CHARACTERIZATION OF ON-ROAD PETROL VEHICLE EMISSIONS PATTERNS IN DAR ES SALAAM CITY (TANZANIA)

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ABSTRACT

Motor vehicle emissions have been identified to be the major source of air pollution in most urban cities. It has serious impact on urban air quality and public health. The Governments of many countries need to adopt stringent vehicle emissions regulations to protect the air quality, the undertaking of which can only be implemented once the problem at hand is known. In the present study, the characteristics of on road vehicle emissions from the selected local areas at the city of Dar es Salaam in a developing country for in-use petrol vehicles for urban driving conditions ranging from idling, 10km/h to 70km/h have been studied under the in situ measurements. This is equivalent to the European On Board Diagnostic, EOBD, testing systems. The measured vehicle exhaust emissions concentrations from the testing system have been further calculated into the vehicle emission factors for different driving conditions. The results indicate that on-road vehicle driving conditions and road characteristics have a direct effect on the characterization of vehicle emission factors. A modest correlation of the calculated average emission factors has been realized when compared with results from other countries and world bodies on the authority.

Key words: Motor vehicle emissions; Gaseous emission factors, European on board Diagnostic System

1. INTRODUCTION

Forecasting technologies reveal that increase in population in the world and especially in the cities of the developing countries by the year 2015 shall result in 27 out 33 cities of more than 8 million inhabitants in the world to be in developing countries (Thomson, 2000). By 2025, 49% of African's residents will live in cities of more than a million people (World Bank, 1992). Growth in population creates more demand for food and services including transport. Tanzania road transport accounts for 60% of the transport sector with the inevitability result in increased consumption of petroleum fuels.

The overall fuel consumption in urban traffic involves a number of interactions with complex traffic systems. The interactions and their complexities vary in all urban centres and more so in developing country cities. The utilization of fuel for transport has resulted into inevitable exhaust gas emissions.

Motor vehicle emissions are the major source of air pollution problems in most urban cities (Mayer, 1999, Chan et al., 2004). The Government of Tanzania has also identified motor vehicles emissions as the major source of urban air pollution in Dar es Salaam (Mwandosya and Meena, 1996, Mulingwe and Kassenga, 1997). It is one of the reasons for choosing the area and also of the fact that more than 60% of the total number of vehicles in Tanzania operate in the city, a normal scenario in many cities of developing countries. For the protection of atmospheric environment, the Government of Tanzania and others of developing countries need as a matter of urgency to put in place stringent vehicle emission regulations. To initiate and support this, many vehicle emission measurements have been carried out to provide criteria for determining the emission reduction, and evaluating the effectiveness of emission control strategies and regulations in order to meet the clean and or better air quality goals.

The most commonly used procedures for quantifying vehicle emissions are the US Federal Test, The United National Economic Commission for Europe (ECE) and the Japanese Test Procedures which deploy the real time data. The characteristics of vehicle emissions standard using the real time testing system have been widely used. McKain and Clark (1999) used the system to develop the regression of vehicle speed and power for the quality control of heavy duty vehicles. Recently, Hawley et al (2003) have carried out the time-alignment sensitivity studies to assess the accuracy of instantaneous No_x emissions on mass basis using the system. Jourmard et al (2003) have tested 39 light duty diesel vehicles deploying the system. The results from the said showed that there is an influence of the average cycle speed, load and vehicle category on vehicle emissions.

The obtained closures are not necessary the best in real situation and in particular in developing country cities such as Dar es Salaam. This is because they are derived from different vehicle, traffic and driving conditions. Real life in developing country cities is characterized by rarely serviced motor vehicles driven at random speeds, on bad and narrow roads. In most cases, motor vehicle stops and idling are the order of the day. Existing models to characterize the vehicle emissions persistent in developing country cities cannot be inferred here as they contain variables whose data are not only uncommon but also difficult to determine. Since the late 1980s, new vehicle emission measurement techniques are in development to measure the instantaneous vehicle exhaust emission profiles from vehicles (Bishop and Stedman, 1990). The testing systems use sampling techniques to measure the gaseous concentration such as CO, CO_2, HC and NO from the vehicle exhaust tailpipe on the roadway. Pokharel et al (2001) and Chan et al (2004) have deployed the system successful.

