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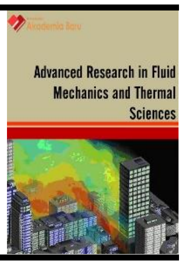

Analytical Study of Performance and Emission Characteristics of a Palm Biodiesel Fuelled Engine using Response Surface Methodology

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ABSTRACT

Alternative fuels are in the limelight due to depleting fossil fuel reserves and alarming environmental impact of pollution. Even though electric mobility is encouraged by the government to reduce the dependence on fossil fuel, lack of high energy density batteries still downplays the mass marketable scope of electric vehicles due to drivable range in which liquid fueled vehicles have the advantage. Response Surface Methodology (RSM), a statistical mathematic technique is utilized to analytically study the impacts of Palm Biodiesel (PBD) blended diesel fuel at enrichment ratio of 10%, 20%, and 40% on performance and emission characteristics of a multi cylinder compression ignition (CI) engine. The study concludes that engine torque and power improve with mild palm oil enrichment of 10% notably at low end speed of 2000 rpm. CO_2 and CO emissions and smoke decline while higher O_2 content present in PBD compared to pure Diesel gives rise to NO_X emissions.

Keywords:
Palm oil; Diesel; Response Surface Methodology

1. Introduction

Energy has become a great ingredient for humans to achieve and maintain industrial growth but this especially fossil fuels come at a cost of environmental and ecological threat. The threat posed by conventional fuels has forced law makers to deploy stringent laws to curb pollution. Biodiesel is an alternative to fossil fuels and when Malaysia is taken into importance along with other south east Asian countries, the abundance of palm derived biodiesels is a major boon to the community [1,2].

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Biodiesels are advantageous considering its factors like bio-degradable, non-toxic, lower sulfur content and lower engine emissions but its disadvantage is lower power delivery in engines [3].

A number of researchers have conducted studies on a variety of biodiesels. Abed *et al.,* [4] have studied the effects of biodiesels derived from Waste Cooking Oil (WCO), Palm, Jatropha and Algae on emission and report lower values of CO, HC and smoke when compared to diesel but NO_X and CO_2 increase. Bari and Hossain [5] have conducted experiment to determine engine out responses using palm oil and conclude that the oxygen molecule present in fuel reduces pollutants like CO and HC but low calorific value reduces BSFC when compared to diesel fueled operation. Palm oil blend of 20% in diesel was used to study the combustion characteristics of a Compression Ignition (CI) engine, Rosha *et al.,* [6] report that ignition delay lowers while peak cylinder pressure and Brake Thermal Efficiency (BTE) raises with increasing Compression Ratio (CR). Researchers have optimized engine operating characteristics using RSM for a variety of fuels, to name a few such as fried oil methyl ester, hydrous ethanol, iso-butanol and methanol [7-10]. Based upon the work carried out by previous researchers, it was understood that there was a knowledge gap particularly in using RSM analysis for engine fuelled by PBD blended fuel for RSM analysis based on experimental engine test results. Thus, this study is undertaken to establish possible findings.

2. Methodology

The present investigation was carried out using 4 different fuel samples which includes baseline diesel and Palm biodiesel blends here after notated as PBD10, PBD20 and PBD40. Fuel blends were manually prepared by agitating proportionate volume of diesel and PBD in a sealed container. Mass and volume of each fuel was measured to calculate density using the formula as stated by Karmakar *et al.,* [11]. A pycnometer kept at 25°C was used to measure the volume. The composition of the used fuels is presented in Table 1. The engine was tested at Wide Open Throttle (WOT) condition at varying speed range from 1000 rpm to 3500 rpm with an interval of 500 rpm.

Table 1
Composition and properties of fuel blend

Fuel type	Palm Biodiesel proportion in Diesel (%)	Fuel Density (g/ml)	Kinematic Viscosity at 40°C (mm^2/s) [12]	Calorific Value (kJ/kg) [12]
Diesel	0	833.7	3.0625	45,632
PBD10	10	836.3	3.8379	45,120
PBD20	20	838.8	3.9180	44,609
PBD40	40	844.7	4.1510	43,474

A 4-cylinder medium-duty diesel engine which featured mechanical fuel injection system and turbocharger was used in this study. The specifications are shown in Table 2.

