three replicated readings were obtained(Figure 3.7).

Acceleration test – printout of readings

Completed acceleration test OPUS 50 Compact can do a printout (see example below)

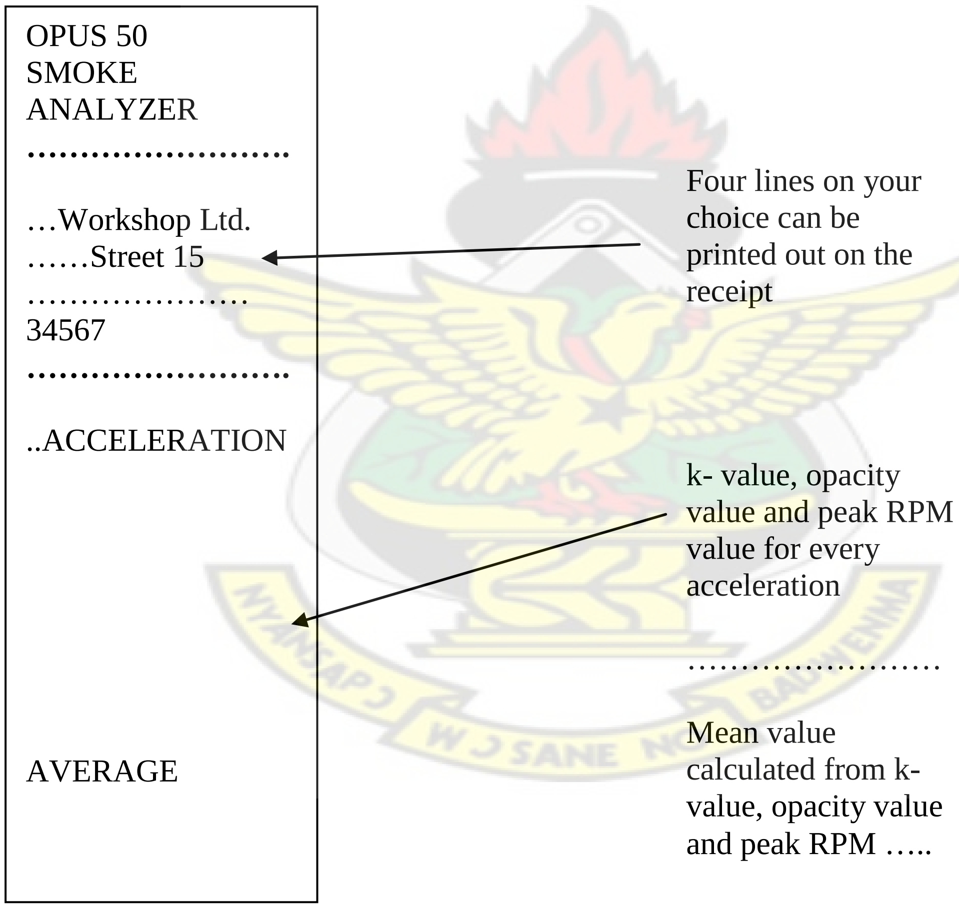

Figure 3.7: Acceleration test-printout of readings from an OPUS 50 smoke analyzer.

3.4 FUEL CONSUMPTION DATA

The Metro Mass Transport Limited Kumasi has its own fuel facility where all their regional fleet refuels, with Ghana Oil (GOIL) being their sole bulk fuel supplier. Monitoring vehicle fuel consumption figures started on 2nd May 2007, together with the emission measurements. Data collection forms designed for this purpose were used to capture fuel issues and odometer readings of all vehicles studied. This monitoring method was chosen to ensure better accuracy in the litre per mileage or kilometer values as gauges of vehicles are often not calibrated.

At the Metro Mass filling facility, the buses are topped up to full tank, each time they refueled. This made it easier for the determination of consumption per mileage by dividing the top-up quantity by the total distance covered since the previous full tank refueling.

3.5 DATA ANALYSIS

Data was analyzed by Analysis of variance (ANOVA) using Statistical Package for Social Scientist (SPSS version 16). Emissions before and after servicing were compared. Results are presented in the form of Tables and graphs using Microsoft Excel.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

Preventive maintenance schedules were found to be in four categories:

P maintenance is performed at every 1,000 km,
A maintenance at every 5,000 km,
B maintenance at every 10,000 km and
C maintenance is performed at every 15.000 km of distance traveled.

4.2 Effects of Preventive Maintenance on Exhaust Emission, DAF VDL Buses

Figure 4.1 illustrates the test results of average emission levels before and after initial Category 'A' servicing of the DAF (VDL) buses. The final test results after 5,000 km of distance traveled is also indicated. The middle bar represents the rise in average emission level from the initial servicing to 2,000 km distance traveled without any maintenance.

