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Durability studies of single cylinder diesel engine running on emulsion fuel

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ABSTRACT

Emulsion fuel is one of alternative fuel for diesel engines. This study is to investigate the durability of a diesel engine that is running on emulsion fuels. Two emulsion fuels contain water, low grade diesel fuel and surfactant in the ratio of 10:89:1 v/v% (E10) and 20:79:1 v/v% (E20) has been tested for 200 h. The results of using emulsion fuels were then compared with that of Malaysian conventional diesel fuel (D2). The Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO_2), PM (particulate matter) and exhaust temperature from the tested fuel were measured before and after 200 h durability test. Analyses were also conducted on the wear of the engine components, viscosity change of the lubricant and carbon deposit formation in the combustion chamber. Emulsion fuel operation in the test engine reduced the PM and NO_x by 15.47% and 54.40% respectively but CO and CO_2 increased by 95% and 34.12% respectively as compared to D2. No abnormal wear could be observed when using emulsion fuels. In addition, emulsion fuels produced less carbon deposit with 65% and 52% reduction for E10 and E20 respectively. All three test fuels exhibits minimal increments in the lubricant's viscosity values after 200 h of engine operation.

1. Introduction

Energy is a key factor in the economic and social development for a country and its citizens. Currently, most of the energy comes from fossil sources, which are non-renewable and impose a negative effect on the environment (e.g. greenhouse gases damaging the ozone). The increasing greenhouse gas emissions have caused the climate and nature to be unstable [1]. Unpredictable climate change is one of the most serious problems faced today. There is growing concern and convincing evidence concerning how the average earth temperature has significantly increased over the last few decades. In addition, the burning of fossil fuels, such as oil, gas and coal accounts for about 75% of the total world's energy use [2].

At present diesel engines are the most efficient internal combustion engines for transportation and industrial activities. This is due to their excellent fuel-to-energy conversion rate, durability and heavy-duty application. However, diesel engines suffer from PM (particulate matters) and Nitrogen Oxides (NO_x) emissions [3]. Emissions from diesel engines significantly contribute to the greenhouse effect, acid rain, ozone layer destruction and the decline in human health (especially respiratory problem) [4]. Newer stringent emission standards have motivated researchers to brainstorm for new ideas concerning ways to reduce emissions, without compromising engine efficiency.

In general, pollutant control methods can be divided into two types: 'after combustion control' and 'during combustion control'. The former includes SCR (selective catalytic reduction) and $DeNO_x$ function to control NO_x emissions [5]. In order to control PM emissions, a DPF (diesel particulate filter) can be used to eliminate PM or soot from the Exhaust gas [6]. For CO_2, the membrane absorption of CO_2 from the flue gas seems to be a promising method [7]. On the other hand, the latter consists of a LEA (low-excess-air) burning mechanism, fuel modification, engine design modification and EGR (exhaust gas recirculation) [8–10]. However, methods that are known to reduce NO_x lead to increasing PM emissions instead [11].

A famous in-cylinder method to reduce the NO_x production rate is WI (water injection) into the air intake [12], directly into the

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cylinder [13] or in emulsion with the fuel [14,15]. A major benefit of WI when compared with EGR is the potential reduction of both NO_x and PM emissions either at low or high loads. However, WI gives the existence of liquid water in the cylinder to affect the lubricant, engine wear and fuel consumption due to poor atomization and degraded combustion [16].

An emulsion can be defined as a combination of two-different fluids that will not physically mix, but one part will stay suspended in another [17]. In general, emulsions are characteristically unstable and they will separate into the stable states of dispersed and continuous phase materials. Surfactants are commonly used to maintain the stability of emulsions. Due to the huge droplet sizes of diesel or biodiesel, combustion takes a longer time, thus the available time frame is not sufficient for complete combustion [18]. However, in emulsion fuels the droplets are relatively smaller due to micro-explosions therefore allowing a complete burning to occur. The micro-explosions would cause the smaller fuel particles to be in contact easily with the air for complete combustion, and reduce the generation of PM without failing the combustion efficiency [19].

As emulsion fuel application is yet to be established, not many engine durability tests were done on emulsion fuels; only few researchers had actually reported on it. A research reported that PM emissions before and after the engine durability test of using both diesel and emulsion fuel showed no destruction present on the parts of the cylinder even after a 500 h durability test on four cylinder diesel engine [20]. The use of emulsion fuel for buses travelling about 50,000 km showed no effect on engine operability and lubricant. Plus, the smoke density was clearly improved with emulsion fuel even in the old buses [21].

