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An experimental study of gaseous exhaust emissions of diesel engine using blend of natural fatty acid methyl ester

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Abstract. Vegetable oil form in Natural Fatty Acid Methyl Ester (FAME) has their own advantages: first of all they are available everywhere in the world. Secondly, they are renewable as the vegetables which produce oil seeds can be planted year after year. Thirdly, they are friendly with our environment, as they seldom contain sulphur element in them. This makes vegetable fuel studies become current among the various popular investigations. This study is attempt to optimization of using blend FAME on diesel engine by experimental laboratory. The investigation experimental project is comparison between using blend FAME and base diesel fuel. The engine experiment is conducted with YANMAR TF120M single cylinder four stroke diesel engine set-up at variable engine speed with constant load. The data have been taken at each point of engine speed during the stabilized engine-operating regime. Measurement of emissions parameters at difference engine speed conditions have generally indicated lower in emission NO_x, but slightly higher on CO_2 emission. The result also shown that the blends FAME are good in fuel consumption and potentially good substitute fuels for diesel engine

1. Introduction

The environmental concern of the global warming and climate change has greatly increased the interest of study of renewable fuels to internal combustion engine. The sharply rising petroleum price on the markets has revived more and more interest in the use of natural fatty acid methyl ester (FAME) as substitute of fossil fuel. FAME have their own advantages: available everywhere in the world, renewable as vegetables which produce oil, “greener” to the environment as they seldom contain sulphur element them. Diesel engines are preferred prime movers due to their excellent drivability and high thermal efficiency [1]. Despite these advantages they produce higher levels of NOx and smoke which affect human health [2]. The original diesel engine that Rudolph Diesel designed ran with vegetable oil. He used peanut oil to fuel one his engines at the Paris Exposition in 1900 [3]. But soon afterward, the application of vegetable oils as fuel was dropped due to cheap supply of petroleum based fossil fuels available in the world during the last century.

Even many investigations of FAME to substitutes for diesel fuel [6-10], but there are still a lot work that needs to be done to make vegetable oil really apply to diesel engine instead of ordinary diesel fuel. The vegetable oil in this experiment study have a lower calorific value compare to pure diesel fuel. Vegetable oil in this experiment is produce from 100% palm oil and it's called natural fatty acid methyl ester. The same with others vegetable oils, it have disadvantages of high viscosity. Modern diesel engines have fuel injection systems that are sensitive to viscosity changes. High viscosity may lead to poor atomization of the fuel, to incomplete combustion, to coking of the fuel injector, to ring carbonization, and the accumulation of fuel in the lubricating fuel [4]. The objective of this study is to carry out an experimental study to investigate the performance and the exhaust emissions characters of diesel engine fuel with FAME and its blends, compared to those of ordinary diesel fuel.

2. Experimental Procedure

A direct-injection diesel engine (model TF120 YANMAR) one cylinder, four stroke, naturally aspirated, water-cooled, was employed to test whose specifications are shown in table 1. This engine experimental work was operated at 1200, 1400, 1600, 1800, 2000, 2200, and 2400 rpm with constant engine load. The experiment by six kinds of fuel (blends by volume) were tested, i.e. blends of 5% FAME with 95% diesel fuel (B5), 10% FAME with 90% diesel fuel (B10), 15% FAME with 85% diesel fuel (B15), 20% FAME with 80% diesel fuel (B20), 100% FAME (B100) and 100% diesel fuel (DO). The test was conducted and repeated five times for every kind of fuel, in order to increase reliability of the test results. The specification of vegetable oil and pure diesel is shown in table 2.

A hydraulic dynamometer type gear pump was used for engine load. Exhaust gas temperature was measured using a thermocouple located downstream of the exhaust valve. Figure 1 shows the diagram of experimental setup. It consist of a test-bed, a diesel engine, a dynamometer, a fuel tank, a data acquisition system, a computer, an operating panel, exhaust emissions analyzer, and various sensors to measure the exhaust temperature, water cooling temperature, etc.