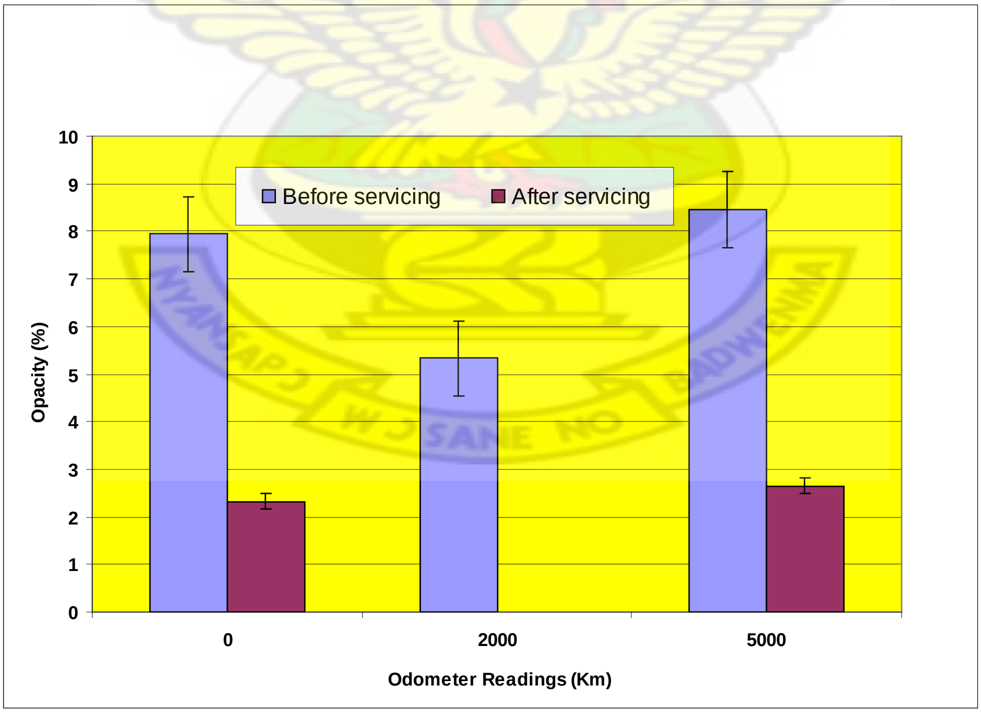

Figure 4.1: Effect of scheduled preventive maintenance on exhaust emissions- DAF (VDL) vehicles

Before the initial category 'A' servicing, the average emission level was 7.94% opacity, but dropped to 2.32% after servicing resulting in a 70.78% reduction in opacity (Figure 4.1). This may suggest that emissions increase with distance traveled, but drop substantially after every major scheduled preventive maintenance such as the category 'A' servicing. A one-way analysis of variance of opacities before and after maintenance at 5% level of significance(Appendix II, Table 2b) showed a significant treatment effect suggesting that opacities before and after maintenance have not been the same and the difference or change is statistically significant (p = 0.000). This observation supports that by McGinn (2003) who noted that engine maintenance results in over 65% reduction in gaseous emission levels. The observed reduction of emissions in this study may be attributed to tune-up, filter change, oil change, and proper tyre pressure which is all included in category 'A' servicing. It enhances stoichiometric air- fuel mixture, a key emission-reduction activity and made the vehicles more fuel efficient.

Emission levels measured at 2,000 km distance traveled indicate an increase from 2.32 % opacity to 5.33% opacity. The increasing trend continued up to 8.46% opacity at the final test when the vehicles had covered a distance of 5,000 km before dropping again to 2.65% opacity, when final preventive maintenance was completed. The drop in opacity from 8.46% to 2.65% represents a reduction by 68.68%. The variability ratio of opacities before and after the final maintenance also showed that preventive maintenance reduced emission levels significantly, corroborating again the finding of McGinn (2003). Moreover the increasing trend of opacity relative to distance traveled confirms that components and engine efficiency deteriorate not just with time but also with distancecovered in operation

Results indicate also that emission levels after both initial and final preventive maintenances fell short of meeting the EURO III standard requirement of 1.9% (Table 4p28). This suggests an imperfect relationship between preventive maintenance and emissions reduction. This means that although preventive maintenance is very important, it does not suffice for complete reduction of emissions, therefore calling for prompt attention to be paid to the other factors such as traffic conditions, driving patterns and fuel types all of which also influence exhaust emissions.

4.3. Effects of Preventive Maintenance on Exhaust Emission, YAXING Buses

The effect of preventive maintenance on the YAXING buses has followed a similar trend as that of DAF buses except in the following areas. Average values for the five tests carried out were lower than that of the DAF buses (Figure 4.2).

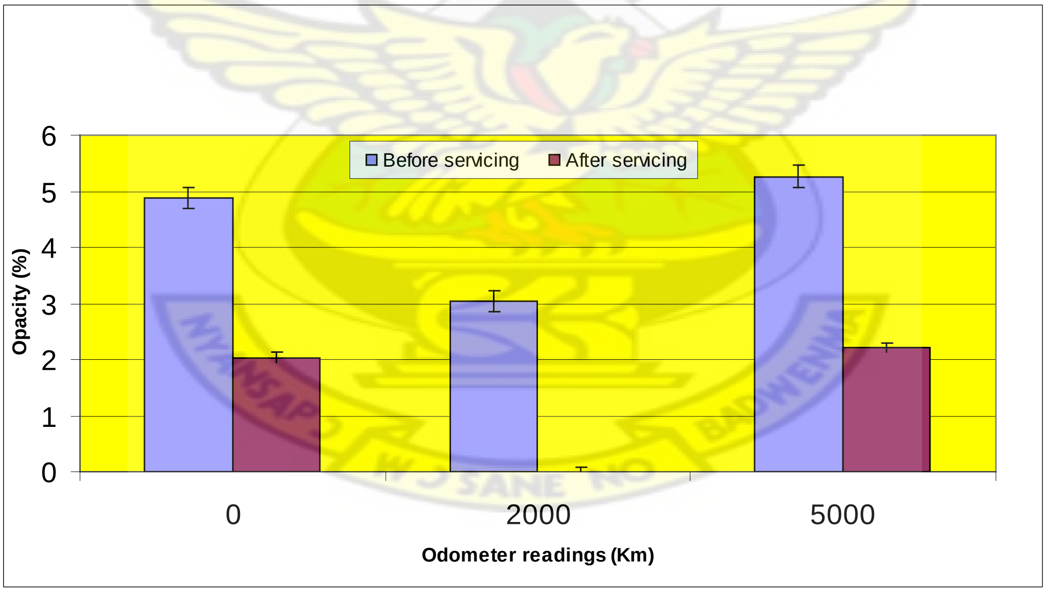

Figure 4.2: Effect of scheduled preventive maintenance on exhaust emission levels-YAXING vehicles

At 95% confidence level, variations in all the test cycles for the initial, 2,000 km, and the final 5,000 km servicing were once again found to be all statistically significant with p

=0.000 (Appendix II, Table 4a). After the first major servicing, average opacities dropped from 4.87 to 2.04%, when the buses covered a distance of 2,000km, average opacity increased to 2.78% and at 5,000km of distance covered, average opacity rose to 5.27% before dropping to 2.20%after major servicing was applied again (Appendix II,Tables 4a,5a and 6a).

