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COMBUSTION PERFORMANCE OF JATROPHA BIODIESEL IN AN OIL BURNER SYSTEM

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Graphical abstract

Abstract

Jatropha Curcas is a non-edible plant that can be used for renewable or alternative energy. The seeds of Jatropha contain up to 60 percent oil. The oil can be converted into biodiesel by well-known two-step using acid-base catalytic transesterification. This paper shows the combustion performance of biodiesel derived from Jatropha oil in an oil burner designed for conventional diesel. Biodiesel used in this study is a blend of diesel with Jatropha Methyl Ester (JME) and combustion performance was measured and compared with that of conventional diesel fuel (CDF). The combustion performance of Jatropha biodiesel is based on wall temperature profiles and the amount of gaseous emissions emitted such as nitrous oxide (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO). It was demonstrated that biodiesel derived from Jatropha is comparable to the combustion properties of CDF and has high potential to be used as alternative fuel for diesel machines.

Keywords: Jatropha, biodiesel, methyl ester, combustion, esterification

1.0 INTRODUCTION

The world is getting modernized and industrialized day by day. As a result, the number of vehicles and engines are increasing. But energy sources used in these engines are limited and the resources are reducing gradually. This situation leads to earnest search for alternative fuels for engines and biodiesel is one of them. The esters of vegetables or seed oils and animal fats are known as biodiesel. Vegetable oil is a promising alternative because it has several advantages; it is renewable and could be produced easily in rural areas, where there is an acute need for modern forms of energy [1]. Therefore, in recent years several researchers have studied the use of vegetable oils as fuel in engines in the form of biodiesel [2]. Furthermore, vegetable oil-based products hold great potential for stimulating rural economic development because farmers would benefit from increased demand for vegetable oils. Various vegetable oils, including palm, soybean, sunflower, rapeseed and canola oils have been used to produce biodiesel fuels and lubricants [3].

Biodiesel should be non-toxic, biodegradable and renewable fuel that can be used alone or in blends with petroleum diesel. Biodiesel has many advantages compared with diesel fuels. Biodiesel has a higher cetane number compared with diesel fuel and contains no aromatics, almost no sulphur and 10–12% oxygen by weight. Moreover, because biodiesel is an oxygenated alternative fuel, it is more completely combusted and produces lower harmful emissions and pollutants [4]. The use of biodiesel has grown dramatically during the last few years and palm based biodiesel was used widely. Lately there is a controversy regarding utilization of edible oils as biodiesel sources. So other sources of biodiesel are required to avoid this controversy.

Jatropha oil derived from the Jatropha Curcas Linnaeus is one of the high potential sources of bio-diesel feedstock [5]. Jatropha oil is a non-edible feedstock and the Jatropha plant can be grown in low grade soils such as sandy and saline soils, even on gravel, which means it can be cultivated almost anywhere. Its water requirement is extremely low. Hence, the use of Jatropha seed oil is no threat to existing cultivable land and the food chain, unlike some other conventional edible feedstock. It was reported that the transesterification process has been proven worldwide as an effective means of biodiesel production and viscosity reduction of vegetable oil. Temperatures, catalyst type, concentration ratio of alcohol to fuel and stirring speed rate have been observed to influence the transesterification process to a greater extent [6]. Combustion performance of Jatropha biofuel can be determined by its temperature profiles and emissions [7]. Emission emitted from the combustor must be within the ASTM standards. Temperature profiles of biodiesel combustion should follow close to that of the baseline fuel so that the powers of combustor remain unchanged [8].

2.0 EXPERIMENTAL

2.1 Preparation of Biodiesel from Jatropha Oil in Laboratory Scale

Biodiesel was prepared with methanol and ethanol each with different reaction conditions. The ratio of alcohol to oil used was found to be 6:1 for most of pervious research work [9]. So by using methanol, the experiment was conducted with optimum molar ratio (6:1) keeping the catalyst concentration (1% NaOH), reaction temperature (65°C) and reaction time (1 hour). With ethanol, the experiment was conducted with optimum molar ratio (8:1) keeping the catalyst concentration (1% KOH), reaction temperature (70°C) and reaction time (3½ hour).