Hence, the aim of the current study is intended to investigate the characteristics of on road vehicle emissions from the selected local representative in-use petrol vehicles (carbureted, fuel injection systems) for urban driving conditions applicable in Dar es Salaam city, Tanzania ranging from idling, 10km/h to 70km/h. The fuel consumption patterns are superimposed solely as a contribution to the source of emissions.

2. EXPERIMENTAL METHODOLOGY

Four local categories representative in-use petrol vehicles totaling 60 vehicles namely; 15 each of; carbureted serviced, carbureted un-serviced, fuel injection serviced and un-serviced saloon cars, were selected. These represent over 70% of the total number of vehicles plying in Dar es Salaam. It is recorded that over 80% of these are imported reconditioned from the Japanese market. These were considered along side with their drivability on road surface finish type to include asphalt road gravel and earth roads at speeds typical of to be encountered in Dar es Salaam. The speeds considered are 10km/hr to 70km/hr. Additionally, for fuel consumption pattern, 30 minibuses and 30 light trucks were involved in the study.

In situ Testing System

The test method involved road testing for measuring vehicular fuel consumption and the corresponding gas emissions from the 120 selected vehicles. For emissions study, these comprised of vehicles of engine capacity of less than 2000 c.c., in the categories deploying carburetor and fuel injection system. For each category, measurements were undertaken for a total of 15 vehicles for each of regularly serviced vehicles (serviced for at least after every 5,000km and un-serviced vehicles- those which have not been serviced for at least 10,000km).

For fuel consumption patterns, these included the Direct Injection, serviced vehicles in addition to diesel propelled minibuses of 3500 c.c., engine capacity and light trucks of similar capacity. The test result can be used to study the vehicles' exhaust gases to understand how to protect and improve the urban air quality. The selected vehicles were tested to collect the emission data of the vehicles under different driving conditions. The emission data are converted to emission factors which can be used to build up the emission factor database and are important parameters as the input values of the line source emission dispersion models.

During the study, the vehicles were tested for different road surface finish namely; asphalt road, gravel road and earth road under the in situ testing system to measure the gaseous emissions of CO, CO_2, HC and NO; together with the vehicular fuel consumption at each instance. The CO, CO_2, HC and NO emissions from the vehicle tailpipes were measured using an Infrared Gas Analyzer model HGA 400, a Crystone, UK, CO Infrared Gas Tester. The vehicle fuel consumption was measured by the Germans made, EDM Model 1404 Electronic fuel flow meter. To ensure the repeatability of the data, each of the vehicles categories was tested for at least 50 times. The exhaust gaseous emissions concentrations of CO, CO_2, HC and NO, vehicle speed data and vehicles fuel consumption profile were recorded simultaneously.

3. DATA ANALYSIS

3.1 Vehicle Fuel Consumption

The predicator variables for motor vehicle fuel consumption and emissions are dependent on variables determined directly from the location and structure characteristics and normal practice within the particular city (Strandh, *http:/ www.vok. lth. Se/)*. These are; *known variables* which include road surface conditions, road profile, vehicle loading conditions and the vehicle average speed; *dependent variables* which result from human behaviour and traffic conditions such as driver's behaviour, number of vehicle starts/stops, vehicle idling time and distance covered; and *unknown variables* change with time and they are number, size and condition of vehicles, motor vehicle owner's income and the type and price of fuel. These assumptions indicate that every amount of fuel consumed by motor vehicles in a given city has the effect and contribution of every predicator variable. Based on this, it is possible to formulate an empirical relationship between the total fuel consumed FC, number of vehicles n, and the corresponding distance covered in a given period of t days as;

$$FC = t\sum_{i=1}^{n} n_i \left[f_o + f_a d_a + f_g d_g + f_e d_e\right] litres/period \qquad (1)$$

where n_i is the number of vehicles of size i, f_o is average fuel consumed (litres) per day by an idling vehicle, f_a, f_g, and f_e are average fuel consumed per kilometer by moving vehicles on asphalt, gravel and earth road sections respectively. d_a, d_g and d_e are the corresponding average distances (kilometer) traveled per day on the respective road surface finish.

