Exhaust Gas Analysis of CI Engine using the Blends of Diesel and Biodiesel from the seed of Pongamia pinnata (L) Pierre

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Abstract:

Exhaust system plays most effective role on the environment as it is that portion of an automobile through which exhaust gases get out from the combustion chamber to pollute the air by their harmful gases. The different blends of diesel and biodiesel from the Pongamia pinnata (L) Pierre are used to run the four stroke compression ignition engine. To make a study of the exhaust gas emission providing with blends of diesel and biodiesel at different ratio and exhaust gas analyzer was used to collect experimental data. All the experimental data and graphical representation concludes that the CO, CO₂, HC, NO, NO₂, NO_x, SO_x in the exhaust gas from CI engine with the use of blending of diesel and biodiesel.

Keywords: Exhaust gas, CI engine, Blending, diesel, biodiesel.

Introduction

Exhaust emissions are produced during combustion and the emissions are harmful. In addition to these harmful emissions, both carbon dioxide (CO₂) and oxygen (O₂) readings can provide additional information on what's going on inside the combustion chamber.

Carbon dioxide (CO₂) is a desirable by-product that is produced when the carbon from the fuel is fully oxidized during the combustion process. As a general rule, the higher the carbon dioxide reading, the more efficient the engine is operating. Therefore air/fuel imbalances, misfires or mechanical problems will cause CO₂ to decrease. It is noted that "ideal" combustion produces large amount of CO₂ and H₂O (water vapour)

Oxygen (O₂) readings provide a good indication of a lean running engine, since O₂ increase with leaner air/fuel mixtures. Lean air/fuel mixtures and misfires typically cause high O₂ output from the engine.

There are a few other exhaust emission components which impact driveability and/or emissions diagnosis, that are not measured by shop analysers. They are (a) water vapour (H₂O), (b) sulphur dioxide (SO₂), (c) hydrogen (H) and (d) particulate carbon soot (C).

Sulphur dioxide (SO_2) is sometimes created during the combustion process from the small amount of sulphur present in the gasoline. During certain conditions the catalyst oxidizes sulphur dioxide to make SO_3 , which then reacts with water to make H_2SO_4 or sulphuric acid. Finally, when sulphur and hydrogen react, it forms hydrogen sulphide gas. This process creates the rotten egg odour we sometimes smell when following vehicles in the highway. Particulate carbon soot is the visible black smoke we see from the tailpipe of a vehicle that's running very rich.

The quantity of NO_x varies from a few hundred to well over 1000 ppm in diesel exhaust. Oxides of nitrogen which also occur only in the engine exhaust are combination of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen and oxygen reacts at relatively high temperatures. Therefore high temperature and availability of oxygen are the two main reasons for the formation of NO_x . When the proper amount of the oxygen is available the higher the peak combustion temperature the more is the NO formed. The NO_x is formed in the atmosphere as NO oxidizes. The combination of HC and NO_x in the presence of sunlight and certain atmospheric condition produce photochemical smog. The conditions that cause highest local peak temperature and have sufficient oxygen give highest NO_x concentration in diesel exhaust.

A pre-combustion chamber engine produces less NO_x than a direct injection engine due to lower peak temperature. The effect of fuel-air ratio is same that on a gasoline engine. At high fuel-air ratio the additional fuel tends to cool the charge, so the localized peak temperatures are lowered resulting in drop in NO_x concentration. The NO_x production is also significantly affected by injection system and time. Also, variations in fuel characteristics such as cetane number, viscosity, modulus of elasticity and rate of burning, etc., all contribute to differences in NO_x levels obtained from different levels.

Literature Review

Some papers in connection with the exhaust gas analysis were studied and brief definitions related to the exhaust gas analysis were given below:

Leung DYC et al considered a single cylinder diesel engine, direct injection, water cooled engine for optimization of exhaust emission with biodiesel⁽¹⁾. They optimized by varying the engine settings, including the injection timing, injection pressure and the fuel pump plunger diameter. The engine emissions were found to be lowered for particulate matters (PM) and hydrocarbon (HC) with the use of biodiesel, but an obvious increase in the oxides of nitrogen (NO_x) was observed, particularly at high engine loadings. For multi parameter engine, adjustment with the consideration of their cross interactive effects can keep the benefit of reducing PM and HC without increasing NO_x emission and sacrificing fuel combustion efficiency.

Breda Kegl investigates in his study the optimal timing of the diesel engine injection pump using biodiesel fuel from rapeseed⁽²⁾. He studied by running experiments on an NA diesel bus engine MAN D2 2566 with direct injection M system for the influence of biodiesel. Experiments with biodiesel and D2 diesel are run on several engine operating regimes and shown that with carefully optimized timing of the pump, the harmful emission of NO_x, smoke, HC and CO can be reduced essentially by keeping other engine characteristics within acceptable limits.