The required amount of Jatropha oil was filtered, measured with measuring cylinders and then poured into the three necked round-bottomed flasks. Then the Jatropha oil was heated to the required temperature. Alkoxide solution was prepared while the Jatropha oil was being heated. The prepared alkoxide solution was introduced into the reaction vessel and it was mixed vigorously during the reaction. When the required reaction period was reached, the mixing was stopped, and the mixture was settled in the separating funnel for 12 hours or overnight. After the mixture settled for 12 hours, the mixture was separated into two layers. The bottom layer is crude glycerine and it can be drawn off simply from the bottom of the separating funnel. The biodiesel layer was purified by washing with warm water to remove methanol, residual catalyst and soaps. Before the washing process, the pH of the biodiesel layer was measured and phosphoric acid was added to the biodiesel layer to neutralize the catalyst residue. After neutralization process, the washing process of biodiesel was started [10].

During the washing process, gentle stirring was required to avoid emulsification. After separation of the layer for 30 minutes, the washed water layer was drained off from the bottom of the separating funnel. The washing process was repeated until the ester layer became clear. The pH value was again measured and more phosphoric acid was added until the pH of the biodiesel layer reached value of 7. After the washing process, the biodiesel was introduced to the sand filter and salt filter. The biodiesel end product was obtained as a clear amber-yellow liquid with a viscosity similar to that of petroleum diesel. Figure 1 shows the experimental apparatus used for the esterification and the transesterification processes.

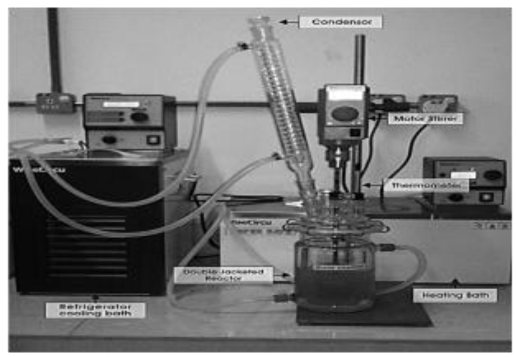

Figure 1 Experimental apparatus setup for esterification and transesterification processes

2.2 Blending Biodiesel Fuel

The biodiesel blends are mixtures of two fuels which are the conventional diesel fuel (CDF) and Jatropha methyl ester (JME). In order to ensure that the blending process is accomplished successfully, a device which can measure the specific gravity (SG), which is hydrometer in the range of 0.8-0.9 kg/ℓ and 0.9-1.0 kg/ℓ, was used. Table 1 shows the volume of CDF and Jatropha oil for the blending process.

Table 1 Volume of CDF and Jatropha oil for blending process

Blends	JME (liter)	CDF (liter)	Total (liter)
B0	0.0	10.0	10.0
B5	0.5	9.5	10.0
B10	1.0	9.0	10.0
B15	1.5	8.5	10.0
B20	2.0	8.0	10.0

2.3 Experiment Set up

Experimental equipment can be divided into three sections, which are combustion chamber, combustor and instrumentation to measure the data values from the experiments such as temperature and exhaust gas emissions sensors [11]. A Baltur BT14GW oil burner was used to combust the biodiesel. Fuel flow rate was maintained constant at 0.2 liter per minutes while air flow rate was varied to produce three different equivalent ratios. The combustion chamber is an open end cylindrical chamber made of 2 mm thick stainless steel sheet. There are 9 holes openings on the combustion chamber walls separated 100mm equally, for inserting the thermocouples. Hy-cast cement was used in between the two rolled stainless steel sheets, forming insulation for the combustion chamber. The thickness of insulation is approximately 8.0 cm. Continuous Graphtec temperature recorder was used to obtain the temperatures. At the exit plane of the combustor, a continuous monitoring Horiba gas analyzer was set up for exhaust emissions gas measurements. This analyzer is capable of measuring continuously the emission gases of NO_x, CO, CO_2, SO_2 and unburned hydrocarbon. Figure 2 shows the schematic diagram of the experimental test rig set-up.

