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Exhaust Monitoring and Control Unit for Portable Generator Engines

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ABSTRACT: The diesel engine is an attractive power unit used widely in many fields, for its great advantages over petrol engines such as lower fuel consumption, lower carbon monoxide emissions, better torque characteristics and higher reliability. However, they are among the main contributors to air pollutions for the large amount of emissions, especially particulates and nitrogen oxides (NO_x). The control of these emissions is one of the most important aspects of modern air quality management.

KEYWORDS: Diesel engine, emissions, air pollution.

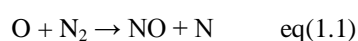
I. INTRODUCTION

The first diesel engine dated back to 1892 when Rudolf Diesel invented it with compression ignition. In a typical diesel engine, only air is inducted into the cylinder and the ignition is initiated by injecting a certain amount of fuel directly into the chamber when the air reaches the right temperature and pressure. It not only achieves the control of the engine load through the adjustment of the fuel amount, but also eliminates the loss existing in spark ignition engines, where air and fuel are mixed externally and throttled before entering the cylinder. This difference in the initiation of combustion also leads to the emissions from diesel engines differing from those from petrol engines.

Typical diesel engine combustion is shown in Fig 1(a) and it can be categorized into four distinct phases: ignition delay, premixed combustion, mixing controlled combustion and late combustion. The liquid fuel injected into the engine cylinder firstly evaporates and mixes with the combustion air. The mixture is compressed by the piston and its pressure and temperature increase until the fuel's ignition point is reached. After this short ignition delay period, the spontaneous ignition starts and initiates the combustion, which raises the in-cylinder pressure to a much higher level. With the combustion processing, it proceeds to a relatively moderate level until it ceases. The burned products along with those unburned are then discharged into the after-treatment system, before being emitted to the atmosphere.

The particulates are probably one of the most critical issues of the diesel engine emissions. They are tiny solid or liquid particles and are sometimes referred to as particulate matter (PM) or fine particles. Particulates consist of primary particles, whose diameters are between 20-50 nm and their sizes depend on the numbers of these spherules, which may vary from several to several thousands. Diesel particulates are mainly composed of three parts: soot, soluble organic fraction (SOF) and inorganic fraction. Soot originates from the carbon in the diesel fuels and generates in the combustion environment where the temperature and pressure can reach up to 2800 K and 100 bar. Through the soot's surface growth, agglomeration as well as oxidation at the same time, the particulates form eventually after a final adsorption and condensation of hydrocarbons.

The nitrogen oxides (NO_x) from diesel engines are comparable to those from petrol engines and it is a collection of nitric oxide (NO) and nitrogen dioxide (NO₂). NO is usually produced through the oxidation of atmospheric nitrogen and is the predominant part in NO_x. Its formation rate has a great dependence on temperature, which is why high temperature and high oxygen concentrations result in high NO formation. The mechanism is often called the extended Zeldovich mechanism, contributed by Zeldovich and Lavoie as follows:

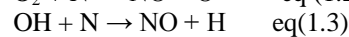
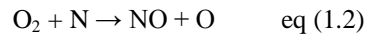


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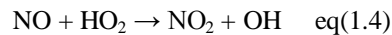
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Generally, the NO₂ in the diesel engine emissions has a part of 10 %-30 % in the total NO_x and it is converted from NO formed in the flame zone as



Unless it is quenched, the NO₂'s conversion back to NO is via



Most of the hydrocarbon (HC) results from the incomplete combustion of the fuels and there are several major causes for the diesel engine HC emissions:

(1) The fuel-air mixture is too lean to auto-ignite or to support a flame during the primary combustion in the cylinder. They will remain unconsumed if not being oxidized in the expansion process that follows (2) The fuel is trapped by the nozzle sac which enters the cylinder in the later process or excess fuel is injected, causing over-fuelling (3) Quenching and misfiring. The first path is most significant when the engine is running at light load or idling and the third path depends on the temperature of the cylinder wall and the fuel spray impingement.

