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Crude palm oil fuel for diesel-engines: Experimental and ANN simulation approaches

T.F. Yusaf [a,*], B.F. Yousif [a], M.M. Elawad [b]

[a] Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba 4350 QLD, Australia
[b] Mechanical Engineering Department, Faculty of Engineering, University of Khartoum, Sudan

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ABSTRACT

In the current work, the effect of using CPO (crude palm oil)–OD (ordinary diesel) blends as fuel on the performance of CI (compression ignition) engine is studied. Three different blends of CPO–OD (25%, 50% and 75%) were investigated using direct-injection, stationary diesel engine. The CPO–OD blends were preheated to about 60 °C before the injection to reduce the viscosity of the blends. The experiments were conducted at variable engine speeds (1000 rpm through 3000 rpm) under fixed throttle opening. The results revealed that the CPO–OD exhibited higher torque and power output at engine speeds lower than 2000 rpm, while the BSFC (brake specific fuel consumption) was found to be higher than the OD at the same engine speeds. CPO enhanced the BSFC at higher engine speeds (above 2000 rpm). The CPO–OD blends exhibited lower emissions of NO_x and higher emission of CO compared to the OD.

1. Introduction

Fossil fuels are identified as the main source of energy for various industrial applications. However, fossil fuel reserves are rapidly diminishing, while the demand for energy worldwide is increasing. On the other hand, the damage to the environment through large quantities of green-house gases and pollutants encourages intensified research for alternative sources of energy, which is environment-friendly. Vegetable oils are found to be a potential source of energy that could substitute the fossil fuels [1–3]. From recent reported works, it has been found that vegetable oils have generally lower calorific values compare to ordinary diesel fuel, see Table 1 [4–6]. The combustion of vegetable fuels leads to a near balanced CO_2 cycle and a favorable reduction in green-house effects [4,7–12]. The high flash-point of vegetable fuels (about 198 °C), as compared to liquefied fossil fuels, makes them safe to store and transport (Table 1) [4–6].

On the other hand, there is a limitation in using pure vegetable oils as fuels in internal combustion engines. The limitation is the formation of carbon deposit in the combustion chamber. This may lead to some problems such as the injector clocking and/or the valve sticking [8]. These problems are mainly occurred because of the high viscosity and the lower volatility of pure vegetable fuels compared to ordinary diesel fuel in reported works [2,3]. It has been found that the viscosity of crude palm oil (CPO) can be reduced by heating the oil in the fuel transport system. This technique was adopted in the present work, and contributed to improve the combustion efficiency and the specific power, and reduce some of the exhaust gas emission components at different blendes CPO–OD ratios. Another attempt by Ref. [2] has been made to overcome the viscosity problems by using a direct-injection system and adding additives to the vegetable oil, the results showed good improvements [2]. As illustrated in Table 1, the kinematic viscosity of ordinary diesel (OD) is 36 mm^2/s, which is lower than the kinematic viscosity of crude palm oil (CPO) of 45 mm^2/s. It is expected that when the CPO percentage increases, the kinematic viscosity of the blend increases as well.

The Cetane rating of palm oil fuel was reported to be slightly lower than the OD, Table 1 [4–6]. Furthermore, the preheating technique was reported to be able to increase the thermal efficiency [4]. From the reported works in Refs. [5,9] biodiesel has a very high potential to replace the conventional fuel and enhance the engine performance. However, NO_x concentration in the exhaust gas emission is considered to be one of the major disadvantages in using biodiesel fuels. In the present work, it was found that using CPO in the diesel engine can reduce NO_x formation at certain engine operating conditions. This can be one of the main motivations in reporting the current work.

* Corresponding author. Tel./fax: +61 7 4631 1373.
E-mail address: yusaft@usq.edu.au (T.F. Yusaf).

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Table 1
Fuel properties [4–6].

Properties	OD	CPO
High calorific value (MJ/kg)	45.91	40.14
Kinematic viscosity (mm^2/s at 40 °C)	36	45
Density (g/cm^3)	0.84	0.86
Flash point (°C)	98	193
Cetane number	52	49
Sulfur content (mg/kg)	0.1	0.04

ANN (artificial neural network) approach has been recently adopted to predict the performance of various thermal systems [13,14]. ANN works in a way similar to biological neurons, i.e. the neurons receive inputs from sources, collect them, perform a non-linear operation on the results, and then predict the final outputs. In other words, ANN is a mathematical model inspired by the biological nervous system. The significance of this technology is that ANN models can be trained based on experimental or real life data to recognize solutions. ANN is simply interconnections of many neurons. The neurons are arranged in three layers. First is the input layer, where the input data set is presented, secondly the hidden layer(s) which is the brain of the system, and finally the output layer, which dictates the outcome of the system [15]. The system maintains an orchestral flow of signals, starting from the input layer, spreading on to the hidden layers and then summing up to the output layer. During the process, the neurons and their interconnections manipulate the input data in each step to finally produce the output. In engineering applications, the most common algorithm is the back-propagation, which has different variants. Back-propagation training algorithm gradient descent with momentum is often slow for practical problems as they require small learning rates for stable learning [9]. The performance of the algorithm depends on the parameters learning rate and momentum constant. Faster algorithms such as conjugate gradient, quasi-Newton, and LM (Levenberg–Marquardt) use standard numerical optimization techniques. ANN operates by back-propagation algorithm, i.e. learns by changing the weights. These changes are stored as knowledge [16]. The use of ANN approach for modeling the operation of internal combustion engines has not been comprehensively reported yet [15].