Table 2
Engine specifications

Make and Model	Type	Fuel Injection System	Combustion Type	Displacement	Compression Ratio
Ford 1.8 XLD 418T	4-stroke, four-cylinder diesel turbocharged, water-cooled	Lucas DPC type fuel-injection pump, single-point fuel injectors	Indirect injection (IDI) with pre-combustion chamber	1.8 L	21.50: 1

An eddy current type Scheneck W130 engine dynamometer with the peak absorbing power of 130 kW was used to control the speed and torque of the engine, as shown in Figure 1. For fuel consumption measurement, a Kobold oval gear type fuel flow meter was employed. Gaseous emissions and smoke opacity in engine-out exhaust was detected by SPTC AUTOCHECK 5-gas analyser and smoke analyser. Collected data was later analysed for Response Surface Methodology (RSM) using Design Expert, a licenced software by Stat Ease, which also used by most of the researchers [13-16].

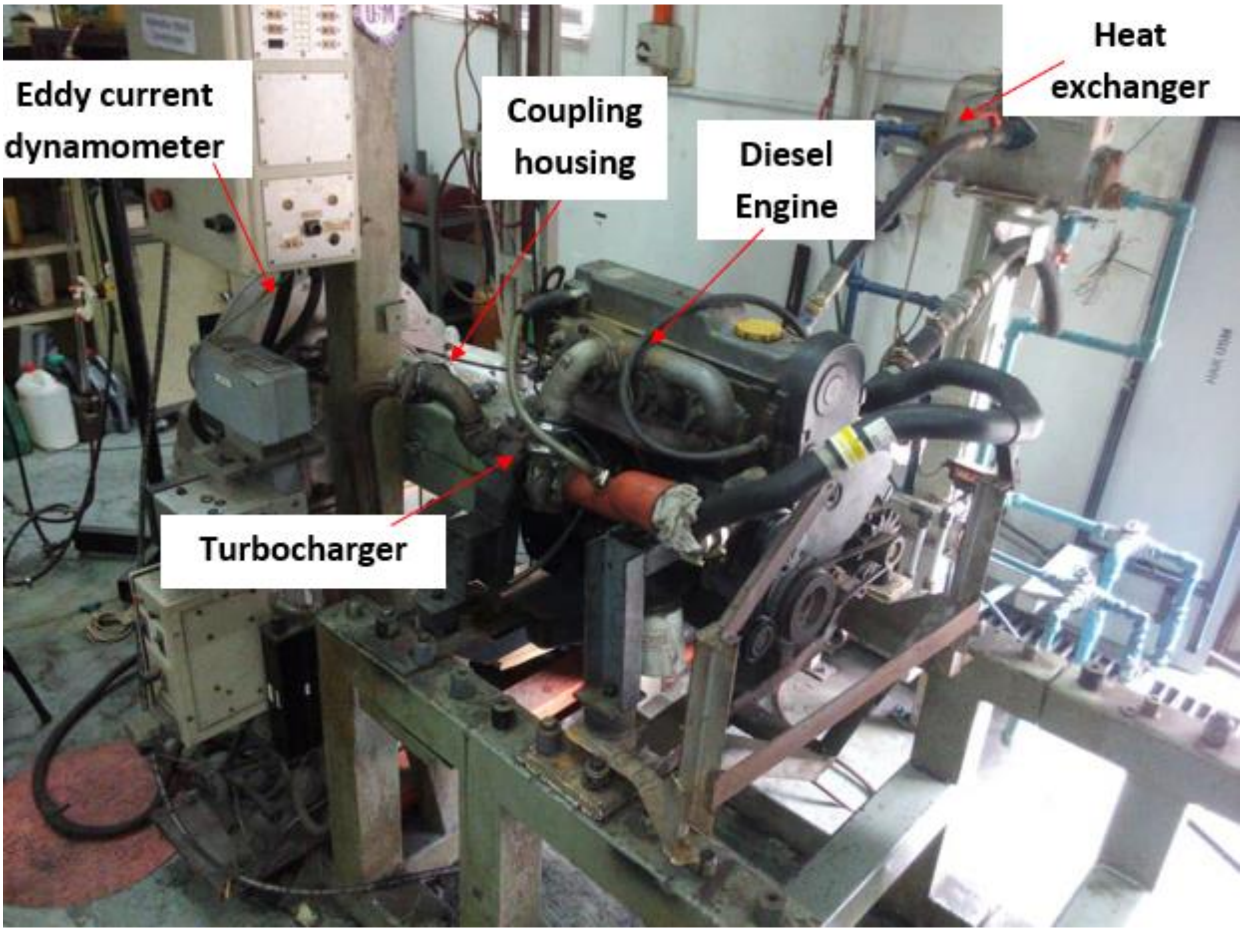

Fig. 1. Engine and dynamometer arrangement setup

3. Results and Discussions

3.1 Performance

Power can be stated as a function of torque and speed. From Figure 2, it is understood that peak power operating region spreads across the speed range approximately from 1750 rpm to 3250 rpm for baseline fuel diesel and PBD blend of 10-40%. As brought out by several researchers, this can be attributed to higher viscosity, lower calorific value and density of PBD fuel [17-23]. Higher value of fuel density and kinematic