Opacities before maintenance 4.87% was significantly greater than opacities after maintenance 2.04%. The average lower levels of emissions by the YAXING buses may be due to their relative newness as compared to the DAF (VDL) buses. These buses started operation in May 2006 while the DAF buses started in July 2005, about a year later. Also the average distance traveled by the DAF buses is about 143,972km while that of the YAXING buses are about 59,538km, a difference of about 84,434 km.

The difference in distance (24,896 km)travelled by the DAF buses (84,434 km) and the YAXING buses (59,538km) could be a factor that contributed to the observed differences in emission levels.

The percentage reduction in emission after maintenance as registered for YAXING buses was however lower than that for DAF buses. After servicing, average emission was reduced by 58% in theYAXING buses, compared to 70.78% reduction in the DAF buses. The availability of engine management system in the DAF buses may have contributed to higher efficiency of its engine operation.

4.4. Effect of Preventive Maintenance on Fuel Consumption, DAF VDL Buses

Scheduled preventive maintenance was found to exert impact on engine efficiency and fuel consumption. The trend in engine performance is expressed in distance traveled per litre of fuel consumed (Figure 4.3). There was a general decline in engine efficiency after the initial category 'A' (designated 0 km) servicing at a distance of 2,000 km. The trend continued up to the next category 'A' preventive maintenance at 5,000 km of distance traveled.

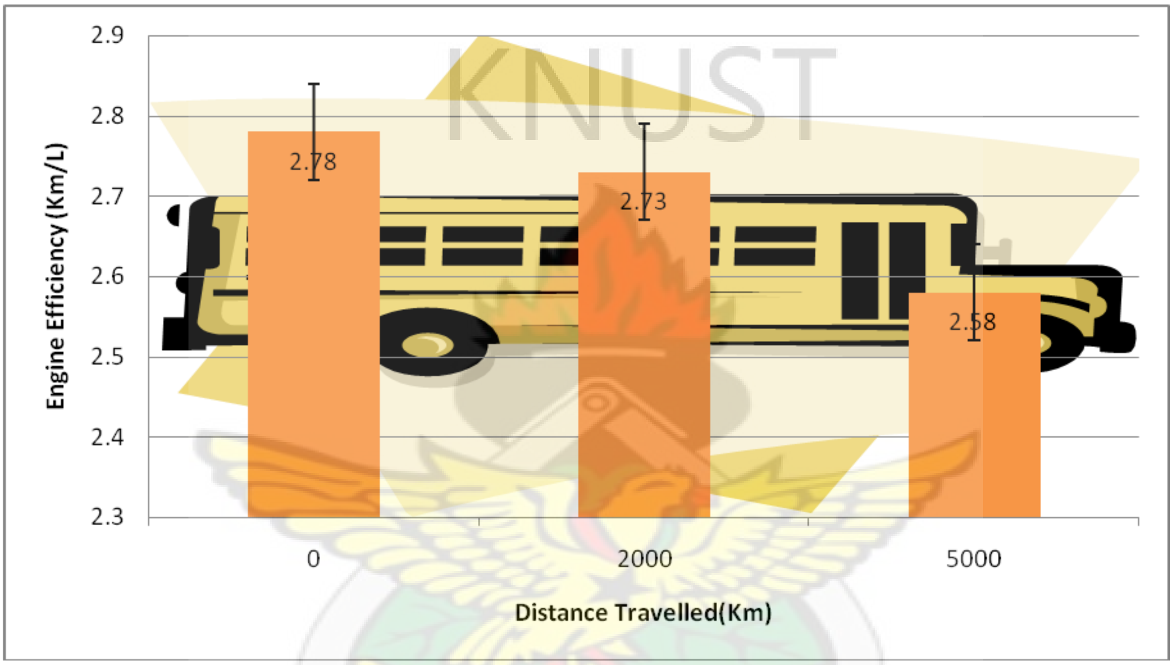

Figure 4.3: Effect of scheduled inspection and preventive maintenance on engine performance of the DAF (VDL) buses.

The average engine performance dropped from an initial value of 2.775 km/l at zero distance to an average of 2.729 km/l when the vehicles had traveled 2000 km. This represents a marginal reduction of emissions by 0.046 (1.66%). An observed F-ratio of $F = 0.511$, $p = 0.479$ (Appendix II, Table 7b) indicating gradual reduction. This in turn suggests that after preventive maintenance, engine performance is optimized and is quite preserved when the vehicle has travelled up to a distance of 2,000 km. The explanation for this is that, the effect of other factors on engine performance may be gradual in urban environment, especially after category 'A' servicing. From a distance of 2,000 km to 5,000 km, the average engine performance dropped further to 2.576 km/l, which is a significant drop statistically (p = 0.004). The overall drop in engine efficiency (2.78 to 2.58 km/l) from the initial servicing to the final 5,000 km servicing is 7.2% percent, which is also statistically significant p = 0.002(Appendix II, Tables 8band 9a)

The designed engine performance for the DAF buses is 3.2 km/l and the performance achieved after 5000 km or category 'A' scheduled maintenance was 2.775 km/l which suggest a reduction by 0.425 km/l (13%.) This deficit may be ascribed to the effect of other factors which also do influence engine performance. This, notwithstanding the 13% deficit which is attributed to the influence of aggregation of other factors, the significant increase in distance traveled per litre of fuel consumed after every category 'A' servicing is an indication of an improved engine efficiency due to scheduled inspection and preventive maintenance, improved engine efficiency which then results in fuel economy.