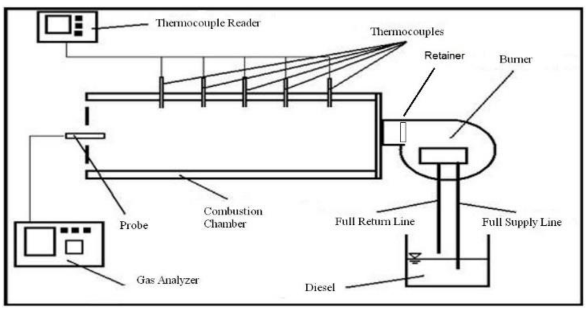

Figure 2 Experimental rig

3.0 RESULTS AND DISCUSSION

Jatropha methyl ester has lower calorific value compared to diesel [12]. The calorific value of JME is 38 MJ/kg of while CDF has 44 MJ/kg. Since Jatropha oil has high fatty acid, esterification must be done first before the next process for converting to biodiesel. The percentage of acid catalyst used and the molar ratio of alcohol should be at their optimum values to enhance the process and decrease the total production cost.

3.1 Properties of Jatropha Biodiesel

Jatropha biodiesel blends are produced from two main components which are Jatropha Methyl Ester (JME) and petroleum diesel. The petroleum diesel needs to be bought in bulk in order to ensure the same physical and chemical properties throughout the experiments. The final measured physical properties of every blend were determined experimentally, and are shown in Table 2.

The properties that needed to be determined were the surface tension, density and viscosity since they have great impact on the spray characteristic [13].

Table 2 Physical properties of Jatropha biodiesel

Blends	Density (g/cm^3)	Surface Tension (mN/m)	Specific Gravity (Interpolation)	Specific Gravity (Test)
0	0.831	30.1	0.839	0.839
5	0.833	30.5	0.841	0.841
10	0.835	30.6	0.842	0.842
15	0.837	30.8	0.844	0.844
20	0.839	30.9	0.845	0.845
100	0.870	34.1	0.870	0.870

3.2 Temperature Profile

There are nine stations along the combustion chamber external wall where wall temperatures were measured and recorded. Figures 3(a), 3(b) and 3(c) show the temperature profiles for conventional Diesel Fuel (CDF) and Jatropha biodiesel blends at equivalent ratios of 0.72, 1.0 and 1.34, respectively. The similarity observed from the graphs is because the temperature profiles are almost similar for all fuel blends. From the graph, it can be seen that the temperature increases starting from the inlet of the combustion chamber (100mm) until it reaches the distance of 400mm, then starts to decrease until the exit of the combustion chamber (900mm).

The highest temperature of 960°C was recorded for B10 at 400mm distance from the inlet of combustion chamber, at equivalent ratio of 0.72. However, the temperatures recorded for B15 and B20 were lower at all points. Theoretically, as the percentage of volume of Jatropha biodiesel increases, the Lower Heating Value (LHV) and the calorific values of the blends will decrease. This will cause the flame temperature to decrease as the Jatropha biodiesel increased from B5 until B20 [14]. At stoichiometry, the temperature profiles for all blends were almost similar except for B5, which recorded lower temperature along the combustion chamber length. At the higher equivalent ratio of 1.34, the wall temperature profiles of the blends recorded lower temperatures compared to CDF.