viscosity can have an adverse effect on air-fuel mixing due to poor fuel atomisation. This phenomenon in turn results in combustion instability and thus lowers power. Lower cetane number reduces combustion quality as chances of self-ignition of fuel are better with high cetane number giving shorter ignition delay. Higher peak in-cylinder pressure and high Heat Release Rate (HRR) at pre-mixed combustion phase is possible with shorter ignition delay. This kind of desired combustion quality elevates the need for high cetane number fuel. Highest power of 29.6 hp at 2000 rpm is obtained for PBD10 compared to 28.7 hp at 2000 rpm for pure diesel fuelling.

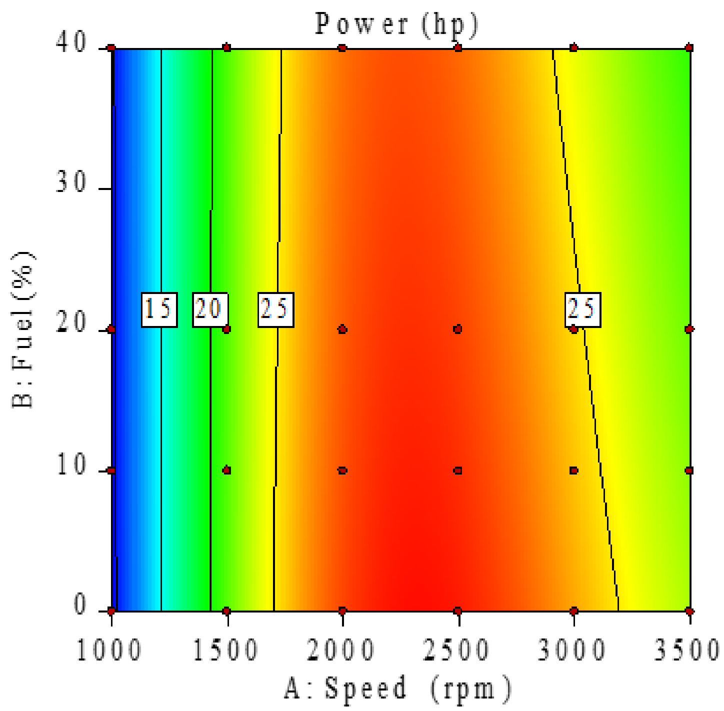

Fig. 2. Interactive effect of fuel blend and speed on engine power

Torque is a measure of rotational effort on crankshaft by piston otherwise an opposing force developed to counteract the torsional resistance (load). As seen from Figure 3, peak torque operating region in speed range approximately from 1000 rpm up to 2000 rpm for baseline fuel diesel and PBD blends satisfactorily up to 80%. Highest torque of 102.2 Nm is attained with pure diesel fuelling at 2000 rpm and 105.5 Nm for PBD10, after which a downward trend is observed for the rest of PBD fuel blends. Factors like low engine speed, higher viscosity and lower heating value and calorific value, longer ignition delay and cetane number of fuels can reduce engine torque [24,25].