4.5 Effect of Preventive Maintenance on Fuel Consumption,YAXING Buses

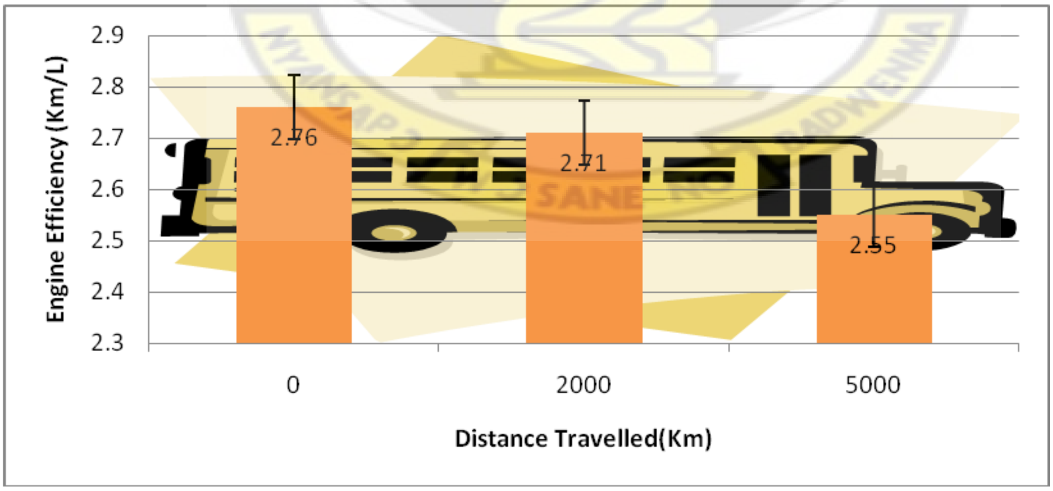

Figure 4.4: Effect of scheduled inspection and preventive maintenance on engine performance, YAXING buses

The mileage or kilometer per litre relationship in the YAXING buses has followed a similar trend as in the DAF VDL buses.The results show a significant improvement in fuel efficiency each time major maintenance (category ‘A’ servicing) is applied (Figure 4.4).The relationship between fuel efficiency and vehicle mileage after the application of major maintenancewas also non-linear, and fuel efficiency drops by 1.8 and 7.6% as the distance reaches 2,000 and 5,000 km respectively. Again the fuel efficiency drop of 1.8% at 2,000 km was not statistically significant P= 0.504 (Appendix II, Table 10b). However, at 5,000 km the drop was 7.6% which is statistically significant, p=0.007 (Appendix II, Table 13b). This confirms the earlier results that after major maintenance, significant decline in fuel efficiency occurs only after the bus has travelled a distance more than 2000 km. This observation supports that by Ang and Deng (1990) who achieved 2.8 and 3.4% drop in fuel efficiency at 3500 and 7000 km respectively after major maintenance.The engine performance or fuel efficiency after the major maintenance (2.76km/l)when compared with the design mileage per litre of YAXING JS 6120 (3.8 km/l) indicated a drop of 26%. This further confirms the prevalence of the effect of other factors other than preventive maintenance on fuel efficiency.

4.6. Fuel Economy in relation to Scheduled Inspection and preventive Maintenance,

DAF (VDL) and YAXING Buses

Efficiency is defined as output per input. In automobiles it is the distance traveled per unit of fuel used; in miles per gallon (mpg) or kilometres per litre (km/L). The amount of fuel used per distance is known as fuel consumption. The progressive increase in fuel consumed per distance travelled after servicing in this study is an indication of greater fuel loss when vehicles in operation are not maintained. Estimationof increases in fuel consumption over a 5000 km distance travelled by the two types of buses isdetermined below:

4. 6.1. Fuel Savings through Scheduled Maintenance, DAF (VDL) BUSES

The efficiency of the DAF buses is 2.775 km/L, when serviced after travelling 5000 km and 2.576 Km/L when not serviced after travelling over the same distance.

In each case, the fuel consumed (C) can be calculated by dividing the distance travelled by the engine efficiency with consumption after servicing and consumption when not serviced is denoted C_1 and C_2 respectively.

Hence, the quantity of fuel consumed C_1 when serviced is given by:

$$C_1 = \frac{\text{Distance (km)}}{\text{Engine Efficiency (km/}l\text{)after servicing}} = \frac{5000 \text{ km}}{2{,}775 \text{ km/}l} = 1{,}799 \textit{ litres}$$

In a similar way, the quantity of fuel consumed C_2 when not serviced is given by:

$$C_2 = \frac{\text{Distance (km)}}{\text{Engine Efficiency (km/}l\text{) when un-serviced}} = \frac{5000 \text{ km}}{2{,}576 \text{ km/}l} = 1{,}939 \textit{ litres}$$

Thus the increase in fuel consumption due to lack of Scheduled Maintenance is:

$C_2 - C_1$= 1,939 litres - 1,799 litres = 140 litres

This means that in the absence of scheduled maintenance, an additional 140 litres of fuel is required to travel the same distance of 5000 km. The monetary value at any time is obtained by multiplying the current price per litre of diesel by the 140 litres. The present price per litre of diesel courtesy Engen Oil Ghana Limited (27 May 2012) was GH¢1.724.