Carbon monoxide (CO) and carbon dioxide (CO₂) from diesel engines are relatively low. The generation of carbon monoxide (CO) is controlled by the fuel/air ratio and it can also be contributed to by the pyrolysis of the carbon dioxide (CO₂). The CO emissions are more significant in the spark ignition engines as the fuel/air ratio is often close to stoichiometric at part load and more at full load. For operating well on the lean side of stoichiometric, diesel fuel is burned in excess air even at full load, at which point the quantity injected per cycle is still about 50% lean. As for CO₂, diesel engines are more efficient than gasoline engines of the same power, resulting in lower fuel consumption (a common margin is 40% more miles per gallon for an efficient turbo-diesel) and thus less carbon dioxide (CO₂).

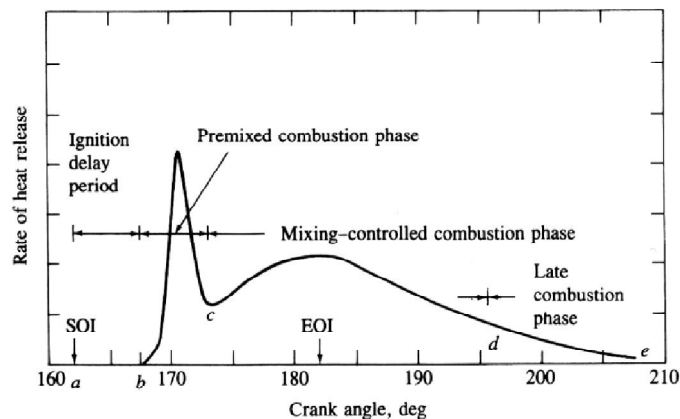


Fig 1 (a) Typical diesel engine combustion cycle

II. RELATED WORK

This chapter starts with some background knowledge on the current engine emission regulations and the most critical issue of diesel engines emissions. It presents the main technologies for the engine emission control, either through the after-treatment or the improvement to the combustion. It also covers new alternative fuels, which might be a solution in the future emission problems.

Eastwood et.al[1] In Europe photochemical smog, which started as early as in the 1940s and the London smog in 1952 are probably two of the most notorious disasters caused by air pollution in the human history, when thousands of people got sick or even died. The first case arose of the high level of ozone through reactions between sunlight and two major vehicle exhausts: oxides of nitrogen and hydrocarbons and the second was due to a combination of smoke from automobiles and coal burning, a low wind speed and dry weather.

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Battigelli et.al[2] The four major types of emissions from combustion engines include the particulate matter, oxides of nitrogen, carbon monoxide and hydrocarbons. The former two are especially significant for diesel engines. Particulate matter (PM) is believed to be a trigger for asthma, lung cancer, cardiovascular issues, and premature death as it can penetrate deep into the lungs and the bronchi, when inhaled by human beings. Thus, its toxicity is closely related to its size and shape. Generally, the smaller the particles, the more dangerous they are and it is assumed that those in the feathery or geometrically angular shape are more harmful. The oxides of nitrogen are not all toxic. Nitric oxide (NO) itself is odourless, colourless and relatively non-toxic however, it can form secondary pollutants such as nitric acid, implicated in acid rain and it also participates in ozone layer depletion. Nitrogen dioxide (NO₂) is more detrimental to human health. This reddish-brown gas can irritate the lungs and produce pulmonary edema and fatality if inhaled at high concentrations. Cough, haemoptysis, dyspnoea, and chest pain can also be caused even when exposed to moderate levels of 50 ppm.

Eastwood et.al[1] Carbon monoxide (CO) is colourless and odourless, just as NO, but it is more dangerous as it can block the delivery of oxygen and cause cellular hypoxia due to haemoglobin's greater affinity for CO than for oxygen. Thus, the human organs with the highest oxygen requirement such as the brain and heart can be affected most significantly. Impairment of judgement, headaches, dizziness and nausea are common symptoms under the effect of CO and the cardiovascular and nervous systems can also be affected by long term exposure to low levels of CO. There are a variety of hydrocarbon (HC) compounds and their toxicities are determined by their chemical properties and how they contact with the human body. Pulmonary, neurologic, cardiac, gastrointestinal, hepatic, renal, dermatologic, and hematologic systems can all be susceptible to them and lungs are believed to be the most commonly affected organ. They can directly cause coughing, sneezing and drowsiness, and they can also form secondary pollutants such as ozone and photochemical smog. Besides the four major tailpipe pollutants, which are subject to law in most countries, there are green-house gas carbon dioxide (CO₂) and other unregulated emissions from combustion engines notably sulphur compounds and ammonia. They all pose a threat to the human being and have drawn great attention.

