Experimental Study on the Effect of Preheated Egyptian Jatropha Oil and Biodiesel on the Performance and Emissions of a Diesel Engine

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Abstract-- Fossil fuel consumption and harmful emissions increase led to intensive search for alternative fuels. The present oil was extracted from Egyptian jatropha nuts by using a designed and manufactured screw press at a preheating temperature of 100°C and operational screw speed of 60 rpm. Esterification followed by transesterification produced biodiesel from jatropha oil. Heat recovery from exhaust gases at a temperature of 90°C was utilized to preheat the produced jatropha oil. Jatropha biodiesel was preheated to a temperature of 40°C. Measured properties of preheated biodiesel and jatropha oil were found to be within ASTM standards. The present research studied the performance and emissions of a diesel engine burning preheated biodiesel and bio oil compared to diesel fuel. Experimental tests were carried out from zero to full load. The results revealed that about 2% decrease in the brake specific fuel consumption and 2% increase in the brake thermal efficiency for preheated jatropha oil compared to diesel oil. Preheating of jatropha oil resulted in CO and smoke emissions reductions by about 51 and 55%, respectively in comparison to conventional diesel oil. Jatropha oil and biodiesel preheating reduced NOx concentrations by up to 35 % and 7% respectively at 75% of engine load with respect to unheated fuels. Preheated jatropha oil showed better engine performance in comparison to other fuels. Preheated jatropha oil is recommended to be used as an alternative fuel in diesel engines.

Index Term-- Jatropha seeds; Screw press; Biodiesel; Preheated biodiesel; Performance; Emissions.

1. INTRODUCTION

Oil ultimate depletion and the production of harmful emissions from burning fossil fuels encourage the search for clean alternative fuels. Edible oils have higher prices than non-edible ones, so biodiesel was produced from non-edible vegetable oils. The oxygen content in ethyl ester is 10 to 12% more than in fossil diesel which results in better combustion and emissions reduction. Biodiesel calorific value is about 9% less than petroleum diesel oil and varies with different feedstock and the production process. The biodiesel viscosity is higher than diesel oil which results in poor atomization and improper fuel mixing. Biodiesel produces lower exhaust emissions and greenhouse gases except NOx. A continuous oil extraction process is favorable to produce higher biodiesel yield. Mechanical pressing of jatropha seeds can produce higher oil yield by up to 20% over that from chemical processes. The screw press is a continuous extraction technique [1–3]. Oil extraction can be produced by several methods: pressing the jatropha kernels mechanically, chemically, or enzymatically [4–7]. The most known oil expeller types are Sundhara and Komet expellers. The seeds were pressed by means of a screw press [8]. Lower calorific value and higher viscosity decreased the thermal efficiency of unheated oil due to value than diesel oil. Preheating of oil improved the thermal efficiency over that of the unheated oil due to reduced viscosity, better atomization, improved vaporization and improved combustion [9–13]. Diesel-biodiesel blends have higher fuel consumption than petro-diesel to develop the same output power [14–16]. Preheated vegetable oil exhibited a decrease in specific fuel consumption as compared to unheated oil due to lower viscosity which causes better atomization [17–19]. Specific fuel consumption was higher than diesel fuel for unheated and preheated biodiesel [11,12,20].

Higher specific fuel consumptions of biodiesel blends resulted in higher exhaust temperature than diesel oil. Lower thermal efficiency for biodiesel blends led to increase in the heat loss [10,14,15,21]. Poor combustion characteristics and higher viscosity led to increase of exhaust gas temperature for preheated jatropha oil as compared with jatropha oil. Exhaust gas temperature is higher for jatropha oil than for diesel fuel due to jatropha oil higher viscosity [14,22,23]. Jatropha biodiesel achieved lower air-fuel ratio as compared to diesel oil. Air-fuel ratio shows a decreasing trend for all
tested diesel-biodiesel blends indicating that a richer mixture is required at higher engine loads [24–28]. A decrease in CO emission was obtained as the percentage of biodiesel increased. The reduction in CO emissions for biodiesel is due to the availability of extra oxygen which enhances the fuel combustion [10,14,24]. Higher oil viscosity and poor fuel atomization lead to incomplete combustion. Preheating of fuel oil led to reduction in CO emissions compared to unheated oils and lower than for diesel fuel [17,19,29,30]. CO emission levels are further reduced for preheated biodiesel due to reduced viscosity and density. The decrease in CO emission is more when the preheating temperature is increased from 75 to 90°C [31,32].

