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Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel ☆

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ABSTRACT

The rapid increasing worldwide demand for energy, continuous increasing of fuel consumption and the progressive depletion of fossil fuels led to an intensive search for biodiesel as alternative fuel for diesel engine. Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel is investigated experimentally. Biodiesel was prepared from palm oil by transesterification process. Diesel, biodiesel and palm oil blends were prepared in volume percentages of 20 and 100% as B20, B100 and PO20. Physical and chemical properties of biodiesel blends were near to diesel fuel. The experimental study is conducted on a diesel engine at different engine loading from zero to full loads using palm oil and palm biodiesel and its blends with diesel fuel. Thermal efficiency of biodiesel and oil blends with diesel fuel was lower than diesel fuel. Specific fuel consumptions for biodiesel and oil blends were found to be higher than diesel oil. Unburned hydrocarbons and carbon monoxide emissions have been decreased for biodiesel blends but it increased for oil blends compared to diesel fuel. Nitrogen oxide emissions have slightly been increased for biodiesel and oil blends compared to diesel fuel. Blends of diesel – biodiesel up to 20% biodiesel percentage by volume are recommended because of the improvement in performance and emissions as compared to diesel fuel.

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1. Introduction

Petroleum fossil fuels are becoming less suitable because of depleting supplies and carbon dioxide emissions [1]. Energy consumption increases rapidly with economic, population growth and fast rising vehicle sales. In Egypt, domestic oil consumption has grown by 30% over the last decade (from 540 bbl/d in 2003 to 757,000 bbl/d in 2013) [2]. Vegetable oils have received a great attention To reduce depending on fossil fuels. It is obtained from renewable sources, biodegradable, not toxic, produces less emissions and can be used alone or blends with petroleum diesel fuels [3]. Operation of diesel engines with vegetable oils produces several problems in atomization and injection of fuel nozzles due to their lower volatility and higher viscosity, molecular weight and density [4]. Vegetable oil was modified through transesterification process to produce biodiesel fuel to improve these properties. Biodiesel is a suitable alternative fuel in diesel engines with minor modifications and thus meet the needs of biodiesel engine [5,6].

Palm methyl ester was produced using an alkali catalyzed transesterification process. Methanol (25% v/v oil) and 1% (w/w oil) potassium hydroxide (KOH) were reacted with palm oil and maintained at 60 °C for 2 h with a stirring speed of 1000 rpm. Biodiesel was separated from glycerin after 12 h. Distilled water was used to remove the entrained impurities and glycerin from biodiesel. A distilled water of 50% (v/v) at 60 °C was sprayed over the esters and shaken gently several times until biodiesel had a neutral pH of 7. A rotary evaporator was used to remove water and methanol from biodiesel under vacuum distillation at 65 °C for 1 h. Biodiesel was dried using anhydrous Na₂SO₄ for 3 h and filtered using filter papers. The fuel properties such as density, viscosity, calorific value and flash point were compared with diesel fuel. Flash point was higher than diesel fuel, so biodiesel is safer than diesel fuel. Density and viscosity of biodiesel were higher than diesel fuel and may result in improper spray characteristics [7–12].

Many researchers investigated that biodiesel provide exhaust emission reductions in carbon dioxide CO₂, unburned hydrocarbons HC and some increases for nitrogen oxides NO_x [13,14]. It is also observed that engine output power and mechanical efficiency were decreased and fuel consumption was increased while using

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biodiesel [15]. Several studies worked in blending either oil feed-stock or use of mixture of diesel fuel with different kinds of biodiesel to improve biodiesel properties [16–20]. Using palm biodiesel and its blends (B5, B10 and B15) leads to lower the fuel consumption, CO, CO₂ and HC emission compared with diesel fuel. While smoke opacity was higher at lower loads and lower at higher engine loads compared to diesel oil. Experimental tests were studied on a four stroke diesel engine with diesel and palm biodiesel blend percentages of 20, 40, 45 and 50%. The results show that 73% reduction in unburned hydrocarbon emissions and 46% reduction in carbon monoxide emission [21,22]. Palm biodiesel of B20 achieved the optimum performance and reduction in exhaust emissions compared to diesel fuel [23]. Several studies illustrated that increasing palm biodiesel-diesel blends percentage leads to specific fuel consumption and NO_x emissions increase and CO and HC emissions decrease [24,25].

This study is targeted to explore technical operation of palm oil and palm oil methyl ester blends with diesel fuel in diesel engine without any hardware modifications. The transesterification process was used to obtain biodiesel from crude palm oil. Physical and chemical properties of biodiesel blends were analyzed and near to diesel fuel. The study aims to investigate the effect of palm oil (PO20) and palm oil methyl ester (B100 and B20) blends with diesel fuel on performance and exhaust emissions in a diesel engine at different engine loads. Specific fuel consumption, thermal efficiency, exhaust gas temperature and air fuel ratio were studied. Exhaust emissions such as CO, NO_x and HC were recorded and compared with diesel fuel.