Brake Specific Fuel Consumption (BSFC) is a measure of fuel efficiency and can be defined as rate of fuel consumption divided by power developed. As seen from Figure 4, the optimum BSFC operating region in speed range from 1000 rpm to 2500 rpm after which it slims down for baseline diesel fuel and PBD blends all the way up to 40%. Lowest BSFC is attained for diesel at 328.4 g/kWh and 326.3 g/kWh for PBD10 at 2000 rpm. BSFC is influenced by several factors of fuel properties such as calorific value, density and viscosity. Fuel injection pump injects more PBD blended fuel mass than pure diesel mass due to higher density of PBD for the same power. For comparison, diesel has a density of 833.7 g/ml whereas PBD20 and PBD40 have density of 838.8 g/ml and 844.7 g/ml, respectively, as shown in Table 1. Poor atomisation of fuel caused by higher kinematic viscosity of PBD increases BSFC. These attributes have well been highlighted by various researchers in their work [20,26-28].

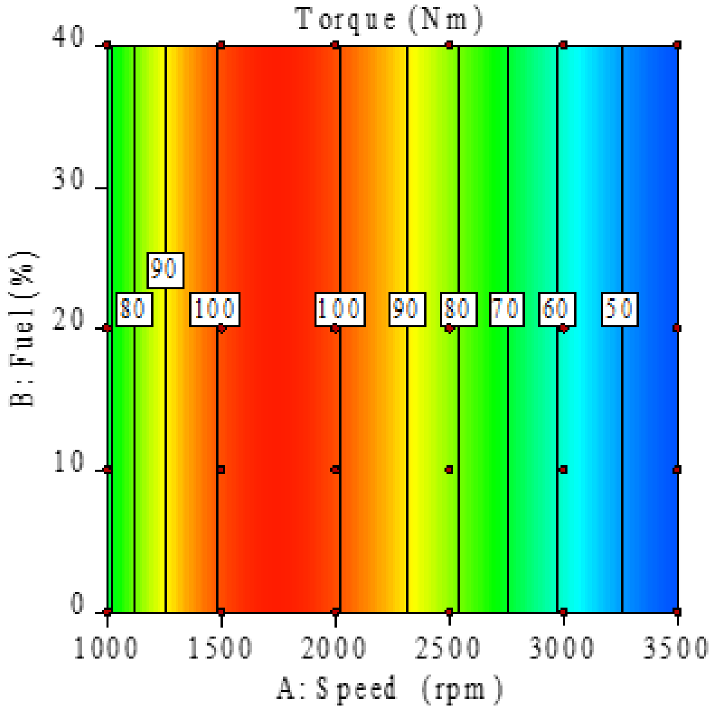

Fig. 3. Interactive effect of fuel blend and speed on torque

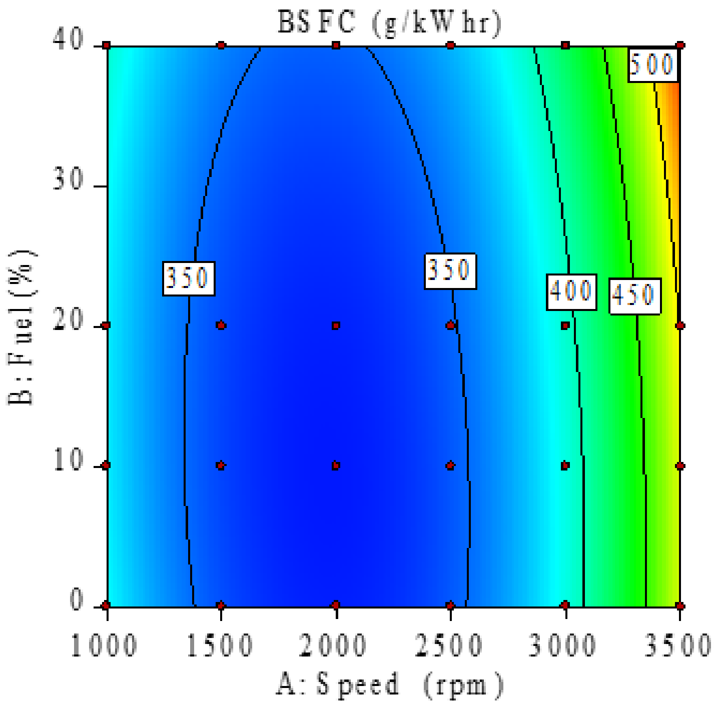

Fig. 4. Interactive effect of fuel blend and speed on BSFC

3.2 Exhaust Emissions

Carbon dioxide (CO_2) emissions are by-products of combustion. As seen from Figure 5, high CO_2 emissions were observed in the operating speed range approximately from 1250 rpm to nearly 2000 rpm after which it lowers down for baseline fuel diesel and PBD blends from 10% to 40%. Highest CO_2 emissions of 10.9 vol. % was noted for baseline fuel diesel whereas for PBD40 was slightly reduced at 0.6 vol. % for 1500 rpm. Biodiesels have higher O_2 concentration and this leads to high O_2 concentration in combustion region oxidizing CO to CO_2 [29,30].

