VEHICULAR EXHAUST EMISSION ESTIMATION AND CONTROL MODELLING

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Abstract:- *Recent technology advances in automotive engineering have resulted in new type engine development with straight exhaust emissions and engine noise reductions. A systematic approach to evaluate these environmental problems should be taken as soon as possible. The highway development is among the activities essential for successful urban development. The transportation segment in India is the most important energy consuming segment. The key dispute in front of India is bottlenecks in power which contribute the limitation of financial development. The rise in amount of automobiles would absolutely add to air pollution which will result in many troubles of health by air and noise pollution. The reduction in visibility during chest hours will raise highway accidents to a large extent and will also increase various security problems.*

Key Words: *control emission, COPART* (Computer Programme to estimate Emissions from Road Transport).

Abbreviations

AAS – Atomic Absorption Spectroscope

C.P.C.B. – Central Pollution Control Board

CC – Cubic Centimeter

CO – Carbon Monoxide

E.I.A. – Environmental Impact Assessment

FPM – Fluid Partial Mechanics

G.C. – Gas Chromatography

G.V.W. – Gross Vehicle Weight

HC – Hydrocarbons

I.S.I. – Indian Standards Institution

L_{10} – Sound Pressure Level Exceeding 10% of monitoring Time

L_{50} – Sound Pressure Level Exceeding 50% of monitoring Time

NDIR – Non-Dispersive Infrared

NO_X – Nitrogen Oxides

PM – Particulate Matter

R.I.T.E.S. – Rail India Technical and Economic Services

SO_X – Sulphur Oxides

UV – Ultraviolet

V.A.P.I.S. – Vehicular Air Pollution Information System

W.H.O. – World Health Organization

Introduction

Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we've been ignorant of their value."

The transportation is a significant infrastructure for socioeconomic growth of our country. The environment noise pollution and air pollution in recent years are recognized as the most important in most of industrialized nations. The traffic is been increasing at a substantial rate over the past three decades although there is still well after the urbanized countries in per capita transportation concentration. The total concentration of registered motor vehicles in overall countries rises vertically. This amount is raised from 213.75 Lakh in 1991 to 372.81 Lakh in 1997 to 1593.6 Lakh in 2011 in India. The table 1 gives World Diesel fuel consumption for transportation in 1991 to 2020.

Table 1 – World Diesel Fuel Consumption (1991-2020) in million barrels of oil per day (Peter et. al. 2004)

Region/ Country	History				Projections	
	1991	1999	2005	2010	2015	2020
North America	2.1	2.8	3.5	4.1	4.5	5.0
West Europe	2.1	2.9	3.2	3.4	3.5	3.8
Russia	1.1	0.6	0.8	1.0	1.1	1.25
China	0.1	0.4	0.6	1.0	1.4	1.8
India	0.4	0.7	1.1	1.6	2.4	2.8

Korea	0.2	0.3	0.4	0.6	0.6	0.8
Other Asia	0.6	1.0	1.3	1.5	1.7	1.9
Africa	0.3	0.4	0.6	0.8	1.0	1.2
South America	0.6	1.0	1.1	1.2	1.3	1.6

According to RITES the probable quantity of vehicles by the year 2020 can attain 2474.32 Lakh (Ray 2001). This is extremely alarming that much enlargement in present size of two wheelers, cars, jeeps and trucks. The philosophy of highway planning and design do not take into consideration of the environmental factors resulting in problems like air pollution, noise pollution, and ecological male effects etc. which are created in the vicinity of the highway systems. In order to achieve the environmental harmony between the roads and its surroundings it is necessary to make an E.I.A. of highway, roadway and railway development proposals.

Standards of Pollution in India – In India the main standards are given by Air prevention control act 1981 following the provision acts given by CPCB.