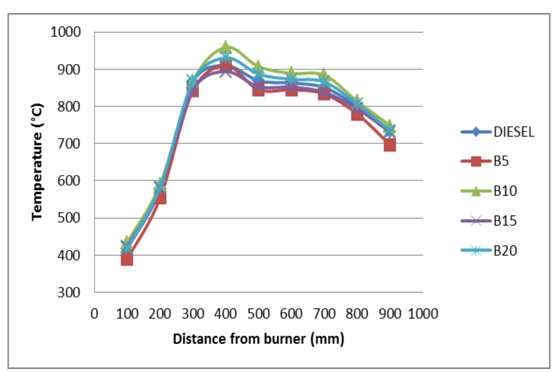

Figure 3(a) Wall temperatures at equivalent ratio 0.72

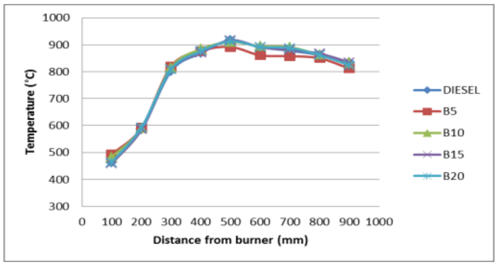

Figure 3(b) Wall temperatures at equivalent ratio 1.0

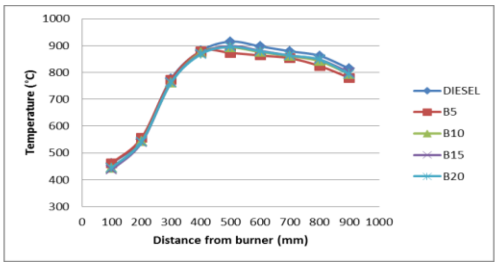

Figure 3(c) Wall temperatures at equivalent ratio 1.34

3.3 Emission Characteristic

The emission characteristics indicate the suitability of the biodiesel blend as the replacement fuel for diesel. In this experiment, gaseous emissions such as NO_x, SO_2, and CO were measured. The emission profiles are essential to make sure lesser quantity of harmful gases are discharged into the environment, ensuring green engineering technology [15]. Figures 4, 5 and 6 show the NO_x, SO_2 and CO emissions from Jatropha biodiesel blends combustions compared to that of conventional diesel fuel.

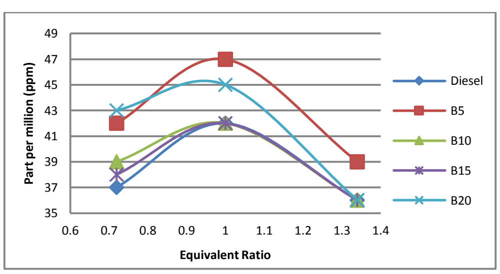

Figure 4 NO_x emissions versus equivalent ratio for each blend

From Figure 4, at equivalent ratio, ϕ = 1.0, nitrogen oxide increases by 5 ppm for B5 blend while for B20 blend increases by 3 ppm. Other blends remain unchanged (i.e. similar values to diesel). These increases are very small, so it is acceptable and will not harm the environment. Figure 5 shows that sulphur dioxide emission emitted from the combustor increases by 4 ppm for B20 blend while B5 blend shows reduction of 2 ppm. The emission profiles maintain the same pattern (similar trend) even though there are slight differences in the magnitude.

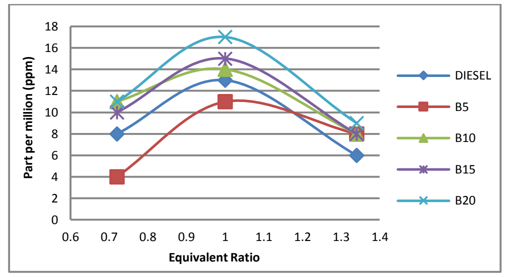

Figure 5 SO_2 emissions versus equivalent ratio for each blend

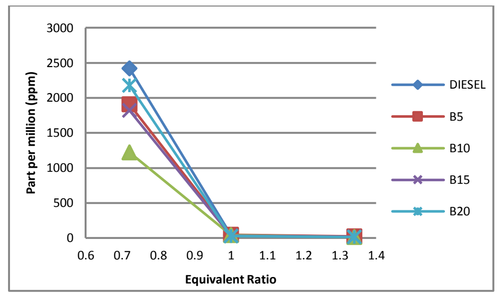

Figure 6 CO emissions versus equivalent ratio for each blend

Carbon monoxide (CO) emission for all blends are almost the same at ϕ = 1.0 and 1.34 (Figure 6). But at ϕ = 0.72 the amount of CO emitted for all blends were less than CDF showing better and more efficient combustion using Jatropha biodiesel.

4.0 CONCLUSION

It is concluded that the data such as surface tension, density and specific gravity obtained from literature are approximately the same as those from chemical analysis of local Jatropha oil, which is within the ASTM specified limits. Emission of NO_x produced from Jatropha biodiesel was shown to increases by a maximum of 12%, while other emissions remain almost the same. Overall, biodiesel from Jatropha oil has a comparable emissions and temperature profile with diesel fuel. It also meets the fuel emission limits set by ASTM standards. It can also be used directly in diesel engine. As a conclusion, combustion performance of Jatropha biodiesel in oil burner is acceptable and was shown to be quite promising as replacement of fossil diesel.

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