The experimental works started with a preliminary investigation of engine running on pure diesel in order to determine the engine's operating characteristics and exhaust emissions levels, constituting the base-line that is compared with corresponding cases when using vegetable oil. The same procedure was repeated for each fuel blend by keeping the same operating condition. For every fuel change, the fuel line was cleaned and the engine was left to operate for about fifteen minutes to stabilize at its new condition. The differences in the measured performance and exhaust emission parameters from the baseline operation of the engine were determined and compared.

Table 1. Engine Specification

Engine Type	YANMAR TF120
Number of Cylinder	1
Bore x stroke (mm)	92 x 96
Displacement (L)	0.638
Continuous Output (HP)	10.5 HP at 2400 rpm
Rated output (HP)	12 HP at 2400 rpm
Cooling system	Hopper
Dry weight (kg)	102

Table 2. Fuel Characteristics

Fuel Type	DIESEL OIL	FAME
Density @15^{0}C, kg/L	0.87	0.874
Viscosity @40^{0}C,	4.0	4.4
Flash Point , ^{0}C	91.0	154
Sulphur , wt%	0.3	0.2
Carbon Residue , wt%	<0.1	<0.01
Cetane Index	55	67.5
Ash content, wt%	0.002	0.01
Copper corrosion	1a	1a

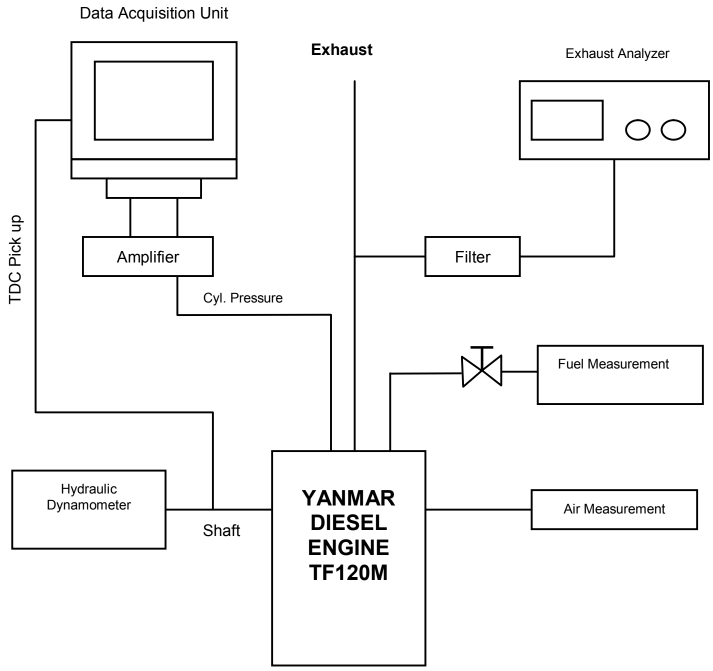

Figure 1. Experimental Diagram

3. Results and Discussions

The diesel engine ran well on all the fuels mentioned above. The performance of engine is greatly influenced by sources of bio-diesel, for example engine fuelled with palm oil bio-diesel is more efficient than bio-diesel produced from tallow and canola oil [5]. Bio-diesel is likely produce less power with high fuel consumption than diesel as the gross calorific value (energy content) of FAME is lower than pure diesel fuel. The calorific value of experimental fuels is shown in fig. 2.
Fig. 3 shows the brake torque results for experiment. The torque increases with the increase of engine speed until the limitation of speed at 1800, and decrease starting from 2000 rpm engine speed until maximum speed. From the figure also can explained that 100% FAME give result in lowest torque compare to other blends fuel and pure diesel fuel. Decrease in torque is due to their lower energy content of FAME. Lower energy content shows lower energy characteristic.