Kawasaki Heavy Industries Ltd. had conducted a pre-operation testing for their ships to run on heavy emulsion fuel in July 2010 to evaluate the level of emission and engine performance. Subsequently in January 2011 implementation was made and the fuel has been used until now due to the success of the pre-operation testing [22]. Analyses on wear of engine components, carbon deposits formation and lubricant viscosity are some of the interesting work that need to be done for emulsion that uses two different percentages of tap water with low grade diesel fuel as it has not been done previously.

2. Experiment details

In this study, two types of emulsion fuel with different water concentrations were employed: 10% (E10) and 20% (E20). The emulsion fuels that consist of Malaysian low grade diesel fuel (D2) and tap water were prepared using an electrical mixer at a propeller speed of 2500 rpm for 5 min. The details of the D2 specification are shown in Table 1. To stabilize the emulsions, a 1% by volume of surfactant known as SPAN 80 was used. All test fuels operated in a constant speed diesel engine generator set to study their effect on the emissions, carbon deposits, lubricant and wear of diesel engine components. The specifications of the engine are given in Table 2. The engine was coupled with an AC (alternate current) generator and the current generated was used by a resistive load bank, thus, in-turn loading the engine. The generator was calibrated and all losses in the generator such as armature current losses, copper losses, friction and windage losses were accounted for and taken into consideration.

Engine emissions tests were conducted before and after the engine durability test to measure any significant increase in NO_x, PM, Carbon Monoxide (CO), Carbon Dioxide (CO_2) and exhaust temperature. The unburned hydrocarbon emission was not included in this study due to technical problem with the sensor of emissions analyser. In this test, three sets of 5 kW diesel engines generator were used for each type of fuel. The engines were operated at a constant speed of 3000 rpm with varying engine loads. The load applied to the engines was controlled by a voltage regulator (acting as a 5 kW of load bank) with a set of Philips QVF 137 Halolite lamps. The schematic diagram of the engine emissions test setup is shown in Fig. 1.

The emissions measurements were done according to the specification and procedures described in SAE Engine Test Code J816b. The device used in the test was a portable Testo 350 emission analyser. The specification of the Testo 350 emission analyser is shown in Table 3. The measurement was recorded for every 5 s interval during the 2 min duration of engine running and the average data were calculated. The temperatures of the exhaust gas were measured using K type thermocouples. The readings were scanned and displayed on the Kyowa scanner monitor.

The PM emissions were measured according to the CARB (California Air Resources Board) standard. A mini-dilution tunnel with a 70 mm inner diameter and 680 mm length was used for PM sampling. The exhaust gas was diluted with clean air that had been heated up to 50 °C and at dilution ratio of 10:1. This ratio was controlled by the amount of CO_2 in the exhaust gas and inside the dilution channel. The amount of CO_2 was measured with Rapidox 3100ZA CO_2 Analyser. This diluted gas was quantified by a wet gas meter and pass through a teflon filter (MILLIPORE FHLP 04700, diameter = 47 mm, orifice = 0.47 μm) to trap some amount of particulates.

Particulate concentrations were then determined by measuring the mass difference of the filter before and after the sampling. In order to remove the effect of moisture, the filter was dehumidified with silica gel for 12 h. The mass of the filter was measured using a Quartz Crystal Microbalance with a reading accuracy of ±0.01 mg. Net mass of PM can be obtained from Equation (1):

$$\text{PM mass (mg)} = (\text{filter mass after}) - (\text{filter mass before}) \quad (1)$$

Table 1
D2 fuel characteristic.

Properties	Unit	D2
Calorific value	MJ/kg	45.28
Cloud point	°C	18
Density @ 15 °C	kg/L	0.854
Total sulphur	mass%	0.28
Viscosity @ 40 °C	cSt	4.64
Distillation temperature, 90% recovery	°C	368
Flash point	°C	93
Pour point	°C	12
Cetane number	–	54.6
Carbon	wt%	84
Hydrogen	wt%	12.8
Sulphur	wt%	0.2
Nitrogen	wt%	<0.1
Oxygen	wt%	3.9

Table 2
Test engine specifications.

Parameter	Specification
Model	Mr. Mark MC-D6500E diesel engine
Engine Type	One cylinder, D I, air cooled, vertical engine
Bore/Stroke	86/72 mm
Rated speed	2000 rpm
Compression ratio	18.7
Displacement	400 cc
Fuel injection release pressure	220 bar