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STUDY OF ENGINE PERFORMANCE AND EXHAUST EMISSION OF A DIESEL ENGINE USING PALM BIODIESEL BLENDS AT HIGH IDLING OPERATIONS

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Abstract*- Rapid depletion of fossil fuel, global warming and climate change due to fossil fuel exhaust emissions are the main reason automotive industry is looking for alternative fuels. Biofuel is one of the main alternatives for fossil fuels. In this paper, engine performance and exhaust emissions using biodiesel derived from palm oil in a diesel engine at high idling operations has been reported. Palm oil biodiesel has superior lubricity and biodegradability, lower toxicity, essentially no sulfur and aromatic content, higher flash point, and positive energy balance. High idling operations are also a major concern for the industry. When the engine is running in idle conditions, fuel consumption and emission levels increase. The result obtained shows that, as HC and CO emissions decreases with increase in blend percentage and idling speed but NO_X emissions increases. Also, BSFC and BTE deteriorates at all conditions compared with diesel fuel.*

Keywords: Palm, Biodiesel, Emissions, Fuel consumption, Renewable.

1. INTRODUCTION

It is known fact that in modern economics, agricultural, telecommunication, transportation, industrial sectors etc. sectors advancement heavily depends upon energy. Consequently, worldwide energy consumption rate is growing faster than the population growth rate. For many countries, this ever growing increase in energy demand is becoming a critical issue. At the present time, transportation sector heavily depends upon petroleum or crude fossil oil. All over the world, petroleum has become a dependent source due to having high density and better handling facility. However, petroleum fuel is depleting rapidly due to the huge increase in usage and also fuel price is rising every day. Also emission from fossil fuel combustion has an adverse effect on environment and human health. For these reasons, worldwide scientists are looking for an alternative source of energy which is eco-friendly, domestically available and technically feasible [1-3]. Many countries are concentrating on a lot of researches to find a suitable replacement of petroleum fuel [4, 5]. One such solution can be biodiesel as it has similar functional properties as diesel fuel [6-8]. Biodiesel is biodegradable, non-explosive, renewable, non-flammable, non-toxic and also environment friendly [9, 10]. The major advantage of using biodiesel is that, pure or blended with diesel, it can be used in a diesel engine without making any modification [11].

When engine is operated with biodiesel and their blends with diesel fuel it affects the engine performance and emissions of diesel engine. Many researches have been done to evaluate engine performance and emissions using biodiesel and their blends [12-15]. Researchers reported that, diesel engine operated with biodiesel-diesel blends results in decrease in CO and HC emission, however it increases NO_X emission [16-21]. However, there has been only one study that was done to investigate the impact of biodiesel on engine performance and emission during high idling condition [22]. When the engine runs at low load and at low rated speed it is called high idling condition. This is one of the major problems transport industry is currently facing. After driving for a certain period, it is mandatory for drivers to take a rest. During this time, the drivers keep the engine idling in order to maintain cab comfort and to provide power to the loads in the cab, such as heating, air conditioning, refrigerators, and microwaves. This is known as high idling condition. Studies indicate that long-haul trucks are idling for between 6 and 16 hours daily. When the engine is running in idle conditions, it takes a rich mixture of air and fuel, such that the fuel consumption rate is high. Furthermore, during idling, the engine is not able to work at peak operating temperature and the combustion of fuel is incomplete, which leaves fuel residues in the exhaust and thus, emission levels increases. Previously, many researches has been done to evaluate the engine performance and emissions using only diesel fuel at idling condition. Researchers found that, NO_X emission while engine idling was higher than vehicle running on road by a factor of 1.5 [23]. Increase in load during idling increases NO_X emission [24, 25]. During idling fuel consumption can be as high as 1.65 gal/h [26], CO emission can be as high as 295 g/h [27], HC emission can be as high as 86.4 g/h [28]. Compared to driving cycle emission HC emission during idling is reported to be 1 to 5 times more than that of driving cycle and idling CO emission were 5%-75% of driving emission [29].

Amongst the plant families, palms are the most popular and extensively cultivated. *Elaeis guineensis* Jacq is the most highly productive species. It can be cultivated in all tropical areas where weather is humid and hot like Malaysia and Indonesia [30]. This particular variety can annually produce 10-35 tonnes/ha of palm fruits. Oil is extracted from both the pulp and the seed. Oil palm trees are commercially cultivated to serve edible oil to the market [31]. Researchers found that Palm biodiesel usually gives lower power, torque and thermal efficiency at higher fuel consumption [16, 32, 33]. But in some cases, it gave higher thermal efficiency and lower fuel consumption than petroleum diesel [34] S. Bari et al. reported that using crude palm oil in diesel engine increased bsfc by 26% percent [35]. Palm biodiesel produces less HC and CO emission compared to diesel fuel [36, 37].