The values of , f_o, f_a, f_g, and f_e are constants which contain specific complex variables related to environmental factors, vehicle and traffic conditions and human behaviour. Specifically, f_o, contains; the number of vehicle stops, vehicle condition and the behaviour of drivers when the vehicle is idling. f_a, f_g, and f_e contains road profile and condition, vehicle mechanical and loading conditions, vehicle speed variations, environmental factors, driver behaviour, vehicle owner's income and the type and composition used

The variables in equation 1 were generated for a period of six months and grouped the motor vehicle fuel consumption equations according to type/use, type/condition of road to generate two sets of four fuel consumption equations for petrol (saloon cars) and minibuses, light trucks. The process resulted in a linear system of equations of the forms;

$$\left.\begin{cases} a_{11}f_o + a_{12}f_a + a_{13}f_g + a_{14}f_e & = b_1 \\ a_{21}f_o + a_{22}f_a + \ldots\ldots + a_{24}f_e & = b_2 \\ . & \\ . & \\ . & \\ a_{51}f_o + a_{52}f_a + \ldots\ldots + a_{54}f_e & = b_5 \end{cases}\right\} \qquad (2)$$

where a_{ij} (i = 1….5; j = 1….4) and b_i (i = 1…5) are constants obtained from the field (historical data) and f_o, f_a, f_g, and f_e are the unknown daily vehicular fuel consumption rates.

The system of equations represented by equation 2 is 5-linear equation in 4 unknowns. The solution of the equation was by the MAPLE computer software to obtain a specific empirical fuel consumption model for a given type of motor vehicles in operation in Dar es Salaam city. The validation of the output was made against fuel consumption quantities measured on in use vehicle in the city. The solution to these equations gave averagely daily vehicular fuel consumption rates in l/100km for saloons, petrol vehicles as 16 litres. The corresponding rate for minibuses and light trucks is 20 litres for the same distance coverage. Solution to equation 2 resulted into vehicular fuel consumption estimation models for petrol propelled saloon vehicles and minibuses, light trucks given respectively by the following equations;

Saloon (Petrol Propelled)

$$FC_1 = \frac{n_1 t}{100}\sum 191 + 14d_{a1} + 15d_{g1} + 19d_{e1}\ l\,/\,period \qquad (3)$$

and

Minibuses and Light Trucks (Diesel Propelled)

$$FC_1 = \frac{n_2 t}{100}\sum 585 + 17d_{a2} + 19d_{g2} + 25d_{e2}\ l\,/\,period \qquad (4)$$

where FC is the total fuel consumed in litres per period, n is the number of vehicles, t is period of period in days, d_a, d_g and d_e is distance covered by a vehicle in kilometers per day on asphalt, gravel and earth road sections respectively.

3.2 Vehicle Emission Factors

Vehicle tailpiece exhaust emissions were measured in order to determine the emissions factors characteristics of Dar es Salaam city.

Many vehicle emission factors models based on the emission measurements have been used widely in order to estimate the emissions contribution from motor vehicles to urban air pollution (Jost et al.,1994, Jourmard et al., 1995). However, the vehicle emissions are highly dependent on the instantaneous vehicle speed profiles and the atmospheric disturbance on the vehicle exhaust plume at the local conditions. Hence, an emission factor model based on the measured emission data simulated to the on-road remote sensing vehicle exhaust emission testing system and a correlation of on-road vehicle emission rates of CO and HC and the instantaneous vehicle speed profiles were developed (Yu, 1998) which involve in situ measurements of the volume concentration of emissions. Emission conversion method used by Pokharel et al (2001) and Chan et al (2004) were deployed. The conversion equations in mass emission concentrations (Pokharel et al., 2001) were expressed as follows;