Biodiesel produced higher NOx emissions compared to crude diesel fuel for all output power due to higher cylinder temperatures in comparison to diesel fuel. The increase trend of NOx emission with engine load for jatropha biodiesel blends. The presence of higher oxygen content in biodiesel facilitates NOx formation [9,14,15]. Unheated and preheated vegetable oil exhibited higher NOx emissions compared to hydrocarbon-based diesel oil. All preheated oils give higher NOx emissions at higher engine loads due to lower viscosity and increase in premixed rapid burning rate as the fuel inlet temperature increases [17,18]. Biodiesel blends of B20 and B40 at preheating temperatures of 60, 75, and 90°C led to increase of NOx emissions [31]. HC emission for biodiesel blends followed a similar attitude as that of diesel oil but comparatively the values were lower [9,10,14]. The higher viscosity of unheated oil compared to diesel fuel resulted in producing higher HC emissions, poor atomization, and improper air-fuel mixing. Preheating of biofuel results in decreased viscosity and hence better combustion [17–19,22,28,33].

CO2 emissions for biodiesel mixtures were less as compared to petro-diesel [9,10,15]. CO2 emissions of unheated oil were higher than diesel fuel due to the presence of higher oxygen content. Preheated oil showed increase in CO2 emissions over unheated oils [17,18]. CO2 emission levels are lowered by biodiesel preheating and the reason is attributed to less fuel consumption caused by higher fuel temperature and improved combustion [19,34]. Smoke emission for jatropha biodiesel blends was less than that of fossil diesel oil. Smoke emission decreased with the increase of biodiesel percentage [34]. Unheated and preheated jatropha oils showed higher smoke emissions. Smoke emission decreases due to lower viscosity and combustion improvement when oil preheating temperature is increased [30,31]. Smoke emission for preheated biodiesel is lower than for unheated biodiesel [32].

Higher viscosity of vegetable oils causes problems in atomization, vaporization and mixing. Oil preheating and conversion of oil to biodiesel are used to overcome oil higher viscosity. Jatropha oil is produced by extraction from Egyptian jatropha seeds by a screw press. Measured properties of the present preheated jatropha oil and biodiesel were near to that of diesel oil. In this research, the exhaust emissions and performance of a diesel engine operating from zero to full load were measured when burning the preheated biodiesel, oil and diesel fuel. Thermal efficiency, exhaust gas temperature, specific fuel consumption and air-fuel ratio were investigated. CO, NOx, HC and smoke emissions were recorded with relative to diesel fuel. Comparisons of engine performance and exhaust emissions were made to obtain higher performance and lower exhaust emissions in comparison to diesel oil.

2. MATERIALS AND METHODS
2.1 Jatropha oil extraction process
Jatropha seeds are grown in dry weather and high temperature regions in Upper Egypt. Oil was extracted from jatropha seeds by using mechanical pressing because of its higher yield. The screw press was designed and constructed by the present authors [2]. The press consists of the base, the housing, and the screw [2]. The screw is accommodated inside the housing which is fixed to the base. The base and housing have circular holes to feed the seeds. The oil is collected from the holes of the housing. The press was derived by an electric motor connected with a gearbox to decrease the rotational speed. The direction switch and frequency inverter were fitted to change the motor rotational speed. Jatropha seeds were preheated by using heaters and a digital temperature thermostat was employed for temperature control. Improvement in screw operating conditions was optimized to obtain a better oil yield at a temperature of 100°C and motor speed of 60 rpm. The oil was extracted to obtain a higher oil yield of up to 20% [2]. Figure 1 depicts the schematic diagram of the screw press parts.
2.2 Biodiesel production process

Esterification followed by transesterification processes were employed for biodiesel production. In the esterification process, methanol and sulfuric acid catalyst were blended for three hours at a temperature of 80°C. Jatropha oil was preheated up to 70°C to get off moisture. Methanol was mixed with potassium hydroxide catalyst with a molar ratio of 6:1 then the mixture was stirred continuously. Then it is left to settle down for 24 hours. The glycerin was removed, and biodiesel was water washed to remove all the unreacted methoxide. The water traces were removed by biodiesel heating to remove to obtain clear biodiesel.