In this paper engine performance and exhaust emission test while running blends of palm biodiesels during idling condition has been reported too. Also, comparison with the results obtained while running the engine with diesel fuel has been reported too.

2. BIODIESEL PRODUCTION PROCESS

All the feedstock oils were purchased from local farm of Malaysia and Indonesia respectively. All necessary chemicals for trans-esterification were purchased from LGC Scientific, Kuala Lumpur, Malaysia.

In General, biodiesel is produced using the following two steps:

a) Acid esterification
b) Base trans-esterification process.

But as acid value of crude palm oil is lower than 4 mg KOH/gm. only base trans-esterification was needed. 1% w/w of KOH dissolved in 25% v/v of methanol was poured into the flus. Then the mixture was stirred at 700 rpm and stirred for 3h and again poured into a separating funnel where it formed two layers. Lowered layer contained glycerol and impurities and upper layer was methyl ester of vegetable oil. Lower layer was discarded and yellow upper layer was washed with hot distilled water (100% v/v) wand stirred gently to remove remaining impurities and glycerol. Biodiesel was then taken in an IKA RV10 rotary evaporator to reduce the moisture content. Finally, moisture was absorbed by using sodium sulphate and final product was collected after filtration.

3. BIODIESEL PROPERTY TEST

The properties of Palm biodiesel (PB100) and Diesel fuel were measured at the Energy Laboratory and the Engine Tribology Laboratory, Department of Mechanical Engineering, University of Malaya. Density, kinematic viscosity, flash point, cloud point, pour point and calorific value, these six main physicochemical properties were measured. Table 1 shows the apparatus used to find out the property of the biodiesel and diesel. Table 2 shows the individual fuel properties along with standard biodiesel properties.

Table 1: Apparatus used for testing fuel properties

Properties	Properties Apparatus
Density	Stabinger Viscometer SVM 3000 Manufacturer: Anton Paar
Kinematic Viscosity	
Flash Point	Pensky-Martens flash pointautomatic NPM 440 Manufacturer: Normalab, France
Cloud and pour point tester	Cloud and pour point tester
Calorific value	Semi auto bomb calorimeter Model: 6100EF Manufacturer: Perr, USA

Table 2 Fuel properties of Diesel and Palm biodiesel

Properties	Unit	Diesel	Palm biodiesel	ASTM D6751-06 standard
Density	kg/m^3	833.1	858	860–900
Cetane number	–	47	52	47 min
Viscosity	mm^2/s	3.556	4.63	1.9–6.0
Flash point	°C	77.5	189	130 min
Cloud point	°C	8	6	−3 to 12
Pour point	°C	6	2	−15 to 10
Calorific value	kJ/g	44.664	39.907	–

4. ENGINE TEST

An inline four cylinder, water cooled Mitsubishi Pajero engine was used to perform the engine test. The engine was coupled with an eddy current dynamometer which can be operated at a maximum power of 20 kW with operating speed ranged from 1000 to 4000 rpm.

The engine test was conducted at three idling conditions, which are: 1000 rpm at 10% load, 1200 rpm at 12% load and 1500 rpm at 15% load. Fuels tested were: Diesel, PB5 (5% palm biodiesel-diesel blend), PB10 (10% palm biodiesel-diesel blend) and PB20 (20% palm biodiesel-diesel blend). Fig 1 shows the schematic diagram of the experimental setup. The engine specification is listed in table 2. In table 3, equipment used in the experiment is listed. Every test was repeated three times and average values were reported in this paper.

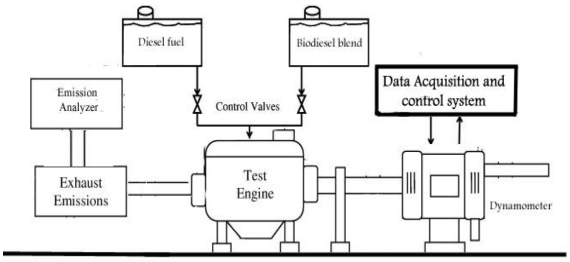

Fig 1: Schematic diagram of the engine test bed

Table 3 Engine Specification

Engine Type	4 cylinder inline
Displacement	2.5L (2476 cc)
Bore	91.1 mm
Stroke	95.0 mm
Torque	132 N-m, at 2000 rpm
Compression Ratio	21:1

Table 4 Equipment used in engine test

Equipment Name	BOSCH BEA-350 exhaust gas analyzer
Measured	HC (parts per million or ppm)
	Carbon monoxide (percentage volume or %vol)
Equipment Name	AVL 4000 (Manufacturer: Graz/Austria)
Measured	NO_x (parts per million or ppm)
Equipment Name	DYNOMAX 2000 data control system
Measured	Brake specific fuel consumption (BSFC)