The Central Pollution Control Board hereby notifies the National Ambient Air Quality Standards with immediate effect, namely:-

Table 2 - National Ambient Air Quality Standards

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential. Rural and Other Area	Ecologically Sensitive Area	Methods of Measurement
P)	(2)	(3)	(4)	(5)	(6)
1	Sulphur Dioxide (SO_2), µg/m³	Annual* 24 hours* •	50 80	20 80	• Improved West and Gaekc • Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m³	Annual* 24 hours'*	40 80	30 80	• Modified Jacob & Hoc heifer (Na- • Arsenate) • Chemiluminesccnce
3	Particulate Matter PM_{10} µg/m³	Annual* 24 hours-	60 100	60 100	• Gravimetric • TO EM • Beta attenuation
4	Particulate Matter $PM_{2.5}$ µg/m³	Annual* 24 hours'*	40 60	40 60	• Gravimetric • TOEM • Beta attenuation
s	Ozone (O_3) µg/m³	8 hours* * 1 hour"	100 180	100 180	• Chcmilmrnesccnce • UV photometric • Chemical Method
6	Lead (Pb) µg/m³	Annual* 24 hours *	0.50 1.0	0.50 1.0	• AAS 1CP method after sampling on EPM 2000 or equivalent filter paper • ED-XRF using Teflon filter
7	Carbon Monoxide (CO) mg/m³	8 hours* * 1 hour**	02 04	02 04	• Non Dispersive Infra Red (NDIR) spectroscopy
8	Ammonia (NH_3) µg/m³	Annual* 24 hours* *	100 400	100 400	• Chemi luminescence Indophenol blue method
9	Benzene (C_6H_6) µg/m³	Annual*	05	05	• Gas chromatography based continuous analyzer • Adsorption and Desorption followed by GC analysis
10	Benzolal Pyrene (BaP) panic late phase only, µg/m'	Annual*	01	01	• Solvent extraction followed by HPL-GC analysis
11	Arsenic (As), ng/m³	Annual*	06	06	• AAS /1CP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel ng/m³	Annual*	20	20	• AAS/1CP method after sampling on F.PM 2000 or equivalent filter paper

• Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

• 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. *2%* of the time, they may exceed the limits but not on two consecutive days of monitoring.

1.1 Motivation of the study

Urban air pollution is one of the major problems confronting the world population [1]. Due to the introduction of recent legislative laws, there has been an urgent need to find appropriate methods of vehicle emission measurement. These means of emission measurement are to ensure the control of the amount of toxic gases these vehicles produce and release into the atmosphere. The harmful emissions that are produced from the exhaust pipes of these vehicles are Hydrocarbons (HC), Nitrogen Oxides (NOx), Carbon monoxide (CO), Carbon dioxide (CO2), Particulate Matter (PM) and Sulphur Oxide (SOx). The consequences of these emissions entail air pollution, smog, acid rain, liver damage, cancer, heart disease and acceleration in global warming.

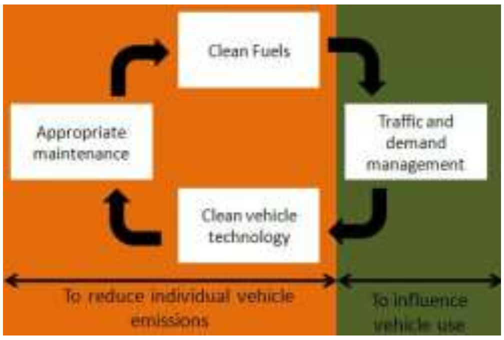

Figure 1.1: Emission reduction approaches.

Car manufacturers and drivers can help reduce these harmful emissions in three separate ways: Figure 1.1.

1. Increasing engine efficiency i.e. electronic ignition, fuel injection systems and electronic control units which control the amount of fuel wasted in the engines fuel system.
2. Increasing vehicle efficiency i.e. lightweight vehicle design, reduced air resistance, improved power train efficiency and regenerative braking.
3. Standardized driving technique, unobstructed traffic conditions, cruising at an optimum speed for the vehicle and the reduction of cold starts.

As an example of decreasing emission through engine technology, Three-way catalytic converter, Figure1.2, is used nowadays and this has three simultaneous tasks:

- Reduction of nitrogen oxides through conversion to nitrogen and oxygen:

$2NO_X \rightarrow xO_2 + N_2$

- Oxidation of carbon monoxide to carbon dioxide:

$2CO + O_2 \rightarrow 2CO_2$

- Oxidation of un-burnt hydrocarbons (HC) to carbon dioxide and water:

$2C_xH_y + (x+y)\ O_2 \rightarrow 2xCO_2 + yH_2O$

Figure 1.2: Three-way catalytic converters

These converters help in limiting pollution emitted from vehicles and a new standard emission limitation comes every few years to control pollutant in new vehicles. In the table 1.1, European emission standards for passenger cars showed a decrease in emission limits for newer cars.