2.3 Properties of preheated oil and preheated biodiesel

The measured properties of the tested fuels are shown in Table 1. The measured heating values of jatropha oil and biodiesel were 39128 and 387 kJ/kg, respectively. The heating values of biodiesel and jatropha oil are less than diesel oil by about 8 and 7%, respectively. Measured cetane number for jatropha oil and biodiesel are 37.83 and 42.62, respectively. The shorter ignition delay leads to higher cetane number. Flash points for jatropha oil are 142°C, and biodiesel is 121°C, respectively. Fuel safe handling and storage are related to flash point temperature. Jatropha oil has a higher flash temperature than biodiesel and diesel oils, so, storage and handling of these oils are relatively less hazardous in comparison to petroleum diesel.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Method</th>
<th>Diesel</th>
<th>Jatropha Oil</th>
<th>Preheated Oil</th>
<th>Biodiesel</th>
<th>Preheated Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 15.56 °C, kg/m³</td>
<td>ASTM D-4052</td>
<td>829</td>
<td>913</td>
<td>872</td>
<td>876</td>
<td>860</td>
</tr>
<tr>
<td>Kinematic Viscosity at 40°C, Cp</td>
<td>ASTM D-445</td>
<td>1.2</td>
<td>6.9</td>
<td>2.1</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>ASTM D-93</td>
<td>75</td>
<td>142</td>
<td>142</td>
<td>121</td>
<td>121</td>
</tr>
<tr>
<td>Lower Heating Value, kJ / kg</td>
<td>ASTM D-224</td>
<td>42000</td>
<td>39128</td>
<td>39128</td>
<td>38789</td>
<td>38789</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>ASTM D-13</td>
<td>45</td>
<td>37.83</td>
<td>37.83</td>
<td>42.62</td>
<td>42.62</td>
</tr>
</tbody>
</table>

The variations in densities for different temperatures of jatropha oil and biodiesel are indicated in Fig. 2. The measured values of densities by test method ASTM D-1298 for jatropha oil and biodiesel at the same temperature of 20°C are 913 and 876 kg/m³, respectively as compared to only 829 kg/m³ for conventional diesel oil. The densities of
oils decrease with increase of oil temperature. The variations in viscosities at different temperatures of jatropha oil for the different methods are presented in Fig. 2. Jatropha oil viscosity is higher than biodiesel and diesel oils. The measured values of dynamic viscosities by test method ASTM D-445 for jatropha oil and biodiesel at 40°C are 4.1 and 1.4 Cp, respectively as compared to only 1.2 Cp for diesel oil at the same temperature. However, the oil temperature increase led to viscosity decrease. This can be inferred by comparing the values of oil viscosities at 40, 60, 80, 60 and 100°C for jatropha oil and biodiesel. Oil preheating is one of the solutions to overcome higher oil viscosity problems in diesel engines.

2.4 Preheating system of jatropha oil

The water passing inside the shell around the fuel in the inner tube was preheated using exhaust shell and tube heat exchangers. Hot water is used to preheat the injected fuel. A schematic diagram of the present preheating system by exhaust sensible heat is shown in Fig. 3. A coil of copper tube was adopted as a heat exchanger around the exhaust pipe. Hot exhaust gases were utilized to increase the water temperature from room temperature to more than 150°C. A control valve was used to control the flow rate of hot water. A thermocouple of type K measured the preheating temperature. Preheating temperature control was achieved by a digital thermometer. The preheated fuel temperature was measured at the exit point of the heat exchanger.
2.5 Experimental rig

A single cylinder diesel engine model DEUTZ F1L511 with cylinder bore of 100 mm, stroke of 105 mm has a maximum power of 5.75 kW was used to perform the experimental tests. Figure 4 shows the experimental set up. An AC generator of 10.5 kW maximum electric output power was coupled directly to the engine. A supported sharp edge orifice connected to the air box was used to evaluate the induction air flow rate. The pressure drop across the orifice was recorded by using a U-tube manometer. Thermocouple probes of type K were used to record the intake air and exhaust temperatures. The engine was fed with the tested fuels by a fuel tank of 5 liters capacity. MRU DELTA 1600-V exhausts gas analyzer and OPA 100 smoke meter were used to estimate exhaust emissions and smoke, respectively.