This therefore means that the increased amount of money spent on fuel to travel 5000 km when the bus is not serviced is:

Additional Amount = 140 x 1.724 = GH¢241.36

4. 6.2. Fuel Savings through Scheduled Maintenance, YAXING BUSES

A similar procedure as outlined in section 4.6.1 above can be followed for the fuel economy in respect of the YAXING buses

Hence, the quantity of fuel consumed C_1 when serviced is given by:

$$C_1 = \frac{\text{Distance (km)}}{\text{Engine Efficiency (km/}l\text{)after servicing}} = \frac{5000 \text{ km}}{2{,}760 \text{ km/}l} = 1{,}812 \textit{ litres}$$

In a similar way, the quantity of fuel consumed C_2 when not serviced is given by:

$$C_2 = \frac{\text{Distance (km)}}{\text{Engine Efficiency (km/}l\text{) when un-serviced}} = \frac{5000 \text{ km}}{2{,}550 \text{ km/}l} = 1{,}961 \textit{ litres}$$

Thus the increase in fuel consumption due to lack of Scheduled Maintenance is:

$C_2 – C_1$= 1,961litres - 1,812litres = 149litres

This means that in the absence of scheduled maintenance, an additional 149 litres of fuel is required to travel the same distance of 5000 km. The monetary value at any time is obtained by multiplying the current price per litre of diesel by the 149 litres.

This therefore means that the increased amount of money spent on fuel to travel 5000 km when the bus is not serviced is:

Additional Amount = 149 x 1.724 = GH¢256.88

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Out of three organizations contacted for permission to collect data from their workshops, two were found to be non-compliant with their own scheduled inspection and preventive maintenance schedules due to lack of finances. Scheduled inspection and preventive maintenance do not only yield environmental benefits by reducing greenhouse gas such as carbon dioxide (CO_2), and other pollutants like particulate matter measuring 10μm (PM10), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Ozone (O_3), Lead (Pb) in PM10, and Manganese (Mn) in PM10 but also confer substantial financial benefitsbrought about through improvement in engine efficiency, reducing maintenance and repair (M&R) costs over time, and increased operating longevity. This in turn promotes fuel economy.

However a percentage difference of 24% between a maximum value of the most efficient engines (3.118 km/l) and the minimum of the least efficient (2.385 km/l) were observed in this study suggesting that among other things some of the engine management systems might not be working effectively.For this same reason, optimal results were not achieved in emission reduction, engine efficiency and fuel economy, relative to the designed levels.Other factors such as traffic congestion may accounts for this.

Although engine efficiency declines and exhaust emissions increase linearly with distance traveledthe study showed that scheduled inspection and preventive maintenance led to a significant (70%) reduction in the exhaust emission, 30% less than the original performances which may be attributed to the inefficiency in other engine systems.

The study establishes that scheduled inspection and preventive maintenance improves engine efficiency significantly andtherefore reduces both exhaust emission and fuel consumption. Also there is the need for additional 140 and 149 litres of fuel in order to travel a distance of 5000 km by the DAF and YAXING buses respectively if preventive maintenance is ignored. These when quantified in monetary terms indicate progressive increase in loss with distance travelled after servicing. This therefore is an indication of greater loss incurred when vehicles in operation are not maintained.

5.2. RECOMMENDATIONS

With the optimal engine performance as per the operating manual of the buses being 3.2 km/l, all vehicles with engine performances below 2.5 km/l as indicated in some test resultsof this study, should be properly re-examined to identify and replace or rectify failing components that may cause inefficient engine operation.

There should be intensified education by stakeholders namely the EPA Ghana, DVLA and MTTU on the effect of driving pattern (including gear-changing habits and speed profile) and other habits that cause increased-exhaust emission and hence air pollution. During education, the emphasis should be on the loss-distance dynamics associated with maintenance.

Exhaust emissions regulation should not only involve smoke levels inspection and perhaps On-board diagnostics (OBD) of emission control systems during vehicle registration, road worthiness renewals by Driver and Vehicle Licensing Authority (DVLA), random traffic officers but should also include a comprehensive scheduled inspection and maintenance programme for vehicle owners as well as organizations. They should be held accountable for noncompliance through a credible audit system by the EPA.

Given the importance of scheduled inspection and preventive maintenance, all vehicle operators (including government and non-governmental institutions and organization) should be well resourced and encouraged to undertake such practices.

Disease control units of Municipal and Metropolitan assemblies should be involved in the implementation process of emission policies, to facilitate quick assessment of the impact of standards on air quality related diseases and if need be, recommend more stringent measures.

Strategies should be adopted to address air quality and the maintenance of clean cities. These should include an aggressive vehicle and equipment maintenance program to ensure regular engine tune-ups and car maintenance checks. Follow manufacturer's recommendation to avoid fuel economy problems due to worn spark plugs, dragging brakes low transmission fluids etc.

National air quality legislation should make it mandatory for all businesses that require environmental permit to operate to have an environmental office with well-defined goals which must be part of the company's vision statement. This is key for the creation of environmental awareness, training of workers and effective compliance with environmental policies and standards.