These converters help in limiting pollution emitted from vehicles and a new standard emission limitation comes every few years to control pollutant in new vehicles. In the table 1.1, European emission standards for passenger cars showed a decrease in emission limits for newer cars.

Table 1.1: European emission standards for passenger cars (Category M*), g/km

Tier	Date	CO	THC	NMHC	NO_x	HC+NO_x	PM	PN [#/km]
Diesel								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.66	-	-	0.50	0.56	0.05	-

Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5a	September 2009	0.50	-	-	0.180	0.230	0.005	-
Euro 5b	September 2011	0.50	-	-	0.180	0.230	0.005	6×10^{11}
Euro 6	September 2014	0.50	-	-	0.080	0.170	0.005	6×10^{11}
Petrol (Gasoline)								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	January 1996	2.2	-	-	-	0.5	-	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.0	0.10	0.068	0.060	-	0.005**	-
Euro 6	September 2014	1.0	0.10	0.068	0.060	-	0.005**	6×10^{11}***
* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N_1-I ** Applies only to vehicles with direct injection engines *** 6×10^{12}/km within first three years from Euro 6 effective dates † Values in parentheses are conformity of production (COP) limits								

There are numerous ways of measuring emissions such as theoretical, experimental and real life measurements. Some of these methods will be described in the following sections:

1- MOBILE-6 Vehicle Emission Modeling Software MOBILE-6 is an emission factor model for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions.

2- Operational Street Pollution Model (OSPM)

OSPM is a street canyon model as seen in Figure 1.3; it can be used to assess pollution resulting from traffic in streets. Concentrations of exhaust gases are calculated using a combination of a plume model for the direct Contribution and a box model for the recirculation part of the pollutants in the street.

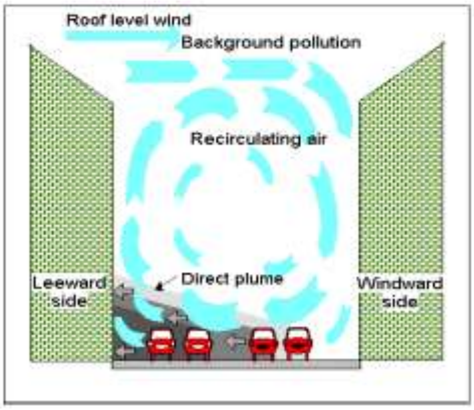

Figure 1.3: Operational Street Pollution methodology.

3- COPERT 4 (COmputer Programme to estimate Emissions from Road Transport). COPERT 4 is a Microsoft Windows software program which is developed as a European tool for the calculations of 0emissions from the road transport sector. The emissions calculated include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation). Figure 1.4 shows the model and version of the software used in this research.

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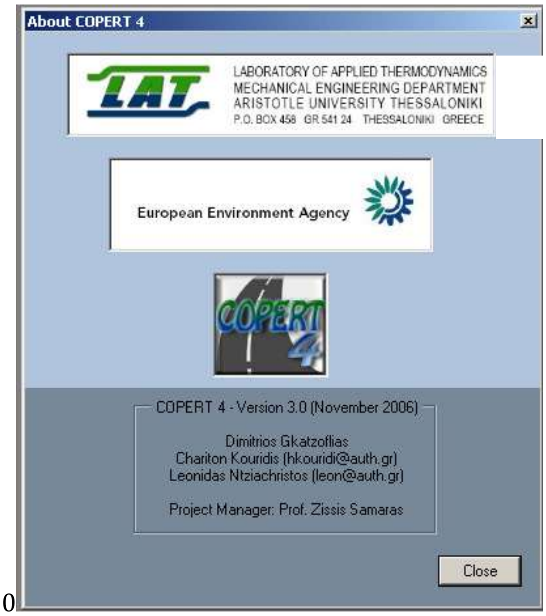


Figure 1.4: The software model and version used in previous research.

The use of software such as COPERT 4 has been in effect for numerous years. It uses equations to interpret the expulsion of emissions from combustion engines. It takes parameters from certain vehicles such as engine size, the technology level and the average speed in kilometers per hour and gives the resultant in (g/km). From calculation of these equations, theoretical values for each particular emission can be obtained. These values can be very accurate but are still only theoretical and do not take into account the drivers influence on the car, more details will come in the literature review.