W. Addy Majewski[3] An increased diesel engine population has created pressures on controlling diesel PM and NO_x emissions. The initial progress in diesel emission control was achieved through engine technologies, including changes in the combustion chamber design, improved fuel systems, charge air cooling, and special attention to lube oil consumption. Emission standards implemented in the 2005-2010 timeframe additionally require the use of exhaust aftertreatment methods on new diesel engines. These methods include diesel particulate filters, urea-SCR catalysts, and NO_x adsorbers.

S. J. Zhang, M. L. Li et.al[4] He initiated a comprehensive vehicle test program in 2008. This program included a sub-task for measuring on-road emission profiles of hundreds of HDDVs using portable emission measurement systems (PEMS). The major finding is that neither the on-road distance-specific (g km^{-1}) nor brake-specific (g kWh^{-1}) NO_x emission factors for diesel buses and heavy-duty diesel trucks improved in most cases as emission standards became more stringent. For example, the average NO_x emission factors for Euro II, Euro III and Euro IV buses are $11.3 \pm 3.3 \text{ g km}^{-1}$, $12.5 \pm 1.3 \text{ g km}^{-1}$, and $11.8 \pm 2.0 \text{ g km}^{-1}$, respectively. No statistically significant difference in NO_x emission factors was observed between Euro II and III buses. Even for Euro IV buses equipped with SCR systems, the NO_x emission factors are similar to Euro III buses. The data regarding real-time engine performance of Euro IV buses suggest the engine certification cycles did not reflect their real-world operating conditions. These new on-road test results indicate that previous estimates of total NO_x emissions for HDDV fleet may be significantly underestimated. The new estimate in total NO_x emissions for the Beijing HDDV fleet in 2009 is 37.0 Gg, an increase of 45% compared to the previous study. Further, we estimate that the total NO_x emissions for the national HDDV fleet in 2009 are approximately 4.0 Tg, higher by 1.0 Tg (equivalent to 18% of total NO_x emissions for vehicle fleet in 2009) than that estimated in the official report. This would also result in 4% increase in estimation of national anthropogenic NO_x emissions. More effective control measures (such as promotion of CNG buses and a new in-use compliance testing program) are urged to secure the goal of total NO_x mitigation for the HDDV fleet in the future.

Dr.H. P. Geering[5] Legislation concerning the pollutant emissions of diesel passenger cars is becoming increasingly restrictive, especially for NO_x and particulate matter (PM). A novel approach to control the pollutant emissions in diesel engines is thus proposed that extends the standard feed forward control in the air and fuel path with a true

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emissions-feedback structure. In order to prove the feasibility of such an approach, a multivariable emissions feedback controller is designed for the NO_x emissions and for the air/fuel ratio, which is used as an indicator for the PM emissions, due to the fact that compact and low-cost PM sensors are not yet commercially available. Since, the new sensors are sensitive to pressure variations, they have to be placed in the low-pressure tract of the exhaust manifold, i.e., downstream of the turbine. Obviously, time delays due to the gas transport now become relevant for the control system. The multivariable controller proposed consists thus of two separate internal model SISO control (IMC) loops developed with a simplified model of the plant and connected by a decoupling term. The IMC structure has the advantage that can compensate for the time delays in the control loop. Since, the controller has to work well in the entire range of operating points, a scheduling of its parameters is necessary.