$$E_{CO}\ (g/l) = \frac{28 \times \dfrac{\%CO}{\%CO_2}}{\dfrac{\%CO}{\%CO_2} + 1 + (3 \times \dfrac{\%HC}{\%CO_2} / 0.493)} \cdot \frac{1}{M_{fuel}} \cdot \rho_{fuel} \qquad (5)$$

$$E_{HC}\ (g/l) = \frac{44 \times \dfrac{\%HC}{\%CO_2} / 0.493}{\dfrac{\%CO}{\%CO_2} + 1 + (3 \times \dfrac{\%HC}{\%CO_2} / 0.493)} \cdot \frac{1}{M_{fuel}} \cdot \rho_{fuel} \qquad (6)$$

$$E_{NO}\,(g/l) = \frac{30 \times \dfrac{\%NO}{\%CO_2}}{\dfrac{\%CO}{\%CO_2} + 1 + (3 \times \dfrac{\%HC}{\%CO_2} / 0.493)} \cdot \frac{1}{M_{fuel}} \cdot \rho_{fuel} \qquad (7)$$

where M_{fuel} is the molar mass of fuel; ρ_{fuel} is the density of fuel.

For the diesel fuel, the carbon to hydrogen ratio is typically 1.85 and M_{fuel} is 0.01385 kg/mol while the density is 0.85kg/l; for the petrol fuels CH ratio is typical 2 and M_{fuel} is 0.014kg/mol and the density is 0.75kg/l (API, 2001). The individual gaseous emission EF_i (gm) can be calculated in terms of the following equation;

$$EF_i = E_{ij} . FC_j \qquad (8)$$

where E_{ij} is the average emission factor g/litre) of the ith gaseous emission of the jth vehicle. In urban traffic conditions the fuel consumption from the jth vehicle, FC_j (litres/period) may be determined from the expression in equation 3 and 4 for petrol and diesel vehicles respectively.

4. RESULTS AND DISCUSSION

4.1 Vehicle Fuel Consumption Pattern

Based on the measured fuel consumption from the representative of in use vehicles, the results and prediction from the formulated model is presented in Figure 1, the model underestimates the measured volume of fuel consumed by an average of at most 6.0% at distances shorter than 90 km per vehicle per day and overestimates the same to a maximum of about 3.0% for distances greater than this. The explanation to these observations is that at modest distances of about 90km/day making 10 trips, translates to distances of about 9 km per trip. Such trips are within the city and, the drivers would be driving in the almost idling mode thus over consuming fuel. At the other range of observations covered distances of over 90km/day, it entails the drivers to drive long distance without impendence thus driving at optimal range for fuel consumption thus overestimating the actual fuel by a small percentage than at the former range. These are additional phenomena which were not considered in the model formulation. Figure 2, shows similar observations for saloon vehicles characteristics albeit at 45 km/day at 60km/hr recorded speed. This outcome provides guidance to transport operators in Dar es Salaam in as far as a compromise between the number of vehicle to meet peoples transport requirements and the reduction in vehicle fuel consumption and exhaust emissions. It is clear that when large capacity buses are used, the given transport requirements will be met by a smaller number of such buses resulting in less fuel consumption for the same services rendered.