The use of On Board Diagnostics (OBD) signal interpreter known as the Elm scan 5 Figure 1.5, can return values for emissions. OBD can also determine the driving cycle. The driving cycle gives the general traffic conditions that the car is being driven in, and also how the car is being driven by the driver. The aim of this project is to estimate vehicle emissions by defining this driving cycle. The use of the OBD and configured Lab VIEW software helps display numerous helpful characteristics for this report such as Acceleration (m/s^2), Deceleration (m/s^2), Engine speed (RPM), Vehicle speed (Km/h) and time parameters (which in turn can be used to define the drive cycle), and even the engine coolant temperature (C°).

Literature Review

The fundamentals of combustion and engine technology have been addressed in this dissertation as an introduction of this study. This includes a brief review of emission inventories and methods of quantifying and how to reduce them.

2.1 Design and Operation of Spark Ignition and Compression Ignition Engines

Internal combustion engines work by converting the chemical energy found in fuel into mechanical power. This energy is released by oxidizing (burning) the fuel in the combustion chamber inside the engine. The internal combustion engines studied for this project is the spark ignition. The components used in both engines differ somewhat. The spark ignition (SI) engine injects the air/fuel mix into the combustion chamber which is then ignited using the spark plug. The compression ignition (CI) engine compresses the air in the combustion chamber and then the fuel is injected into the cylinder alone which is then compressed to a point where the mix spontaneously combusts causing the crank to rotate [5]. Therefore the combustion process in the compression ignition occurs at constant pressure, whereas the combustion process in the spark ignition occurs at constant volume. The SI and CI engines are known as reciprocating engines. With a reciprocating engine, the piston moves up and down in the cylinder and transmits power through a connecting rod and crank mechanism connected to the drive shaft. The steady rotation of the crank produces a cyclical motion. There are two types of cycles used for reciprocating engine known as the two-stroke and the four-stroke. The two stroke uses only one rotation of the crank to complete combustion of the air/fuel mix. The four-stroke, Figure 2.1, uses two rotations to achieve the same effect, [5]. The four stroke engine is the mainly used with passenger vehicles and was used for this study.

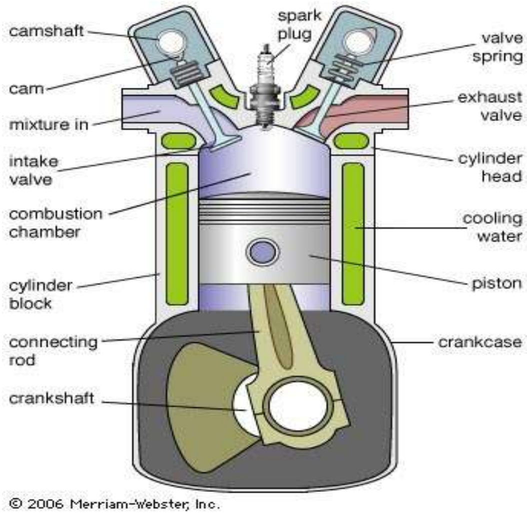


Figure 2.1: Design of an internal combustion Engine Cylinder [6]

1. An intake stroke, Figure 2.2, which starts at top dead centre (TDC) and ends with the piston at bottom dead centre (BDC), which draws fresh mixture into the cylinder. To increase the mass inducted, the inlet valve opens shortly before the stroke starts and closes shortly before it ends.

2. A compression stroke, when both valves are closed and the mixture inside the cylinder is compressed to a small fraction of its initial volume. Toward the end of the compression stroke, combustion is initiated and pressure rises more rapidly.

3. A power stroke, or expansion stroke, which starts with the piston at TDC and ends at BDC as the high-temperature, high-pressure, gases push the piston down and force the crank to rotate. About five times as much work is done on the piston during the power stroke as the piston had to do during compression.

4. As the piston approaches BDC the exhaust valve opens to initiate the exhaust process and drop the cylinder pressure close to the exhaust pressure. An exhaust stroke, where the remaining burned gases exit the cylinder. These burned gases exit as the pressure may be substantially higher than the exhaust pressure. The exhaust gases are swept out by the piston moving towards TDC. As the piston approaches TDC the inlet valve opens. Just after TDC the exhaust valve closes and the cycle starts again.