Zhang et al investigated the impact of biodiesel on NO_x emission in a 2.5L common rail direct injection diesel engine under both low load and high load conditions with different fuel injections strategies⁽³⁾. They used three fuels (i) an ultra low sulfur diesel fuel (BP15), (ii) a blend of 20 vol% biodiesel in BP15 and (iii) a blend of 40 vol% biodiesel in BP15 (B40). Biodiesel blends were found to generally produce slightly lower NO_x emissions than the baseline diesel fuel at the low load condition. Under the high load condition, evidently higher NO_x emissions for biodiesel blends were observed under both single and double injection conditions. Overall, biodiesel blends and the baseline diesel fuel had very similar heat release rate profile. For injection systems, retarding injection timing under single injection conditions was found to be the more effective approach to reduce the NO_x emissions than using pilot injection with retarded main injection in terms of NO_x and fuel consumption trade off. The performance of the 40 vol% biodiesel blend under various exhaust gas recirculation (EGR) rate condition was investigated, the biodiesel blend showed no further combustion deterioration compared to baseline diesel fuel. A low NO_x and fuel efficient engine operating condition was achieved with the 40 vol% biodiesel blend.

Cheng C. S. et al in their study aimed to investigate the effects of fumigation methanol on the emission of a diesel engine fueled with biodiesel as the baseline fuel⁽⁴⁾. The biodiesel used in this study was converted from waste cooking oil. Experiments were performed on a 4-cylinder naturally aspirated diesel engine operating at a constant speed of 1800 rev/min for three engine loads of 0.19 MPa, 0.38 MPa and 0.56 MPa. The results indicate no significant change in the brake thermal efficiency and carbon dioxide (CO₂) emission, an increase in both carbon monoxide (CO) and unburned hydrocarbon (HC) emission and a decrease in both nitrogen oxide (NO_x) and particulate matter (PM) emissions.

Their paper presents the results of investigations carried out in studying the fuel properties of karanja methyl ester (KME) and its blend with diesel from 20% to 80% by volume and running a diesel engine with these fuels⁽⁵⁾. Engine tests have been carried out with the air of obtaining comparative measures of torque, power, specific fuel consumption and emission such as CO, smoke density and NO_x to evaluate and compute the behavior of diesel engine running on the KME fuel. The reduction in exhaust emissions together with increase in torque, brake power, brake thermal efficiency and reduction in brake-specific fuel consumption made blends of karanja esterified oil (B20 and B40) a suitable alternative for diesel and could help controlling air pollution.

In their study, a number of experiments with 10 vol% (B10) biodiesel fuel of palm oil origin were performed on a light duty common-rail Euro 3 engine⁽⁶⁾. The measurements included in-cylinder pressure, pollutant emission and fuel consumption. Combustion effects were limited but changes in the start of ignition and heat release rate could be identified. Emission effects included both higher and lower smoke and NO_x , depending on the operation point. The results on the engine bench were compared against a Euro 3 common-rail high-duty vehicle driven on the chassis dynamometer, in order to include the effects of emission control system (EGR & oxidation catalyst). In addition to the palm biodiesel, an RME-diesel blends was also tested to examine the effect of a fuel with different characteristics. Both biodiesel blends reduced PM emissions and only marginal effects on NO_x over the certification test could be identified. The results of this study show that up to 10% biodiesel could be used on current diesel vehicles, without significantly affecting vehicle emission performance.

Blends of diesel oil and soybean biodiesel with concentration of 3% (B3), 5% (B5), 10% (B10) and 20% (B20) were used as fuel on a passenger vehicle and exhaust pollutant emissions were investigated⁽⁷⁾. The effects of anhydrous ethanol as an additive to B20 fuel blend with concentration of 2% (B20E2) and 5% (B20E5) were also studied. The emissions tests were carried out following New European Driving Cycle (NEDC). Results shows that increasing biodiesel concentration in the fuel blend increase CO_2 and oxides of nitrogen (NO_x) emissions, while carbon monoxide (CO), Hydrocarbon (HC) and particulate matter (PM) emissions are reduced. The addition of anhydrous ethanol to B20 fuel blend proved it can be a strategy to control exhaust NO_x and global warming effects through the reduction of CO_2 concentration.

Engine Setup

Experiments were conducted on an existing test unit. The test unit was a Single Cylinder, Naturally Aspirated, Direct Injection, and Compression Ignition Engine using standard diesel fuel

Fig.1: Schematic diagram of engine test unit (Source: www.elsevier.com/locate/peccs)

Exhaust Gas Analysis

Exhaust emissions are produced during combustion and the emissions are harmful. In addition to these harmful emissions, both carbon dioxide (CO₂) and oxygen (O₂) readings can provide additional information on what's going on inside the combustion chamber.

Fig. 2: Exhaust Gas Analyser

Analysing Exhaust Emission Readings

Hydrocarbons are measured by an exhaust analyser in parts per million (ppm). It is known that HC is unburned fuel that remains as a result of a misfire. When combustion does not take place or when only part of the air/fuel charge burns, hydrocarbon levels goes up.

Carbon monoxide (CO) is measured by an exhaust analyser in percentage (%) or parts per hundred. CO is a by-product of combustion; therefore, if combustion does not take place, carbon monoxide will not be created. Based on this premise, when a misfire occurs, the carbon monoxide that would have normally been produced during the production process is not produce. Generally speaking, on fuel injected vehicles, high CO means too much fuel is being delivered to the engine for the amount of air entering the intake manifold.