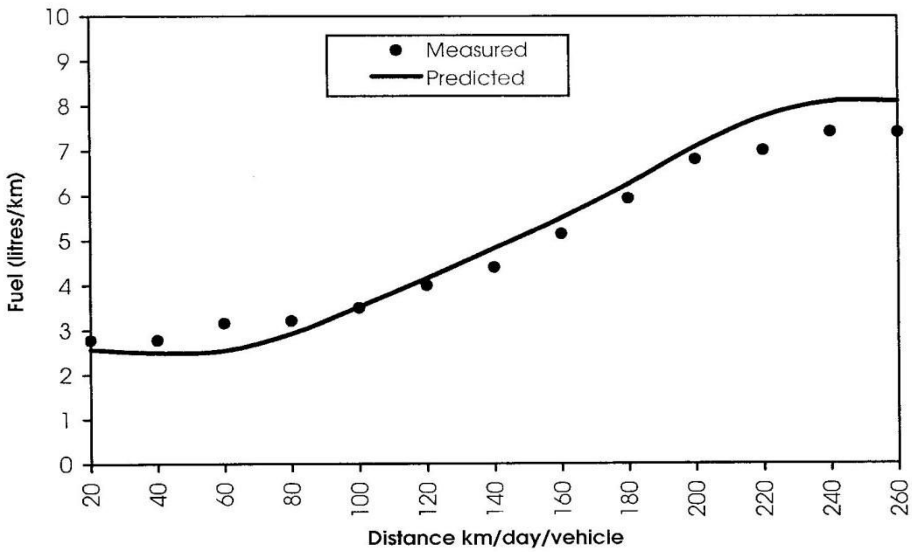

Figure 1: Measured and Predicted Fuel Consumption (l/km) pattern for Minibuses plying in Dar es Salaam

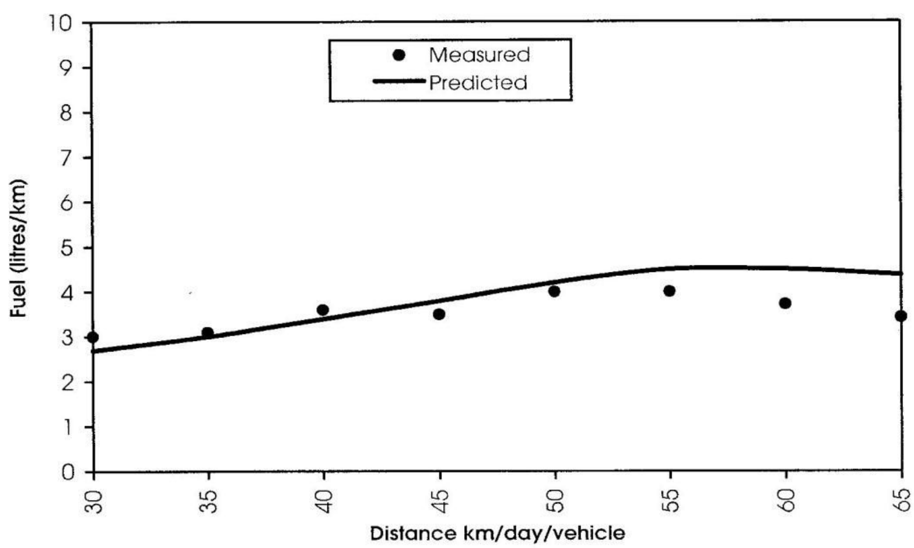

Figure 2 Measured and Predicted Fuel Consumption (l/km) pattern for saloon vehicles plying in Dar es Salaam

4.2 Vehicle Gaseous Emissions Factors

Vehicle gaseous emissions factors are discussed in view of the mostly used vehicles in Dar es Salaam which are saloon cars, both carbureted and those of direct injection fuel systems.

Based on the measured gaseous emissions of the selected local representative vehicles, the average vehicle gaseous emission factors of different fuelled vehicles for different engine speeds were calculated. Figures 3(a)-3(c) show the calculated average vehicle EF_{CO}, EF_{HC} and EF_{NOx} of Direct Injection and Carbureted vehicles in Dar es Salaam for different vehicle speed ranges of 10km/h to 70km/h.