3. Results and discussions

3.1 Engine performance

Brake specific fuel consumptions (BSFC) at different engine loads for jatropha biodiesel, jatropha oil, jatropha biodiesel at 40 °C, and preheated jatropha oil at 90°C are illustrated in Fig.5. BSFC decreased as the engine load increased for all fuels. Higher viscosities and lower calorific values of biodiesel and jatropha oil led to higher specific fuel consumptions of biodiesel and jatropha oil with respect to diesel oil. A reduction in specific fuel consumption was observed for preheated jatropha oil with relative to other fuels. Oil preheating reduces the fuel viscosity and thus resulted in improving combustion characteristics, volatility, and fuel atomization which led to lower specific fuel consumption over unheated fuels. BSFC decrease of up to 2% was achieved for preheated jatropha oil compared to diesel fuel.

Brake thermal efficiency (BTE) for jatropha biodiesel, jatropha oil, jatropha biodiesel at 40°C and preheated jatropha oil at 90°C at different brake power are given in Fig.5. BSFC decreased with the engine load increase. This is due to improved combustion characteristics and improved vaporization at higher engine loads. There is an increase in BTE for preheated jatropha oil compared to the unheated one due to improved spray characteristics. Higher viscosity, lower calorific value and less biodiesel volatility lead to poor atomization and vaporization of fuel particles. The heating value loss of preheated oil is compensated by higher fuel consumption to maintain the same power. Preheated jatropha oil managed a thermal efficiency increase by up to 2% compared to diesel oil.
Jatropha biodiesel, jatropha oil, preheated biodiesel at 40°C and preheated oil at 90°C exhaust temperature values at different brake power are exhibited in Fig. 6. Increase of exhaust gas temperature (T_{exh}) was associated with the increase in load because of thermal efficiency decrease, mass of fuel injected increase, and heat loss increase compared to diesel oil. Jatropha oil and biodiesel preheating led to the decrease of T_{exh}. Oil preheating led to oil viscosity decrease, better combustion, and enthalpy loss reduction in the exhaust. A decrease of up to 41% in exhaust gas temperature for preheated jatropha oil was achieved over that for diesel fuel.

Air-fuel ratios (A/F) at different engine loads for jatropha biodiesel, jatropha oil, jatropha biodiesel at 40°C and preheated jatropha oil at 90°C are described in Fig. 6. A/F ratios decreased to the increase of fuel consumption. A/F for preheated oil are greater than all fuels due decrease in fuel density, viscosity, and consumption. Preheated jatropha oil announces air-fuel ratio increase by up to 7% compared to diesel oil.

**3.5 Engine emissions**

Figure 7 depicts the influence of engine brake power on CO_{2} emissions for jatropha biodiesel, jatropha oil, jatropha biodiesel at 40°C and preheated jatropha oil at 90°C. The increase in CO_{2} emission with engine load increase was due to higher fuel consumption. All fuels produced lower CO_{2} emissions than diesel oil. Diesel oil contains higher carbon content than in biodiesel. CO_{2} emission is lower for preheated jatropha oil in comparison to diesel oil. Increase of preheating temperature leads to viscosity decrease and improvement of combustion characteristics, thus CO_{2} emission decrease compared with unheated jatropha oil. Burning of preheated jatropha oil brought down CO_{2} emission significantly by up to 45% related to petroleum diesel.
Carbon monoxide emissions for jatropha biodiesel, oil, preheated biodiesel and preheated oil with engine loads are indicated in Fig. 7. The fuel consumption increase led to an increase in CO emission from partial to full load. CO emission decrease for biodiesel is due to its higher oxygen content in comparison to diesel fuel which results in better combustion. Oil preheating temperature directs to a decrease in CO emissions due to oil viscosity decrease, enhanced oxidation, and improved combustion. CO emissions for preheated biodiesel and preheated jatropha oil are lower than that for unheated fuels due to increase of vaporization rate. Poor fuel atomization and improper fuel-air mixing inside the combustion chamber occurred because of the higher jatropha oil viscosity which resulted in incomplete combustion. Combustion of preheated jatropha oil gifted us with a decrease in CO emission of up to 51% compared to diesel oil.