Debora Fino[6] The European diesel engine industry represents a vital sector across the Continent, with more than 2 million direct work positions and a turnover of over 400 billion Euro. Diesel engines provide large paybacks to society since they are extensively used to transport goods, services and people. In recent years increasing attention has been paid to the emissions from diesel engines which, like gasoline engine emissions, include carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen (NO_x). Diesel engines also produce significant levels of particulate matter (PM), which consists mostly of carbonaceous soot and a soluble organic fraction (SOF) of hydrocarbons that have condensed on the soot. Meeting the emission levels imposed for NO_x and PM by legislation (Euro IV in 2005 and, in the 2008 perspective, Euro V) requires the development of a number of critical technologies to fulfill these very stringent emission limits (e.g. 0.005 g/km for PM). This review is focused on these innovative technologies with special reference to catalytic traps for diesel particulate removal.

Timothy V. Johnson et.al[7] The paper summarizes the key developments in diesel emission control, generally for 2005. Regulatory targets for the next 10 years and projected advancements in engine technology are used to estimate future emission control needs. Recent NO_x control developments on selective catalytic reduction (SCR), lean NO_x traps (LNT) and lean NO_x catalysts (LNC) are then summarized. Likewise, the paper covers important recent developments on diesel particulate filters (DPFs), summarizing regeneration strategies, new filter and catalyst materials, ash management, and PM measurement. Recent developments in diesel oxidation catalysts are also briefly summarized. Finally, the paper discusses examples of how it is all pulled together to meet the tightest future regulations.

III. METHODOLOGY

According to the setup shown in fig 3 (a), during operation, the exhaust from the engine is let into the exhaust chamber which consists of baffle plates placed at an angle 45° and inlet for air supply unit the velocity of the exhaust gas entering the gas chamber is brought down by the baffle plates placed in path of its motion. Baffle plate enables mixing of exhaust gas and fresh air such that concentrations of emissions is reduced. The exhaust gas from the engine enters the exhaust chamber and gets filtered while passing through trap. The gas is then circulated in the chamber and turbulence is created due to cross flow of fresh air from the atmosphere which is supplied by the air supply unit connected to exhaust chamber. This fresh air mixes with the exhaust coming from the engine for sufficient amount of time before being let into atmosphere. The gas coming out of exhaust chamber is less concentrated as compared to that of exhaust and is less harmful. This setup does not alter any performance of engine.

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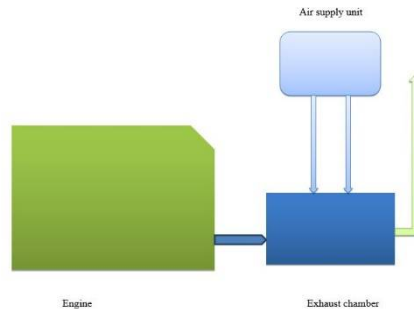


Fig 3 (a) Experimental setup for exhaust monitoring

IV. EXPERIMENTAL RESULTS

With a growing demand for transportation IC engines have gained lot of importance in automobile industry. It is therefore necessary to produce efficient and economical engines. While developing an IC engine it is required to take in consideration all the parameters affecting the engines design and performance. There are enormous parameters so it becomes difficult to account them while designing an engine. So, it becomes necessary to conduct tests on the engine and determine the measures to be taken to improve the engines performance.

Case study 1:

Table 4 (a) At 0.5 Kg Load condition without chamber

Carbon monoxide	0.022% by volume
Hydrocarbon	11 ppm
carbon dioxide	1.53% by volume
Oxygen	16.05% by volume

Table 4 (b) Concentration of exhaust at 0.5kg load with chamber

Carbon monoxide	0.012% by volume
Hydrocarbon	3ppm
carbon dioxide	0.4% by volume
Oxygen	19.44% by volume

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Case study 2:

Table 4 (c) Concentration of exhaust at 1kg load without chamber

Carbon monoxide	0.03% by volume
Hydrocarbon	16 ppm
Carbon dioxide	1.82% by volume
Oxygen	15.49% by volume

Table 4 (d) Concentration of exhaust at 1kg load with chamber

Carbon monoxide	0.018% by volume
Hydrocarbon	4ppm
Carbon dioxide	0.9% by volume
Oxygen	18.91% by volume