2. Materials and methods

2.1. Fuel characterization

Diesel and palm oils were obtained from local market in Egypt. Anhydrous methanol (99.8%), acidic acid and potassium hydroxide (97%) purity were purchased from a chemical supplier. All chemicals used are analytical grade.

Transesterification was carried out in conical flask equipped with reflux condenser, thermometer and magnetic stirrer. The flask was initially charged with palm oil and preheated to 65 °C. Potassium hydroxide (KOH) as a catalyst was dissolved in methanol. The resulted solution was added to the agitated flask and the reaction was timed (2 h). Then the mixture was left in a separating funnel to separate glycerol layer. Methyl esters were washed twice using warm water with 5% acidic acid then with water. The residual methanol and water were separated from biodiesel via rotary evaporator under vacuum at 80 °C. Then palm oil methyl ester was dried at 100 °C.

Blending was done by adding either palm oil or palm oil methyl ester to diesel fuel at lower stirring rate for 20 min and left to reach equilibrium before use. Palm oil or palm oil methyl ester was added at different proportions of 20% by volume to diesel fuel. Density, kinematic viscosity, flash point and heating value were measured as shown in Table 1.

Table 1
properties of diesel fuel, B100, B20, palm oil and 20% palm oil (PO20).

Properties	Density at 15 °C gm/ml	Kinematic viscosity at 40 °C mm ² /s	Flash point, °C	Heating value MJ/kg
Method	ASTM D1298	ASTM D445	ASTM D92	ASTM D270
Diesel	0.827	2.28	64	44.852
B100	0.877	4.56	196	40.560
B20	0.835	2.82	71.5	41.206
Palm oil	0.925	41	260	39.849
PO20	0.845	3.4	72	41.306

2.2. Experimental set up and methodology

The experimental program was carried out using a single cylinder, four stroke, air cooled, direct injection, naturally aspirated, constant compression ratio, diesel engine with a developing power of 5.775 kW at 1500 rpm at National Research Centre, Engine Research lab., Egypt. The technical specifications of the engine are given in Table 2, and the schematic diagram of the experimental arrangement is shown in Fig. 1. AC generator of maximum electric power output of 10.5 kW equipped with a load controller and other auxiliary items have been coupled directly to the test engine to determine the engine output brake power. The intake airflow was measured by a sharp edged orifice mounted in the side of an air box, coupled to the engine inlet to dampen the pulsating airflow into the engine. A U-tube manometer was used to measure the pressure drop across the orifice. Calibrated thermocouple probes of type (K) were used for temperature measurements at different locations in the experimental set up; including: intake air manifold and exhaust gas. The crankshaft rotational speed was measured using speed tachometer. Two fuel tanks of 10 Liters capacity were mounted for storing the fuels on the rear side of the panel at highest position. One burette with stopcock and two way valves was mounted on the front side of the panel for fuel flow measurements and selecting between both diesel and biodiesel fuels. MRU DELTA 1600-V Gas Analyzer were used for the measurements of various exhaust gas emissions such as CO, HC and NO_x. The experiment was carried out by varying engine load from zero to full load by maintaining constant rated speed of 1500 rpm throughout the experiment. All the equipments were calibrated in accordance to the respective manufacturer's specifications, prior to conducting the tests.

3. Results and discussions

3.1. Effect of biodiesel blends on specific fuel consumption

Variation of specific fuel consumption with engine load for diesel, biodiesel (B100), diesel-palm biodiesel blend (B20) and diesel palm oil blends (PO20) was shown in Fig. 2. Specific fuel consumptions for biodiesel and oil blends are higher than diesel fuel due to the lower calorific values of palm biodiesel and palm oil compared to diesel fuel. There are increases in fuel consumption of biodiesel and oil blends proportional to the amount of biodiesel or oil blended to the diesel fuel [8,9,12].

This was due to lower calorific values of palm biodiesel and oil blends than that of diesel fuel. In case of biodiesel, palm oil and its blends with diesel fuel, diesel engine consumes more fuel than diesel fuel to develop the same power. Specific fuel consumption values for diesel, B20, B100 and PO20 are 0.28, 0.316, 0.346 and 0.325 kg/kW.hr, respectively at full load.

3.2. Effect of biodiesel blends on thermal efficiency

Fig. 3 showed the thermal efficiency for the biodiesel blends (B20, B100) and oil blends (PO20) as compared to the neat diesel

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