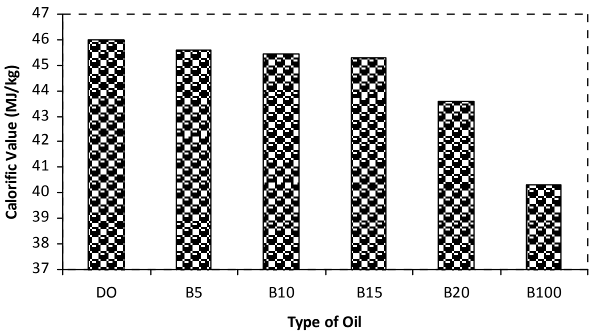

Figure 2. Calorific Value of Fuel Experiment

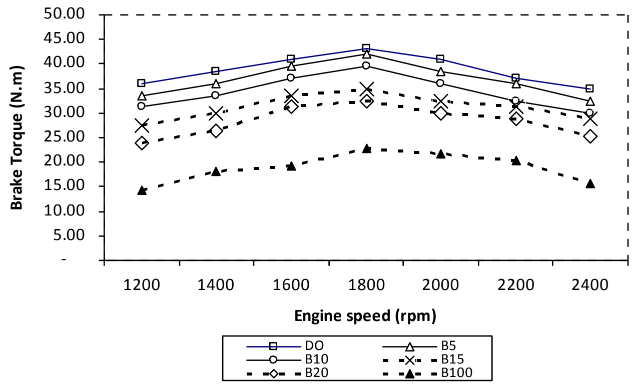

Figure 3. Brake Torque versus engine speed

The comparison of fuel consumption of experimental result is shown in fig. 4. It can be seen that fuel consumption generally increase with blend ratio compare to pure diesel fuel. A fuel consumption increases by 4%. This trend can be explained by lower calorific value of FAME compared with pure diesel fuel. Fig. 5 shows the result of NO_x emission for the all fuel test. NO_x emissions decreased with the increase of engine speed. Thermal NO_x refer to NO_x formed through high temperature oxidation of nitrogen (N_2) in combustion chamber. The formation rate of NO_x is primary function of combustion (flame) temperature, residence time of nitrogen at that temperature, and the contents of oxygen in the reaction regions in the combustion chamber. The NO_x emissions of blended fuels were slightly higher than those of the pure diesel fuel at all engine speed. The higher combustion temperatures and the presence of fuel oxygen in the blended fuels caused higher NO_x emissions. It is well known that the external oxygen supplied within air itself is less effective than the fuel borne oxygen in the production of NO_x. From the fact that when the speed increases, the friction horsepower decreases according to decrease in mechanical efficiency in order to maintain torque output, leading to an increase in the fuel consumption rate. This significant increase of consumption results in lesser evaporation rate which consequently lead to the reduction of NO_x emissions.