Case study 3:

Table 4 (e) Concentration of exhaust at 1.5kg load without chamber

Carbon monoxide	0.035% by volume
Hydrocarbon	19 ppm
Carbon dioxide	3.06% by volume
Oxygen	12.71% by volume

Table 4 (f) Concentration of exhaust at 1.5kg load with chamber

Carbon monoxide	0.02% by volume
Hydrocarbon	5ppm
Carbon dioxide	1.4% by volume
Oxygen	19.45% by volume

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Comparison of results:

Fig 4 (a) shows variation of concentration of carbon dioxide with load in kg. It is evident that without using chamber the concentration levels are high and after using chamber concentration levels are comparatively reduced. X axis indicates load in kg, Y axis indicates percentage by volume.

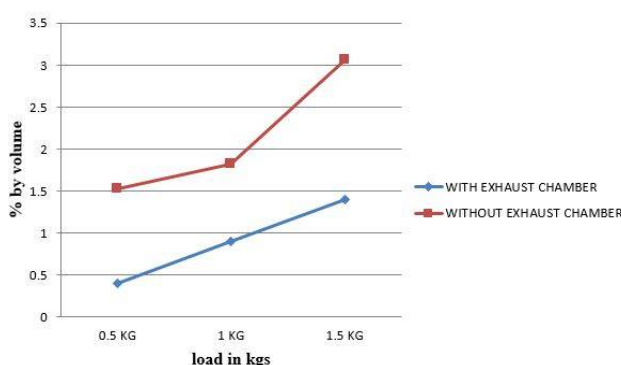


Fig 4 (a) Variation of carbon dioxide with load

Fig 4 (b) shows variation of concentration of carbon monoxide with load in kg. It is evident that without using chamber the concentration levels are high and after using chamber concentration levels are comparatively reduced. X axis indicates load in kg, Y axis indicates percentage by volume.

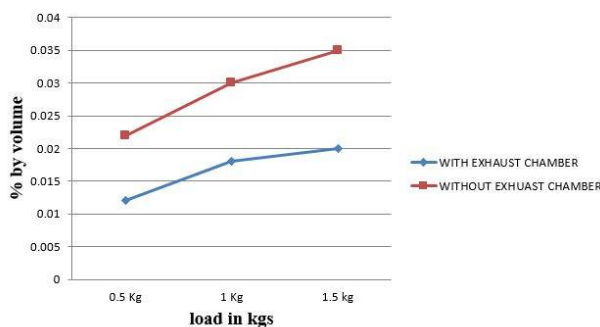


Fig 4 (b) variation of carbon monoxide with load

Fig 4 (c) shows variation of concentration of hydrocarbons with load in kg. It is evident that without using chamber the concentration levels are high and after using chamber concentration levels are comparatively reduced. X axis indicates load in kg, Y axis indicates percentage by volume.

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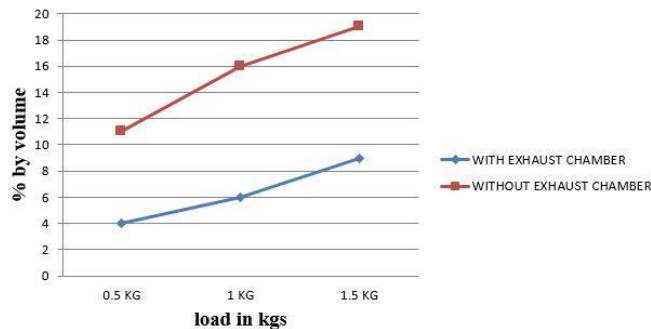


Fig 4 (c) Variation of hydrocarbon with load

V. CONCLUSION

From the present experimental study results were tabulated and graphs were plotted. By various case studies with different loading arrangements, with exhaust chamber and without chamber the graphical results were plotted and tabulated. In the tabulated results, it clear that the emission of CO, HC, smoke, NO was considerably reduced due to the introduction of the chamber. The control unit designed is economical and suitable for various applications.

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