5. RESULT AND DISCUSSION

5.1 BRAKE THERMAL EFFICIENCY

Brake Thermal Efficiency is defined as break power of a heat engine as a function of the thermal input from the fuel. It is used to evaluate how well an engine converts the heat from a fuel to mechanical energy. Fig 6 demonstrates brake thermal efficiency at different idling conditions for diesel and palm biodiesel-diesel blends. The equation to calculate BTE is,

$$BTE = \frac{3600 * 10^6}{HV * BSFC} \% \qquad (1)$$

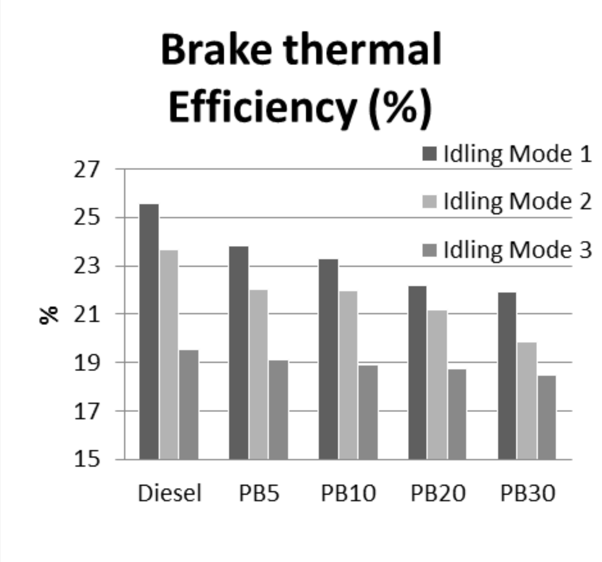

Fig 2: Brake thermal efficiency Palm biodiesel-diesel blends and diesel at various idling modes

Fig 2 illustrates brake thermal efficiency of diesel and palm biodiesel-diesel blends at three idling modes. For idling mode 1 and 2 Brake Thermal Efficiency deteriorates significantly as blend percentages of palm biodiesel increases compared to diesel. But for idling mode 3 the decrease in efficiency is almost negligible compared to diesel. In mode 1 and 2, in these two speeds, increase in bsfc of biodiesel blends are not as much as they were supposed to be as the heating value of biodiesel decreases. But at idling mode 3, bsfc increases constantly as heating value decreases. For all the fuels tested, with increase in speed and load BTE decreases as fuel consumption increases.

5.2 Brake Specific Fuel Consumption

Brake Specific Fuel Consumption (BSFC) is considered a measure of combustion efficiency, how efficiently a given amount of fuel is being converted into a specific amount of horsepower. Figure 3 shows the brake specific fuel consumption at different idling modes for diesel and Palm biodiesel-diesel blends

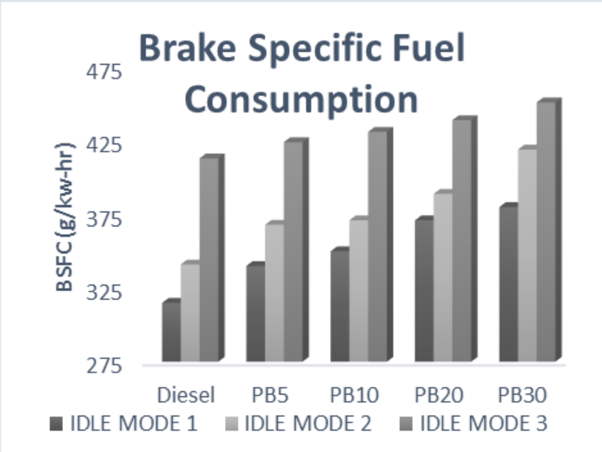

Fig 3 brake specific fuel consumption at different idling modes for diesel and Palm biodiesel-diesel blends

From Fig 3, it is seen that at all idling modes diesel fuel consumptions were the lowest and as blend percentages increased fuel consumption increased. This is due to reason that as palm biodiesel has lower heating value than diesel, thus bsfc increases. BSFC of PB30 were highest at all modes, supports the theory.

5.3 CO Emission

Generally CO formation is resulted from incomplete combustion. Incomplete combustion occurs when flame front approaches to crevice volume and relatively cool cylinder liner. Therefore, flame temperature is cooled down and results in incomplete progression to CO_2. Diesel and Palm biodiesel-diesel blends CO emission at different idling modes are shown in Fig 4.