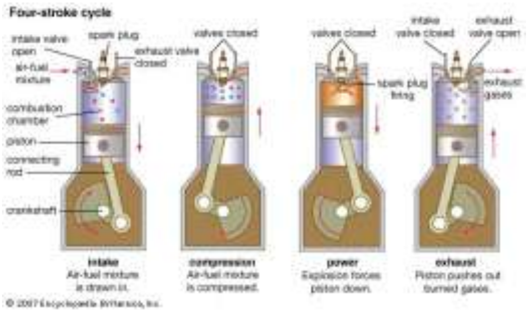


Figure Figure 2.2: Four Stroke Spark Ignition Combustion Process [6]

2.2 Combustion of Hydrocarbon fuels

A fuel can be defined as any material that can be burned to release chemical energy [5]. The reaction that occurs when a fuel is burned is known as combustion. There is a certain amount of air that is needed to complete the combustion process. This air is known as stoichiometric or theoretical air. During combustion, all the fuel is burned with the air theoretically available. The burning of air available is known as stoichiometric combustion of that fuel, Figure 2.3.

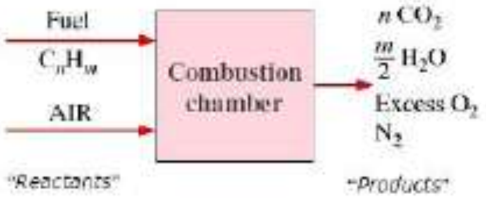


Figure 2.3: Ideal Combustion of a Hydrocarbon Fuel in a Combustion Chamber [7] During the combustion process, the components that exist before the reaction are known as the reactants and the components which exist after the reaction are known as the products [7]. Chemical equations are balanced on the basis of the conservation of mass principle. Chemical equations are balanced on the basis of the conservation of mass principle, which states that the total mass of each element is conserved during the chemical reaction. The equation below describes the ideal combustion of octane (C8H18), a commonly used hydrocarbon fuel, in air.

C8H18+12.5O2+ (12.5) (3.76) N2→8CO2+9H2O +47N2 (2.1)

This equation can be extended to give the general case as shown below

$$C_aH_b + (a+\frac{b}{4})O_2 + 3.76N_2 \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.76(a+\frac{b}{4})N_2 \quad (2.2)$$

As can be seen from the above equations, CO2, H2O and N2 are the only products in idealised stoichiometric combustion process of a hydrocarbon fuel in air. In reality however, many other intermediate products are also formed. These products are formed for reasons such as dissociation, additives present in the fuel and the alteration of the air/fuel ratio to optimize the operation of the engine. In the case of octane, the air/fuel ratio on a mass basis is given by

$$\frac{A}{F} = \frac{(59.5)(28.96)}{(1)(114)} = 15.1 \quad (2.3)$$

2.3 Pollutant formation

Air pollution in urban areas is a very relevant and topical problem. Over the past fifty years, the emissions produced from internal combustion engines have come under increased scrutiny due to their negative contribution to urban air pollution. Emissions can be categorized into three groups.

Evaporative Emissions

Evaporative emissions occur through the vehicle fuel system (carburetor, storage tank, flow pipes). They occur due to fuel volatility and daily variation in temperature [8].

Engine-Out Emissions

Engine out emissions refer to emissions prior to any chemical change that happens in the exhaust chamber.

Tail Pipe Emissions

Tail pipe emissions refer to emissions values after the catalytic reactions have taken place. These values are generally referred as emission limit figures. CO production is strongly related to the air/fuel ratio compared to other negligible factors [7]. CO emissions occur due to the quenching of the reaction in equation 2.4 at about 1700K [9].

C02 + H2O ↔ CO + H2O (2.4)

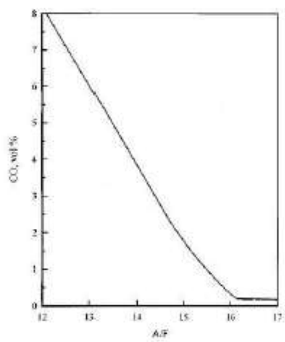


Figure 2.4: CO Emissions of SI engine vs Air/Fuel ratio [7]

The Figure 2.4 above shows the affect of air/fuel ratio on CO emissions. It is shown that at rich conditions, the CO content is significantly higher (factor of 10) than at stoichiometric. With lean mixtures, CO can be generated due to a poor mixture, some local rich regions, incomplete combustion, and a lack of time for the oxidation of CO to CARBON-DI-OXIDE to reach equilibrium [8].