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APPENDIX I

LIST OF MAINTENANCE PLANS

Table 1

MAINTENANCE FORM DAF TB 2175 PF

W.O.Number: …………………

Date:	Bus nr:	Km:	Maintenance: ……………

P	A	B	In the bus.		PF
			Check instrument penal, all functions		
			Check dashboard lights, interior lights and destination lights		
			Lubricate drivers chair, check working and adjusting.		
			Check operations of horn, wipers, washer and defroster.		
			Check steering, play and abnormal operation.		6.4
			Check clutch pedal and gearlever.		8.2
			Check level clutch fluid.		8.1
			Check for damages passenger seats, handrails and stairs.		
			Check for damages on the floor (damages by water)		
			Check all doors (operational) and windows and sliding windows.		
P	**A**	**B**	**Around the Bus**		**PF**
			Visual checking paint, logos, number plates, damages and corrosion.		
			Check lights, front and rear. Adjust headlights if necessary.		
			Tyres and rims damages and wearing.		8.14
			Check attachment of wheels. **(Retorque 700 Nm).**		8.15
			Check pressure of the tyres./ replace loosen caps		8.16
			Lubricate hinges, locks of doors and panels.		
			Check damages and attachment on mirrors.		
			Check windscreen-, wipers and mechanism on wearing or damages.		
			Check and clean battery connections.		1.1
			Check battery fluid level, topping up if necessary.		1.2
			Check earthing- and plus terminals of the chassis.		1.3
			Check level power steering fluid.		6.1
			Renew filter power steering.		6.2
			Check level of engine oil.		
			Check coolant level.		5.2
			Clean between radiator and intercooler use special tool.		5.6
P	**A**	**B**	**Under the Bus**		**PF**
			Clean chassis with cold water.		Page 9
			Check chassis frame on damages and corrosion.		
			Check suspension front and rear. U-bolt, centre bolt and broken leaves.		
			Check for body mountings and looseness bolts and nuts.		
			Check shock absorbers and stabilisers front – and rear axel.		
			Check steering system ball joint . check rubbers for damages.		6.5
			Check toe-in, kingpin play and wheel bearing play.		6.7
			Clean and grease wheel bearings. Only maintenance **B4,B8,B12** etc.		8.13
			Lubricate kingpin **(lift front axle)**		9.2
			Lubricate shackle pins front and rear axel		11.4
			Lubricate spring shackles front and rear axel		11.4
			Lubricate slack adjusters front and rear axel		11.4
			Lubricate brake camshaft front and rear axel.		11.4
			Lubricate propeller shafts the universal and sliding joints.		9.2
			Check propeller shaft for wearing.		9.1

91D DAF & YAXING

OLD DAF AND YAXING BUS CONTINUATION

P	A	B			PF
			Check shaft centre bearing for wearing.		
			Check propeller shaft bolts and nuts.		
			Check Telma on mounting, electric wiring system and air gap		8.11
			Check thickness of brake lining front and rear axel.		7.3
			Check brake hoses and measure the brake travel. (max. 45 mm)		7.4
			Adjust, if necessary, the slack adjusters and check wearing centre pin!!!!		7.5
			Check oil level gearbox		8.9
			Renew oil gearbox and clean breather.		8.9/8.10
			Check oil level oil rear axel hubs/differential		8.3
			Renew oil rear axel hubs/differential and clean breather.		8.4
			Check oil, fuel, coolant and air leakages under vehicle.		
			Check air reservoir for condensate and oil.		7.1
P	**A**	**B**	**Engine**		**PF**
			Clean engine with hot water cleaner.		Page 9
			Check bolts of engine mounting.		5.9
			Clean outer air cleaner filter by air. **(inside – outside)**		
			Renew air cleaner filter. **inner filter at B4 maintenance or 100 000 Km.**		4.2
			Check turbo compressor on damage, dirt and play inside.		
			Check bolts of intake and exhaust manifold on attachment and leakage.		4.3
			Remove injectors and clean nozzles, check and adjust pressure. **B4.maintenance**		3.6
			Check or adjust valve clearance. **B4 maintenance**		4.1
			Compression test. **B4 maintenance**		2.4
			Change engine oil. ****Take oil sample**		2.1
			Renew oil filter.		2.2
			Renew fuel filter.		3.3
			Clean hollow screw in fuel system. (in feed pump).		3.4
			Remove water separator and clean inside.		3.1
			Check water separator on water if necessary drain fuel tank		3.1
			Renew coolant filter.		5.4
			Check V-belt on worn out or damages.		4.5
			Lubricate throttle control unit. Check max. and min. bolt.		3.9/10.1
			Renew filter air dryer.		5.7
			Check the presence of oil in the air system.		7.1
			Check air compressor and air dryer.		5.8
			Test by inspector		**inspector**
			Check engine for easy starting.		
			Check engine oil pressure and all instrument on dashboard.		
			Test all driving and braking.		
			Visual check exhaust smoke.		
			Check filling air system.		
			Check repairs and maintenance.		
			Check tachograph on speed and distance		

✓ = **Checked**

-- = **Needs repair.**

\+ = **Is repaired**

Inspector: ....

Date : ....

Signature: ....

DAF VDL BUS
Table 2
MAINTENANCE FORM DAF TB 2175 PE

W.O.Number: …………………

Date:	Bus nr:	Km:	Maintenance: ……………

P	A	B	C	In the bus.
				Before tests drive check by Davie faults in Upec motor management. Clear the system
				Check instrument penal, all functions
				Check dashboard lights, interior lights and destination lights
				Lubricate drivers chair, check working and adjusting.
				Check operations of horn, wipers, washer and defroster.
				Check steering, play and abnormal operation.
				Check clutch pedal and gearlever.
				Check level clutch fluid.
				Check for damages passenger seats, handrails and stairs.
				Check for damages on the floor (damages by water)
				Check all doors (operational) and windows and sliding windows.