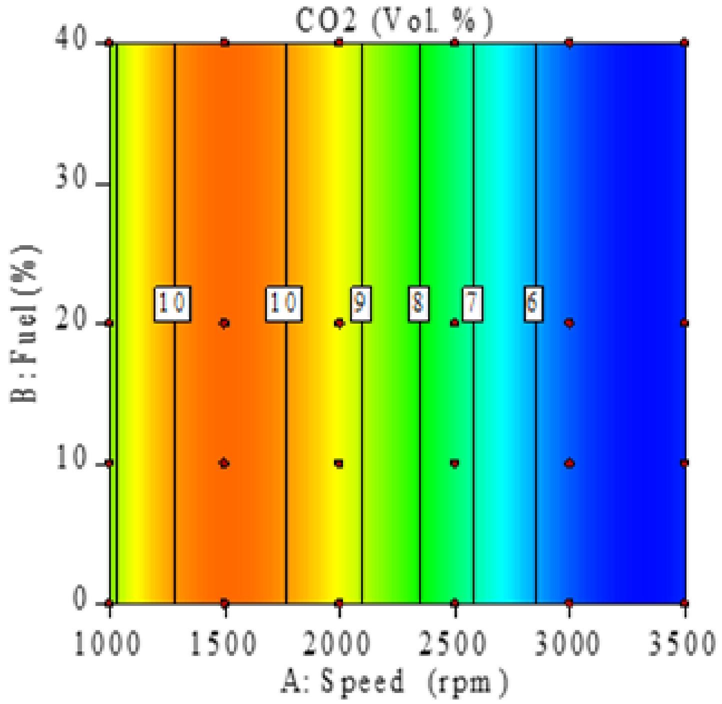

Fig. 5. Interactive effect of fuel blend and speed on CO_2 emissions

Incomplete combustion causes Carbon Monoxide (CO) emissions formation in diesel engine. As seen from Figure 6, increased CO emissions were observed in the operating speed range from 1000 rpm to 1500 rpm for baseline fuel diesel and PBD blends from 10% to near 40%. Highest CO emissions of 0.028 vol. % was noted for baseline fuel diesel whereas for PBD10 was slightly higher at 0.030 vol. % for 1500 rpm. Researchers point out that biofuels contain 10% oxygen while diesel has zero presence of oxygen. Oxygen rich fuel combustion region increases the chances of complete combustion thereby reducing CO formation [29,30].

Oxides of Nitrogen (NO_X) emission formation is caused by reaction of nitrogen and oxygen at high flame temperature. As seen from Figure 7, elevated NO_X formation region is observed in the operating speed range from 1500 rpm to nearly 3000 rpm for baseline fuel diesel and PBD blends up to 40%. Highest NO_X emissions of 294 ppm was noted for baseline fuel diesel whereas for PBD20 was slightly higher at 304 ppm for 2000 rpm. Researchers highlight that increased NO_X emission is due to more oxygen content in PBD, presence of double bounds, higher viscosity and density in fuel, and also adding that a number of coupled reaction mechanisms may either strengthen or weaken NO_X formation depending upon operating conditions [20,31-34].