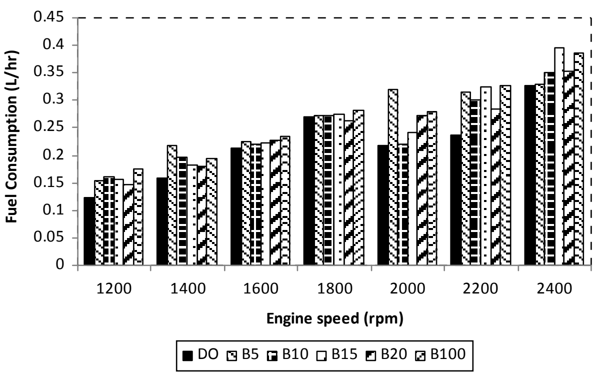

Figure 4. Fuel consumption versus engine speed

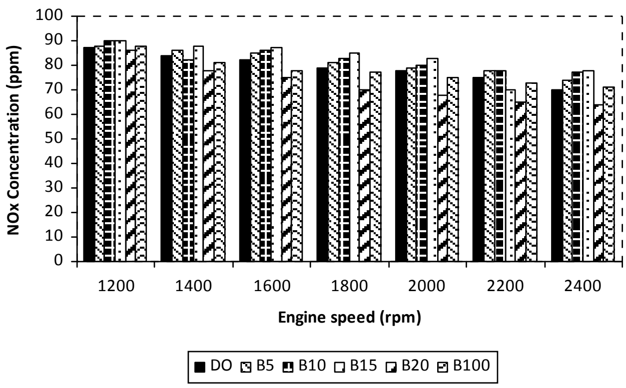

Figure 5. NO_x emission versus engine speed

Fig. 6 shows the CO emissions from the engine at the variable engine speed. The concentration of CO emissions was increase with increase of engine speed. From the figure show that the changed of CO emissions is not significant compare with blends fuel and pure diesel fuel. It can be explain that the in all condition the temperature in cylinder were high, which made the chemical reaction of fuel with oxygen be easier and the combustion become more complete.
Fig. 7 shows the exhaust gas temperatures versus engine speed. The exhaust gas temperatures rise with the increase of engine load for all of the fuel. From that figure can be seen that exhaust temperature at different fuels, are nearly the same at all engine speed condition. Only in the case of lower speed at 1200 rpm with 10% (B10) and 15% (B15) vegetable oil the exhaust temperature slightly higher than the others fuel. The differences are between 10% and 14% compare to the pure diesel fuel.

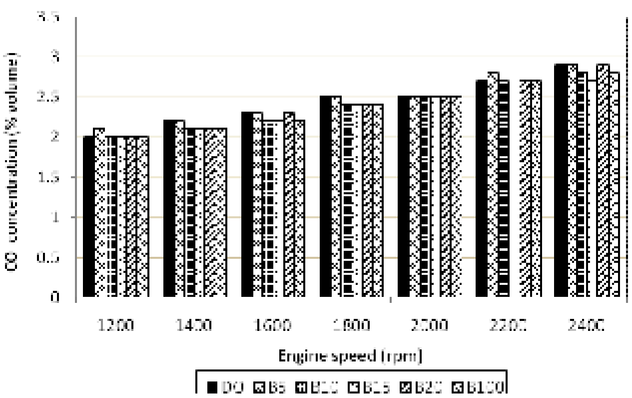

Figure 6. CO emission versus engine speed

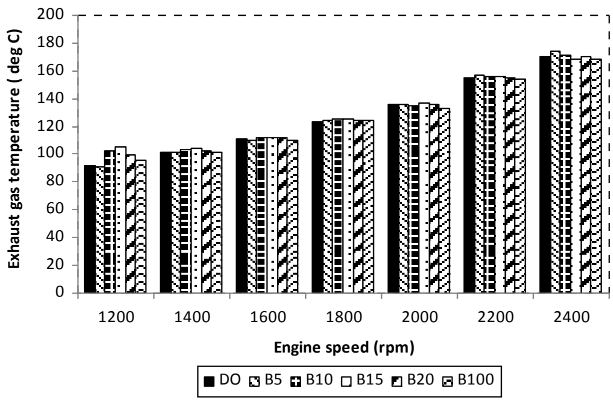

Figure 7. Exhaust temperature versus engine speed

3. Conclusions

This study investigated the use of fatty acid methyl ester (FAME) in unmodified diesel engine, with specific reference to performance and emissions with variable engine speed and blend ratio. The engine torque is lower when the engine fuelled with FAME and its blends compared with that of pure diesel fuel. The fuel consumption is higher when using FAME. The emissions of nitrogen oxide (NO_x) from FAME and its blends, at the range of tests, are generally lower than that pure diesel fuel. This is the most important gaseous emissions characteristic of FAME and its blends. FAME having higher oxygen content can lead less CO emissions with increasing blend ratio due to complete combustion in diesel engine. The results from the experiments prove that the FAME and its blends are potentially good substitute fuels for diesel engine in the near future when petroleum deposits become scarcer.

Acknowledgement

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