P	A	B	C	Around the Bus
				Visual checking paint, logos, number plates, damages and corrosion.
				Check lights, front and rear. Adjust headlights if necessary.
				Check tyres and rims on damages and wearing.
				Check attachment of wheels. **(Retorque 700 Nm).**
				Check pressure of the tyres./ replace loosen caps
				Lubricate hinges, locks of doors and panels.
				Check damages and attachment on mirrors.
				Check windscreen wipers and mechanism on wearing or damages.
				Check and clean battery connections.
				Check battery fluid level, topping up if necessary.
				Check earthing- and plus terminals of the chassis.
				Check level power steering fluid.
				Renew filter power steering.
				Check level of engine oil.
				Check coolant level.
				Clean radiator outside (with air pressure max 3 bar)

P	A	B	C	Under the Bus
				Clean chassis with cold water.
				Check chassis frame on damages and corrosion.
				Check suspension front and rear. U-bolt, centre bolt and broken leaves.
				Check for body mountings and looseness bolts and nuts.
				Check shock absorbers and stabilisers front – and rear axel.
				Check steering system ball joint . check rubbers for damages.
				Check toe-in, kingpin play and wheel bearing play.
				Lubricate kingpin **(lift front axle)**
				Lubricate spring pins front and rear axel
				Lubricate propeller shafts.

DAF VDL BUS

CONTINUATION

P	A	B	C	
■				Check propeller shaft for wearing.
■				Check shaft centre bearing for wearing.
■				Check propeller shaft bolts and nuts.
				Check thickness of brake lining front and rear axel.
				Check the brake disc on wearing or damage
■				Check oil level gearbox
■	■			Renew oil gearbox and clean breather.
■				Check oil level differential.
■	■			Renew differential oil and clean breather.
				Check oil, fuel, coolant and air leakages under vehicle.
				Check air reservoir for condensate and oil.
P	**A**	**B**	**C**	**Engine**
■	■			Clean engine with hot water cleaner.
■	■			Check bolts of engine mounting.
				Clean outer air cleaner filter by air. **(inside – outside)**
■	■			Renew outer air cleaner filter.
■	■	■		Renew safety air cleaner filter
■	■	■		Check turbo compressor on damage, dirt and play inside.
■				Check bolts of intake and exhaust manifold on attachment and leakage.
■	■	■		Remove injectors and clean nozzles, check and adjust pressure.
■	■	■		Check or adjust valve clearance.
■	■	■		Compression test
■				Change engine oil. ****Take oil sample**
■				Renew oil filter.
■				Renew fuel filter.
■				Clean filter in fuel system. (in feed pump).
■	■			Remove water separator and clean inside.
■				Check water separator on water if necessary drain fuel tank
■	■			Renew coolant filter.
■				Check V-belt on worn out or damages.
■	■			Renew filter air dryer.
				Check the presence of oil in the air system.
■				Check air compressor and air dryer.
P	**A**	**B**	**C**	**Test drive**
■				Check engine for easy starting.
■				Check engine oil pressure and all instrument on dashboard.
				Visual check exhaust smoke.
				Check filling air system.
				Check tachograph on speed and distance
■	■			After test drive check Upec system by Davie.

✓ = **Checked**
-- = **Needs repair.**
\+ = **Is repaired**

Inspector: ....
Date : ....

Signature: ....

APPENDIX II

LIST OF ANOVA TABLES

ANOVA TABLE 1 EMISSION -DAF

ANOVA Table 1a: opacity levels measured before initial servicing at (5000 km), at 2000km distance traveled and at 5000 km before final servicing

Test before servicing at:	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 km	60	7.94	5.44	0.70	6.54	9.35	1.10	23.70
2000 km	60	5.33	2.84	0.37	4.60	6.07	1.10	15.20
5000 km	60	8.46	6.16	0.80	6.87	10.05	1.10	29.80
Total	180	7.24	5.18	0.39	6.48	8.01	1.10	29.80

ANOVA

Table 1b: opacity levels measured before initial servicing at (5000 km), at 2000km distance traveled and at 5000 km before final servicing

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	337.21	2	168.60	6.69	0.002
Within Groups	4461.68	177	25.21		
Total	4798.88	179			

DAF VEHICLES

ANOVA Table 2a: Initial emission (opacity) levels, before and after servicing (5000 km)

Initial category 'A' servicing	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before Servicing	60	7.94	5.44	0.70	6.54	9.35	1.10	23.70
After Servicing	60	2.32	1.30	0.17	1.99	2.66	0.20	5.80
Total	120	5.13	4.84	0.44	4.26	6.01	0.20	23.70

ANOVA

Table 2b: Initial emission (opacity) levels, before and after servicing (5000 km)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	946.97	1	946.97	60.56	0.000
Within Groups	1845.17	118	15.64		
Total	2792.14	119			

DAF VEHICLES

ANOVA Table 3a: Final opacity levels, before and after servicing at (5000 km)-DAF vehicle

Final category ‘A’ servicing	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before Servicing	60	8.46	6.16	0.80	6.87	10.05	1.10	29.80
After Servicing	60	2.65	1.30	0.17	2.32	2.99	0.90	6.90
Total	120	5.56	5.31	0.48	4.60	6.52	0.90	29.80

ANOVA

Table 3b:.Final opacity levels, before and after servicing at (5000 km)-DAF vehicle

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1012.10	1	1012.10	51.05	0.000
Within Groups	2339.63	118	19.83		
Total	3351.74	119			

YAXING VEHICLES

ANOVA Table 4a: opacity levels measured before initial servicing at (5000 km), at 2000 km distance traveled and at 5000 km before the final servicing

Test before servicing at:	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 km	30	4.87	1.18	0.22	4.43	5.31	2.80	6.70
2000 km	30	3.04	0.84	0.15	2.72	3.35	1.90	5.10
5000 km	30	5.27	1.04	0.19	4.88	5.65	3.10	6.90
Total	90	4.39	1.41	0.15	4.10	4.69	1.90	6.90