The current work aims to investigate the use of crude palm oil (CPO) as a fuel extender for diesel fuel on a direct-injection engine at different blend ratios (volume) of 25%, 50% and 75%. In addition, engine power output, fuel consumption, and exhaust-gas emission are evaluated and then predicted using ANN technique.

2. Experimental engine test bed test procedure

2.1. Experimental set-up

A stationary Perkins diesel engine model 4–108 V was used in the experiments. The specifications of the engine are water cooled, direct-injection engine, 4 cylinders, 4 stroke with bore of 79.5 mm and stroke of 88.9 mm. The compression ratio of the engine is 22:1 and the rated power is 32 kW at 2500 rpm. Engine torque, fuel consumption, and speed were measured. The load on the engine was applied using a Heenan Froude hydraulic dynamometer which is regularly calibrated. The dynamometer consists of a rotor keyed connected to a shaft supported by bearings in an outer casing. The shaft and rotor were organized for coupling to the engine shaft and revolve inside the casing through water circulation. The torque measurement accuracy is ±0.25% while the speed measurement accuracy is ±1 RPM with very high rapid respond. The engine brake power is calculated using equation (1)

$$BP = \frac{W \times N}{K} \quad (1)$$

where,

W = Load (kg)
N = Speed (RPM)
K = Constant (vary with the length of the arm).

A portable gas analyzer, Lancom 6500, was used to measure the exhaust-gas emissions components, i.e. O_2 with accuracy of ±1%, CO, NO_2, NO with accuracy of ±2% and HC with accuracy of ±0.1% volume. A monthly calibration is conducted. In order to measure gas concentration, an electrochemical sensor is used to measure CO, HC, O_2, NO and NO_2, while infrared is used to measure CO_2.

To form CPO–OD blend, the two fuels were blended in various volume fractions as 25%, 50%, and 75% CPO. Proper mixing was achieved by using a small air blower placed in the mixing tank. The prepared blends were heated up using water bath heated by an electric-resistance heater. A set of thermocouples and simple electric circuit were used to control the electric power of the heater. A three-way valve was used to switch the fuel supply from the diesel-fuel tank to the mixing tank. The fuel in desired blend ratio was filtered and supplied to the engine. Fig. 1 shows a schematic diagram of the engine test bed.

2.2. Engine testing procedure

The engine was tested at different loads and engine speeds (1000 rpm–3000 rpm) using different CPO–OD blends. At the beginning of each test, the throttle opening was adjusted to give a speed of 3000 rpm at a minimum dynamometer load. A high precession speed tachometer was used in calibrating the recorded speeds of the test bed dynamometer. In the experiments, the load was increased gradually as the engine speed dropped in a step of 200 rpm down to 1000 rpm. For each engine speed, the torque was incrementally applied while the fuel consumption rate was recorded. In the case of CPO–OD blends, the engine was started with the ordinary diesel fuel first and left to warm up for about 15–30 min, and then the CPO–OD blend was gradually introduced. At the end of each test, the engine was run using ordinary diesel fuel for about 15–30 min in order to flush the fuelling system from any CPO residues.

Three series of complete tests were conducted for each fuel blend and the average of the three tests was determined. The CPO was provided by the Malaysian Palm Oil Board (PORIM formerly)

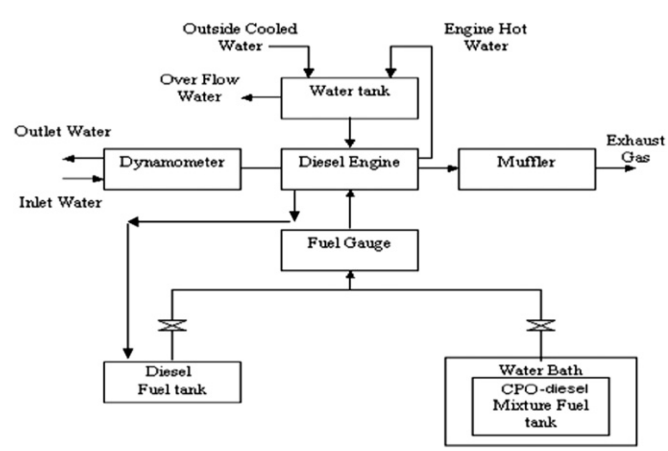

Fig. 1. Schematic layout of the test setup.