![Fig. 7. CO and CO₂ emissions variation with brake power for all tested fuels.](image)

NOₓ emissions for preheated, unheated jatropha biodiesel, jatropha oil, preheated Jatropha biodiesel to 40°C and jatropha oil to 90°C are shown in Fig. 8. NOₓ emissions were reduced for preheated biodiesel and jatropha oil compared to unheated fuels. NOₓ values of preheated oil are less than preheated and unheated biodiesel. The engine load increase led to increase of NOₓ emissions due to higher adiabatic flame and cylinder temperatures. NOₓ formation depends on cylinder combustion temperatures, ignition delay and oxygen content. Air fuel mixing rates and lower air entrainment result in low cylinder temperature and NOₓ values for preheated jatropha oil. Combustion rate enhancement, increased cylinder temperature and consequently higher thermal NOₓ formation were due to the oxygen content in the biodiesel structure. NOₓ emission of preheated jatropha oil and biodiesel decreased about unheated jatropha oil and biodiesel. Preheating of Jatropha biodiesel leads to reduction in NOₓ formation due to reduced intensity of premixed combustion regime, retarded injection, spray properties improvement, improved evaporation and mixing. At 75% of engine load, a significant decrease in NOₓ emission was up to 35% for preheated jatropha oil related to unheated oil. Preheated biodiesel reduced NOₓ emission by up to 7% in comparison to unheated biodiesel. Preheating proved to be a necessary requirement in diesel and future biodiesel engines in order to help in reducing engine NOₓ emissions [35].

Figure 8 displays HC emissions for jatropha biodiesel, jatropha oil, preheated jatropha biodiesel at 40°C, and preheated jatropha oil at 90°C at different loads. HC emissions increased from part to higher engine loads. Higher cetane number, shorter ignition delay and oxygen content of the fuels led to a reduction in the over mixing of fuel and higher emissions of hydrocarbons. Unheated biodiesel and jatropha oil produced higher HC emissions than diesel fuel. Poor volatility and higher viscosity of jatropha oil results in improper air-fuel mixing, improved spray, and higher HC emissions. Fuel preheating results in viscosity reduction, vaporization improvement and lower HC emissions.

![Figure 8. HC emissions variation with brake power for all tested fuels.](image)
Fig. 8. NOx and HC emissions at different engine brake power for all tested oils.

In Fig. 9, smoke emissions with engine brake power for all fuels are shown. The engine load increase led to smoke emission increase due to fuel consumption increase. Decrease of smoke emissions for biodiesel was due to the oxygen molecules in comparison to diesel oil which lead to better combustion. The presence of aromatic compounds in biodiesel and lower carbon to hydrogen ratio compared to diesel fuel reduce the smoke emission of biodiesel. Increase of fuel oil preheating temperature leads to a decrease in oil viscosity which leads to better combustion and decrease in smoke emission. Smoke emissions for preheated biodiesel and preheated jatropha oil are lower than for unheated fuels but these emissions for unheated fuels increased about diesel fuel. Unheated biodiesel and unheated jatropha oil showed higher smoke emissions than diesel oil, preheated jatropha oil, and preheated biodiesel. Burning of preheated jatropha oil decreases smoke emission abundantly by up to 55% compared to diesel oil.