ANOVA

Table 4b: opacity levels measured before initial servicing at (5000 km), at 2000 km distance traveled and at 5000 km before the final servicing

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	120.13	1	120.13	143.62	0.000
Within Groups	48.52	58	0.84		
Total	168.65	59			

YAXING VEHICLES

ANOVA Table 5a: Initial opacity levels, before and after servicing at 5000km

Initial category 'A' servicing	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before servicing	30	4.87	1.18	0.22	4.43	5.31	2.80	6.70
After servicing	30	2.04	0.53	0.10	1.84	2.24	1.10	2.90
Total	60	3.46	1.69	0.22	3.02	3.89	1.10	6.70

ANOVA

Table 5b: Initial opacity levels, before and after servicing at 5000km

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	120.13	1	120.13	143.62	0.000
Within Groups	48.52	58	0.84		
Total	168.65	59			

YAXING VEHICLES

NOVA Table 6a: Final emission (opacity) levels, before and after servicing (5000 km)-YAXING vehicle

Final category 'A' servicing	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Before servicing	30	5.27	1.04	0.19	4.88	5.65	3.10	6.90
After servicing	30	2.20	0.45	0.08	2.04	2.37	1.10	3.10
Total	60	3.74	1.74	0.22	3.29	4.18	1.10	6.90

ANOVA

Table 6b: Final emission (opacity) levels, before and after servicing (5000 km)-YAXING vehicle

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	140.76	1	140.76	220.55	0.000
Within Groups	37.02	58	0.64		
Total	177.78	59			

ANOVA TABLE 1 F.CONSUMPTION

ANOVA Table 7a: Engine performance after initial servicing at 5000 km
to 2000km of distance traveled – DAF VDL

Engine performance from:	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
After initial servicing 0 Km	20	2.78	0.21	0.05	2.68	2.87	2.35	3.12
to 2000 km	20	2.73	0.19	0.04	2.64	2.82	2.39	3.08
Total	40	2.75	0.20	0.03	2.69	2.82	2.35	3.12

ANOVA

Table 7b: Engine performance after initial servicing at 5000 km
to 2000km of distance traveled – DAF VDL

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.02	1	0.02	0.51	0.48
Within Groups	1.53	38	0.04		
Total	1.55	39			

ANOVA TABLE 2 F. CONSUMPTION

ANOVA Table 8a: Engine performance (efficiency) from 2000 to 5000 km distance traveled DAF VDL

Engine performance from:	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
2000 km to	20	2.58	0.12	0.03	2.52	2.63	2.39	2.88
5000 km	20	2.73	0.19	0.04	2.64	2.82	2.39	3.08
Total	40	2.65	0.17	0.03	2.60	2.71	2.39	3.08

ANOVA

Table 8b: Engine performance (efficiency) from 2000 to 5000 km distance traveled – DAF VDL

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.24	1	0.24	9.44	0.004
Within Groups	0.95	38	0.03		
Total	1.19	39			

ANOVA TABLE 3 F. CONSUMPTION

ANOVA Table 9a: Engine performance (efficiency) between initial servicing at (5000 km) and final servicing after another 5000km distance traveled – DAF VDL

Engine performance from:	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 km to	20	2.78	0.21	0.05	2.68	2.87	2.35	3.12
2000 km and to	20	2.73	0.19	0.04	2.64	2.82	2.39	3.08
5000 km	20	2.58	0.12	0.03	2.52	2.63	2.39	2.88
Total	60	2.69	0.20	0.03	2.64	2.74	2.35	3.12

ANOVA

Table 9b: Engine performance (efficiency) between initial servicing at (5000 km) and final servicing after another 5000km distance traveled – DAF VDL

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.44	2	0.22	6.85	0.002
Within Groups	1.81	57	0.03		
Total	2.25	59			

ANOVA Table 10a Engine performance after initial servicing at 5000km to a distance of 2000km travelled - YAXING

Engine performance from	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
	10	2.76	0.20	0.06	2.62	2.91	2.37	3.00
0 to 2000km	10	2.71	0.11	0.04	2.63	2.80	2.53	2.87
Total	20	2.74	0.16	.04	2.66	2.82	2.37	3.00

ANOVA Table 10b: Engine performance after initial servicing at 5000 km to 2000km of distance traveled – YAXING

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.01	1	.013	0.47	0.504
Within Groups	0.48	18	.027		
Total	0.50	19			

ANOVA Table 12a: Engine performance (efficiency) from 2000 to 5000 km distance traveled YAXING

Engine performance from	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
	10	2.71	0.11	.036	2.63	2.80	2.53	2.87
2000 – 5000km	10	2.55	0.08	.026	2.49	2.61	2.39	2.68
Total	20	2.63	0.13	.028	2.57	2.69	2.39	2.87

ANOVA Table 12b: Engine performance (efficiency) from 2000 to 5000 km distance traveled – YAXING

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.13	1	0.13	13.25	0.002
Within Groups	0.18	18	0.01		
Total	0.31	19			

ANOVA Table 13a: Engine performance (efficiency) between initial servicing at (5000 km) and final servicing after another 5000km distance traveled – YAXING

Engine performance from	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 to 2000Km	10	2.76	0.20	0.06	2.62	2.91	2.37	3.00
to 5000Km	10	2.71	0.11	0.04	2.631	2.80	2.53	2.87
	10	2.55	0.08	0.03	2.49	2.61	2.39	2.68
Total	30	2.68	0.16	0.03	2.62	2.74	2.37	3.00

ANOVA Table 13b: Engine performance (efficiency) between initial servicing at (5000 km) and final servicing after another 5000km distance traveled – YAXING

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.24	2	0.12	6.03	0.007
Within Groups	0.54	27	0.02		
Total	0.79	29			