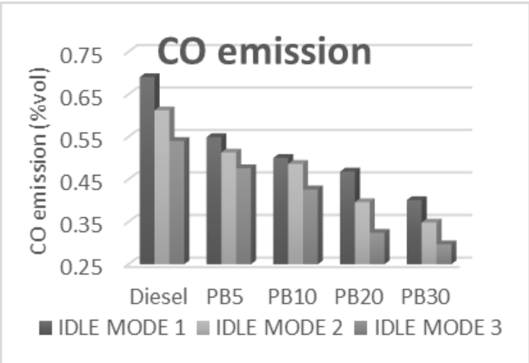

Fig 4 Diesel and Palm biodiesel-diesel blends CO emission at different idling modes

From fig 4, it is seen that PB30 emits significantly low CO whereas at all modes Diesel emitted highest CO. CO emission decreases as blend percentages increases, due to the fact that palm biodiesel contains more oxygen compare to diesel which ensures better combustion and thus less emission.

5.4 HC Emission

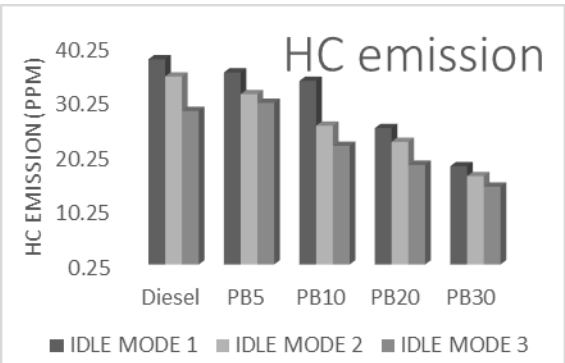

Fig 5 Diesel and Palm biodiesel-diesel blends HC emission at different idling modes

Fig 5 illustrates diesel and palm biodiesel-diesel blends HC emission at different idling modes. From fig, it can be seen that increase in blend percentages of biodiesel decreases HC emission. As there is higher oxygen concentration in the biodiesel-diesel blends which enhances the oxidation of unburned hydrocarbons. PB30 emitted lowest HC at all idling modes where Diesel emits highest HC. Furthermore, increase in speed decreases HC emission for all tested fuel. This is due to the reason that increase in speed ensures better mixing of air and fuel.

5.5 NO_X Emission

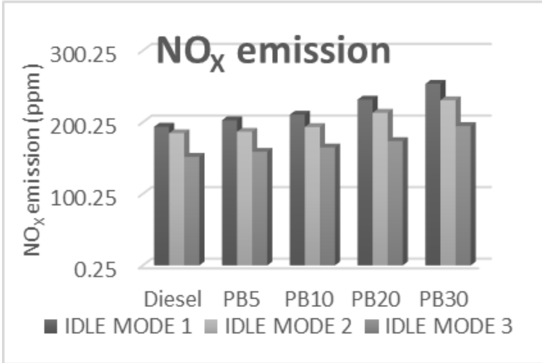

Fig 6 NO_X emission at different idling modes for diesel and palm biodiesel blends

Fig 6 demonstrates NO_X emission at different idling modes for diesel and palm biodiesel blends. Diesel fuel exhibited lowest emission at all condition. As blend percentages of biodiesel increases emission increases. PB30 emits highest amount of NO_X. Biodiesel blends produce higher emission due to having lower cetane number and higher ignition delay. It is observed that, as idling speed increases emission decreases due to the fact that increase in speed reduces the ignition delay which results in less amount of time to form NO_X.

6. CONCLUSION

Biodiesel has been produced from Palm oil and its properties have been evaluated in the lab. Also, an unmodified diesel engine was operated with diesel and Palm biodiesel-diesel blends (5%, 10%, 20%, and 30%) at three high idling modes and engine performance and emission parameters were explored.

The most important findings derived are summarized as follows:

- As biodiesel produced from palm oil using transesterification process satisfied the ASTM standards it can be used along with diesel fuel.
- Compared to diesel fuel, at high idling modes brake specific fuel consumption all Palm biodiesel-diesel blends increased.
- With the increase of blend percentages of biodiesel fuel consumption increased.
- CO and HC emissions decreased for Palm biodiesel-diesel blends and were lower than diesel at all tested condition.
- Increase in NO_X emission for small blend percentages were negligible compared to diesel
- With the increase in blend percentages NO_X emission increased. Emission from PB20 and PB30 were significantly higher than diesel.

7. ACKNOWLEDGEMENT

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9. NOMENCLATURE

Symbol	Meaning	Unit
BSFC	Brake Specific Fuel Consumption	g/kW-hr
BTE	Brake Thermal Efficiency	%
CO	Carbon Monoxide	%vol
NO_X	Nitrogen Oxides	(parts per million
HC	Hydrocarbon	(parts per million
PB	Palm Biodiesel	