2.3.1 NOx Emissions

NOx is the term that relates to all oxides of nitrogen emissions from engines [5].

NOx emissions consist almost entirely of NO (90-98%) [7]. the catalyst for NO to be formed from oxygen is given by the Zeldovitch mechanism.

$$O + N2 \leftrightarrow NO + N \quad (2.5)$$

$$N + O2 \leftrightarrow NO + O \quad (2.6)$$

$$N + OH \leftrightarrow NO + H \quad (2.7)$$

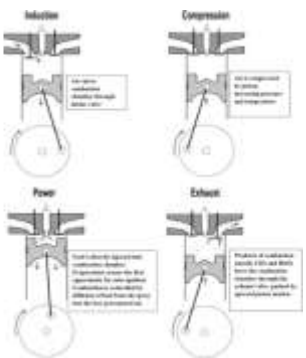
It has been seen that the temperature of the burned gases and the level of NO formed indicates that thermodynamic equilibrium is not obtained in the timescale of engine combustion [9]. The production of NOx heavily depends on the combustion temperature and available oxygen [7]. NO formation increases exponentially with temperature. This shows that the peak NO emissions occur at slightly lean mixtures (O=0.9) [9]. It can be seen from the Arrhenius Equation how the rate of NO formation varies with both temperature and oxygen concentration.

$$\frac{d[NO]}{dt} = \frac{Const}{T^{1/2}}.\exp\left(\frac{-Ea}{T}\right)[N_2]_e.[O_2]^{0.5}{}_e \quad (2.8)$$

Where

- d[NO]/dt is the rate of formation
- T is the temperature at which NOx formation occurs
- Ea is the activation energy
- [N2]e and [O2]0.5 e are the equilibrium concentrations of nitrogen and oxygen in a mixture dissociated at high temperatures

Equation 2.8 explains why the majority of engine related parameters (load, air/fuel ratio, spark timing, ignition angle, and compression ratio) have a major influence on NOx formation. It is noted that NOx emissions vary considerably with parameters affecting local temperatures [8]. NOx formation is generally formed in the post flame region where temperatures are high enough (reached 2000°C) [8].



2.3.2 HC Emissions

Hydrocarbons refer to the unburned hydrocarbons in the fuel that have not changed during the combustion process and products resulting from various hydrocarbon reactions [9]. Four major mechanisms for HC emission formation have been clearly identified [5]. A stroke by stroke diagram of HC formation can be seen in Figure 2.5.

Flame Quenching

Flame quenching has been considered for a long time to be the primary source of HC emissions [9]. This process occurs on the walls of the combustion chamber. The cool walls act as a heat sink thus reducing the cylinder temperature and affecting the fuel combustion.

Filling of crevice volumes during compression and combustion strokes Unburned HC will remain in areas where the flame does not propagate [8]. Crevice volumes can be defined as narrow regions in the combustion chamber into which the flame cannot enter due to heat transfer to the walls [5]. The largest crevice volumes are spaces between piston, piston rings and cylinder walls. Crevice volumes are highly dependent on crevice entry geometry and crevice surface area.

Incomplete Combustion

Incomplete combustion refers to the bulk quenching of the flame in the fraction of the cycle where combustion is particularly slow [5]. Such conditions are likely to occur during transient engine operation. During this period, the air-fuel ratio, spark timing, and fraction of gas recycled for emission control may not be properly matched.

Absorption of fuel vapour into oil layers on cylinder during compression and intake

Studies have shown that the addition of engine oil to fuel can result in two or three times the HC emissions from a clean engine [5]. It has been speculated that this increase is due to the absorption of fuel vapour into the lubricating oil layers.

2.3.3 Particulates

Particulate Emissions are mainly related to diesel engines. This is due to soot forming from the carbon in the diesel fuel. Particulate formation takes place in a combustion environment of 1000K to 2800K and at pressures of 50 to 100atm. The formation occurs due to a deficiency of air in the combustion chamber. The carcinogenic and mutagenic soot particles are formed by oxygen-deficient thermal cracking of long chained molecules. Particulate emissions consist of a solid and a liquid state. Figure 2.6 shows the overall composition of diesel exhaust gas.