Nitrogen oxide measured by an exhaust analyser in parts per million (ppm). Nitrogen oxides are a by-product of combustion. NO_x is formed in large quantities when combustion temperatures exceed about 1370°C (2500°F). Anything which causes combustion temperatures to rise will also cause NO_x emissions to rise. Misfire can also cause NO_x to rise because of the increase in oxygen that it causes in the catalytic converter feed gas.

Carbon Dioxide measured by an exhaust analyser in percentage (%) or parts per hundred. Carbon dioxide is a by-product of efficient and complete combustion. Near perfect combustion will result in carbon dioxide levels which approach the theoretical maximum of 15.5%. Carbon dioxide levels are affected by air/fuel ratio, spark timing and any other factors which affect the combustion efficiency.

Oxygen is measured by an exhaust analyser in percentage (%) or parts per hundred. The amount of oxygen produced by an engine is affected by how close the air/fuel ratio is to stoichiometry. As the mixture goes lean of stoichiometry, oxygen increases. As mixture goes rich of stoichiometry, oxygen falls to zero. Because oxygen is used up in the combustion process, concentrations at the tailpipe will be very low. If misfire occurs, however, oxygen will increase dramatically as it passes unused through the combustion chamber.

General Rules of Emission Analysis

If CO goes up, O₂ goes down and conversely if O₂ goes up, CO goes down. It is noted that CO readings are indicator of a rich running engine and O₂ readings are an indicator of a lean running engine.

If HC increases as a result of a lean misfire, O₂ will also increase.

CO₂ will decrease in any of the above cases because of an air/fuel imbalance or misfire.

An increase in CO does not necessarily mean there will be an increase in HC. Additional HC will only be created at the point where rich misfire begins (3% to 4% CO).

High HC, low CO and high O₂ at same time indicates a misfire due to lean or EGR diluted mixture.

High HC, high CO and high O₂ at same time indicate a misfire due to excessively rich mixture.

High HC, Normal to marginally low CO, High O₂, indicates a misfire due to mechanical engine problem or ignition misfire.

Normal to marginally high HC, Normal to marginally low CO and high O₂ indicates a misfire due to false air or marginally lean mixture.

Ambient values of the exhaust parameters are given below:

CO = 6 mg/m³; CO₂ = 0%; HC = 0 ppm; NO = 1 mg/m³; NO₂ = 0 mg/m³; NO_x = 1 mg/m³; SO_x = 0 mg/m³ and Ambient temperature = 24 °C

The different values of the exhaust gas elements are shown in the following tables and the respective figures are shown as follows:

Table 1: Particulars of exhaust gas for the samples at different loads.

Sl. No	Particulars	Load (kg)	Samples				
			B00	B10	B20	B30	B100
1	CO (mg/m ³)	5	81	76	61	36	34
		10	80	76	61	36	34
		15	79	75	63	38	33
2	CO ₂ (%)	5	1.2	1.1	1.1	1.2	1.2
		10	1.3	1.3	1.3	1.3	1.3
		15	1.5	1.5	1.5	1.5	1.4
3	HC (ppm)	5	25	25	27	28	28

		10	25	25	26	27	27
		15	25	25	26	26	27
4	NO (mg/m ³)	5	59	60	60	60	60
		10	88	97	101	101	101
		15	133	136	139	140	143
5	NO ₂ (mg/m ³)	5	43	45	47	49	49
		10	45	49	57	57	59
		15	55	56	58	58	60
6	NO _x (mg/m ³)	5	106	109	112	115	121
		10	133	135	142	152	163
		15	188	219	249	271	288
7	SO _x (mg/m ³)	5	3	-	-	-	-
		10	3	-	-	-	-
		15	3	-	-	-	-

Figure 3: Change of CO with respect to load for different samples

Figure 4: Change of CO₂ with respect to load for different samples

Figure 5: Change of HC with respect to load for different samples

Figure 6: Change of NO with respect to load for different samples

Figure 7: Change of NO_2 with respect to load for different samples

Figure 8: Change of NO_x with respect to load for different samples

Figure 9: Change of SO_x with respect to load for different samples

7.4 Result and Discussion

In figure 1 the change of CO with respect to load for different samples are decreasing as the content of biodiesel increases. That means the diesel give rich running engine and it becomes lean running at biodiesel fuel. It is noted that CO readings are indicator of a rich running engine. In fig. 2, 4, 5 it is seen that the values of the CO_2 , NO, NO_2 , with respect to different load for different samples remains mostly equal, so it may conclude that the biodiesel and its samples can used directly to the compression ignition engine. In fig. 3 it is seen that the value of HC remain same for the sample B00 and B10 and then increases with increase the increase value of the biodiesel in diesel. The values of NO_x remain almost same for different samples at lower load and at high load it increases with increase in value of biodiesel blending as shown in the fig. 6. In fig. 7 it is observed that the blending of diesel and biodiesel gives nil value of the SO_x for different sample at all loads.

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