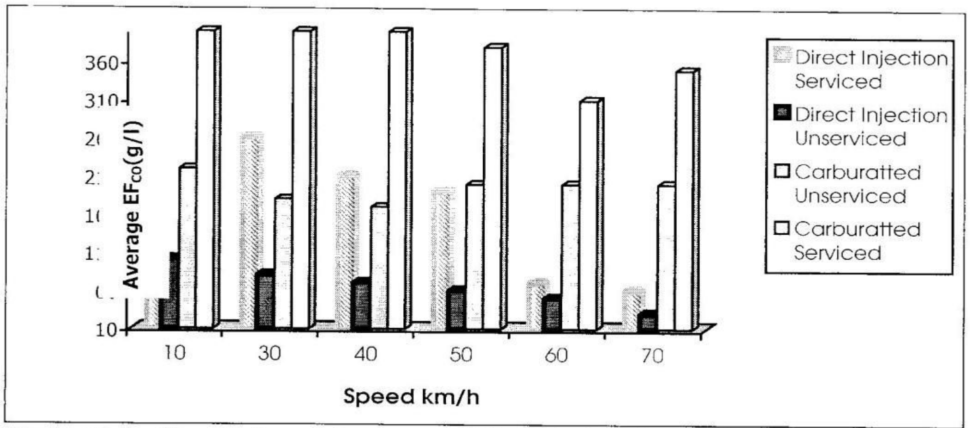

Figure 3(a): Comparison of average CO emission factor from a 4 cylinder, 1500 c.c. Carbureted and Direct Injection Saloon Cars in Dar es Salaam

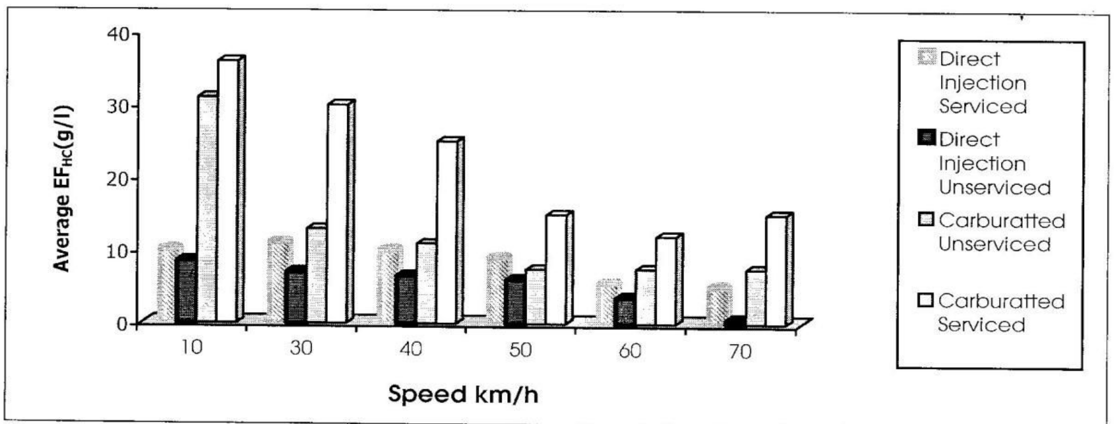

Figure 3(b): Comparison of average HC emission factor from a 4 cylinder, 1500 c.c. Carbureted and Direct Injection Saloon Cars in Dar es Salaam

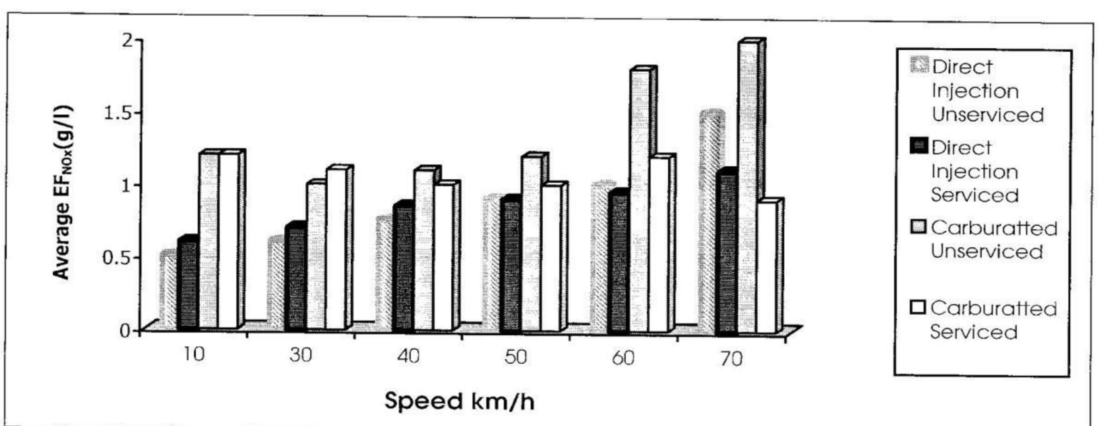

Figure 3(c): Comparison of average NOx emission factor from a 4 cylinder, 1500 c.c. Carbureted and Direct Injection Saloon Cars in Dar es Salaam