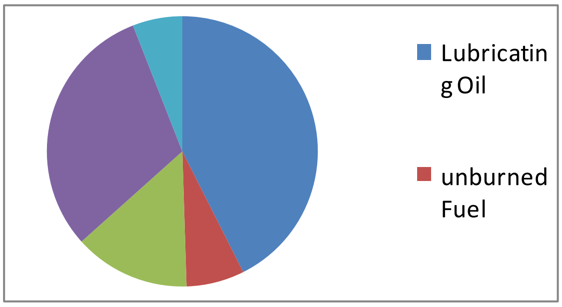


Figure 2.6: Particulate Matter Composition of a Diesel Engine.

Experimental Study

3.1 Introduction

The transport sector is one of the major contributors of hazardous emissions to the environment in recent years. In 2005 40% of NOx emissions (about 119Mt) and 25.6% of CO2 emissions (about 55.6 Mt) originated from the transport sector in Ireland [77]. Various approaches to help decrease these emissions by; using new technologies, where fuel consumption has been minimized using dynamic optimization [26]; applying new legislation standards for newer cars; using alternative fuel systems, such as using liquefied natural gas or bio-fuels in heavy duty vehicles [78-80]; applying new strategies, such as a road transport system based on renewable resources [81], or developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption, had proposed [82]. Moreover, the design of 100% renewable energy systems has been discussed in literature with the analyzes and results that includes the transport sector [83].

Since emission estimation from road transport can assist researchers in evaluating the air quality in urban areas, many projects have validated modeling methods in order to represent accurate results [84]. Car testing includes pre-test vehicle certification using chassis dynamometer emissions test equipment as manufacturers must prove that their vehicles comply to emissions standards (type approval tests) [85], thus making the vehicle valid in terms of emission limitations over a period of time. Thereafter, a vehicle should pass a compulsory vehicle inspection test in order to ensure that the vehicle's emissions are under a certain limit.

This chapter provides information on the experimental work, details of the testing steps, the equipment used and the characterization of the trips chosen. The first section of this chapter describes the preparation of the testing. Also in the first section, equipment and its use are clarified. The last section of this chapter provides information on where data is obtained and how the data is exploited. Results from regulatory measurement methods are not sufficient, and chassis dynamometer testing must be carried out. This can be done by either instantaneous or model emissions in parallel with the aggregate bag measurements required for certification [48].

As it has been discussed in the previous chapter, using limited number of driving modes is not representative. In addition, vehicles could conceivably be tested differently depending on their performance levels and usage characteristics [86]. In this regard, many researchers have developed real-world driving cycles [54 and 87] and compared its differences in measured emissions. Using on-board emission monitoring for measuring instantaneous emissions provides data quickly, reducing the cost of testing and providing the driving cycles and emission factors to be evaluated [56-59]. Comparisons between measured and estimated emission data have been found to be within 5% for carbon dioxide (CO2) and nitrous oxide (NOx) [60], and within 10% for hydrocarbon (HC) and carbon monoxide (CO) [61]. In conjunction with recent advancements, many software packages have been utilized to estimate vehicle emissions. The advantages of using these software techniques include cost and time savings. Good correlations between the predicted results of the software packages and the actual data obtained by direct measurement are still maintained. In order to estimate vehicle emissions, driving cycles in a city are analyzed by researchers using the same approach in many other countries. Many projects have been conducted to establish the drive cycle of a specific area/city. When validating these estimates, significant differences between measured and modeled emission rates have been found [74]. Sometimes, tunnel studies have been conducted in order to validate the emission estimations [37]. In Edinburgh, for instance, the driving cycle was obtained from recorded data in actual traffic conditions, using the car chase technique, and compared with the European driving cycle [52]. In Athens, emissions and fuel consumption measurements showed significant variations between Athens driving cycle and the European driving cycles [88]. Outside of Europe in Hong Kong, a systematic and practical method for developing representative driving cycles has been developed with focusing on cost effectiveness for continuous refinement of the driving cycle [89].

Some research has been done using emission analyzers in order to calculate the instantaneous emissions. For example, Ayala et al. identified the different hydrocarbon species emitted from the tailpipe [62]. In some of the following experiments, a gas analyzer has been used in order to evaluate the results obtained from the calculated method. The possibility of finding the correlations between the experimental and calculated results is also discussed.

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