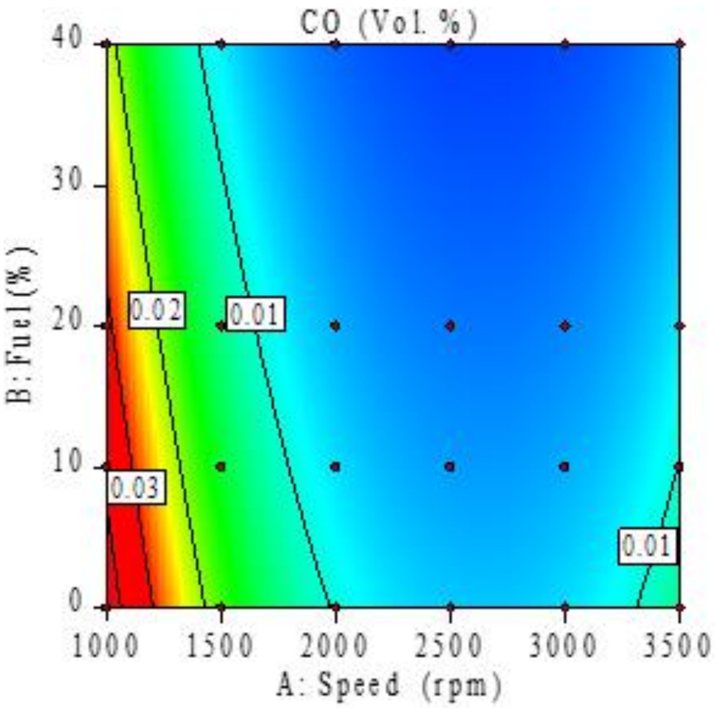

Fig. 6. Interactive effect of fuel blend and speed on CO emissions

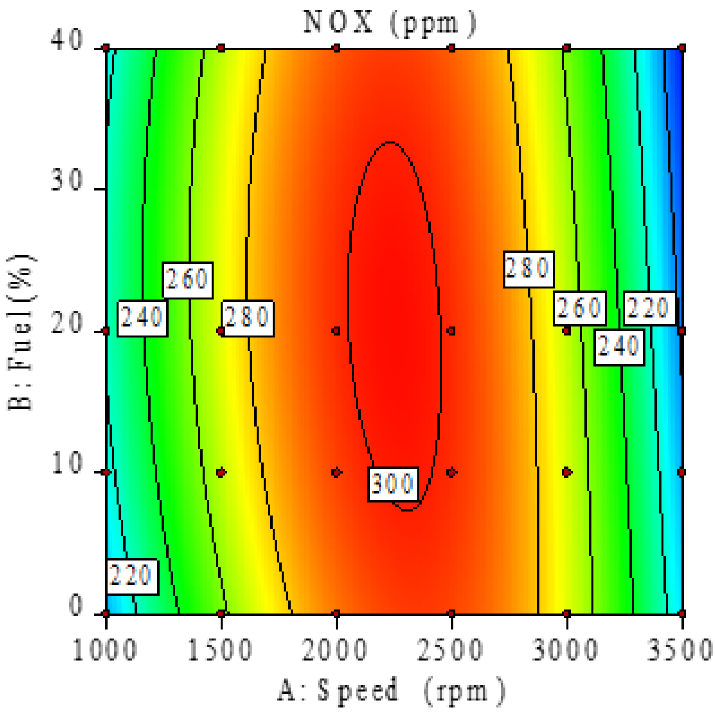

Fig. 7. Interactive effect of fuel blend and speed on NO_X emissions

4. Conclusions

PBD blends of various ratios have been successfully tested in a multi cylinder diesel engine. The experimental data captured during the test were used for RSM analysis using a mathematical software. The concluding statements are as follows

i. Highest power and torque of 29.6 hp and 105.5 Nm at 2000 rpm is obtained for PBD10 compared to 28.7 hp and 102.2 Nm at 2000 rpm for pure diesel fueling. Minimum BSFC attained at 2000 rpm for PBD10 at 326.3 g/kWh but slightly higher than diesel at 328.4 g/kWh.
ii. Highest CO_2, CO and O_2 emissions of 0.6 vol. % (PBD40), 0.030 vol. % (PBD10), 5.7 vol. % (PBD10) was observed at 1500 rpm compared to pure diesel at 10.9 vol. %, 0.028 vol. % and 5.50 vol. %.
iii. NO_X emissions increased to 304 ppm for PBD20 from 294 ppm for diesel at 2000 rpm. While lower smoke reduced from 54.9% for diesel to 49.7% for PBD10.

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