Generally, carburetted motor vehicles emit more CO and HC gases than their direct injection counterparts. On average, a carburetted engine emits about two to eight folds the amount of CO emitted by an equivalent direct injection engine. In both the carburetted and direct injection petrol vehicles, the concentration of CO and HC drops with rise in vehicle speed. As the vehicle speed increases, the concentration of CO_2 rises in carburetted vehicles but drops in the case of direct injection petrol vehicle. Emissions of NO_x from both the carburetted and direct injection petrol vehicles rise with vehicle speed.

These results are attributed to the difference between carburetted and fuel injection systems in petrol engines. In carburetted vehicles the air-fuel (A/F) mixture is controlled and delivered to the combustion chamber by the carburettor. The combustion of the carburettor makes it less accurate in metering the A/F mixture for complete combustion. It is not possible for the carburettor to meter accurately all fuel to the engine cylinders. Some cylinders can get richer mixture than others. As a result of these variations, instances of incomplete combustion are encountered. Inadequate oxygen in these cases results in the emission of CO. Furthermore, the layers of mass of fuels on the cylinder and piston head do not burn. The metal surfaces chill these layers below the combustion point and therefore, un-burnt fuel (HC) is swept out of the cylinder on the exhaust stroke.

In the fuel injection system, the fuel is metered more accurately and the same amount of fuel is supplied to each cylinder. The system uses an Electronic Control Unit (ECU), which monitors and delivers A/F mixtures in accordance with altitude temperature, speed and load requirements. In this, incomplete combustion cases are minimized.

Increase in vehicle speed is associated with more air-fuel stratification and consumption and therefore increased heat from the combustion process. Since heat activates combustion, high vehicle speeds result in more complete fuel combustion, which account for the drop in CO and HC emissions from both carburetted and direct injection vehicles. The burning of CO and HC to CO_2 and water results in the rise in CO_2 from carburetted vehicles operating at high speed. NO_x emissions are formed in the higher-temperature regions of the combustion flame by direct oxidation of the fuel bound nitrogen. The higher the speed, the higher the temperature of combustion and, therefore the higher the generation of NO_x emissions.

Assessment of the influence of serviced/not serviced vehicles on the emission was further undertaken. The result for EF_{CO}, EF_{HC} and EF_{NO} in Figures 3 reveals that serviced vehicles emit more CO than unserviced, this is the same for HC emission. NO emissions are observed to behave appositively.

It is noted that on average these factors are higher than those specified by the WHO guidelines for urban areas (WHO, 2000). IPPC (1991) recommend the values of 240, 1.74, and 12 for EF_{CO}, EF_{HC} and EF_{NOx} respectively for petrol vehicles. This study, therefore show that the petrol propelled vehicles in Dar es Salaam emit more of these gases than the limits dictated by the relevant authorities.

5. CONCLUSIONS

The characterization of on-road motor vehicle fuel consumption and emissions from selected local representative in-use vehicles for Developing country city driving conditions have been investigated. This has yielded two models one for predicting fuel consumption for light petrol fuel vehicle and another for light mini-buses and trucks using diesel fuel. The validation of the ensuing models predicted reasonably well the fuel consumption.

The measured vehicle exhaust emission concentrations from the in situ measuring of these have been further calculated into the vehicle emission factors for different petrol propelled vehicles commonly driven in Dar es Salaam. These show that the factors are grossly higher than those recommended by WHO. However, the overall trend of the result indicates that the vehicle type and service conditions have a direct effect on the characterization of vehicle gaseous emission factors.

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