4. ENGINE PERFORMANCE AND EXHAUST EMISSIONS COMPARISON

Comparison of results was made at 75% of engine load as presented in Table 2. Brake thermal efficiency for preheated jatropha oil increased by up to 2% compared to diesel fuel, however for unheated biodiesel, unheated oil, and preheated biodiesel it is decreased by about 9, 11, and 13%, respectively with respect to diesel oil. Exhaust gas temperature decreases were about 41 and 44%, respectively, for preheated jatropha oil, and preheated biodiesel when compared to petroleum diesel and increased by about 9 and 11% for unheated biodiesel and unheated oil, respectively compared to diesel oil. The increases in A/F ratio for preheated jatropha were up to 7% in comparison to hydrocarbon diesel fuel. For unheated biodiesel, unheated oil and preheated biodiesel it decreases by about 16, 17, and 18%, respectively compared to diesel oil. Preheated jatropha oil at 90°C produces improvement in engine performance.
At 75% engine load, the effect of unheated and preheated biodiesel and jatropha oil related to diesel oil on exhaust emissions are demonstrated in Fig. 3. CO₂ emission is lowered down to 45, 13, 7, and 23% for unheated biodiesel, unheated oil, preheated biodiesel, and preheated oil, respectively compared to petroleum diesel. CO emission is reduced by up to 51, 9, 15, and 26% for unheated biodiesel, unheated oil, preheated biodiesel, and preheated oil, respectively compared to petro-diesel. The increases in HC emissions were up to 44, 122, and 11% for unheated biodiesel, unheated oil, and preheated biodiesel, respectively in comparison to diesel oil. Smoke emission for preheated jatropha oil decreased by about 55% compared to fossil diesel fuel. Smoke emission decreased to 51, 47 and 55% for unheated biodiesel, unheated oil and, preheated biodiesel, respectively compared to diesel oil. It is obvious that the engine exhaust emissions were less for jatropha oil preheated to 90°C.

Table IV reports comparison of diesel engine NOₓ emissions when burning preheated biodiesel and jatropha oil at different engine loads compared with unheated biodiesel and jatropha oil. NOₓ emission decreased by up to 7% for preheated biodiesel compared to unheated biodiesel and decreased by up to 35% for preheated oil compared to unheated oil at 75% of load.

5. CONCLUSIONS
The present research concludes the following:
1. Emission concentrations of CO₂ and smoke were reduced for all tested fuels with respect to diesel oil. HC and CO increased for unheated tested fuels and were reduced for preheated tested fuels compared to diesel oil.
2. NOₓ concentrations were decreased by up to 7 and 35% for preheated biodiesel and oil, respectively compared to the unheated fuel at 75% of engine load. Preheating of biofuels is a good cheap tool for reducing NOₓ emissions.
3. BSFC increases were noticed for all fuels compared related to diesel fuel but decreased for preheated jatropha oil at 90°C.
4. Brake thermal efficiency was improved for preheated jatropha oil at 90°C.
5. Exhaust temperatures for various blends gave an upward increase trend with jatropha biodiesel concentration increase in the blends. It increased

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**Table II**

<table>
<thead>
<tr>
<th>No.</th>
<th>Performance</th>
<th>Unheated Biodiesel</th>
<th>Unheated Oil</th>
<th>Preheated Biodiesel</th>
<th>Preheated Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brake thermal efficiency</td>
<td>-9%</td>
<td>-11%</td>
<td>-13%</td>
<td>+2%</td>
</tr>
<tr>
<td>2</td>
<td>Exhaust gas temperature</td>
<td>+3%</td>
<td>+5%</td>
<td>-44%</td>
<td>-41%</td>
</tr>
<tr>
<td>4</td>
<td>Air-fuel ratio</td>
<td>-16%</td>
<td>-17%</td>
<td>-18%</td>
<td>+7%</td>
</tr>
</tbody>
</table>

**Table III**

<table>
<thead>
<tr>
<th>No.</th>
<th>Emissions</th>
<th>Unheated Biodiesel</th>
<th>Unheated Oil</th>
<th>Preheated Biodiesel</th>
<th>Preheated Oil</th>
</tr>
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<tr>
<td>1</td>
<td>CO₂</td>
<td>-13%</td>
<td>-7%</td>
<td>-23%</td>
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</tr>
<tr>
<td>2</td>
<td>CO</td>
<td>-9%</td>
<td>-15%</td>
<td>-26%</td>
<td>-51%</td>
</tr>
<tr>
<td>3</td>
<td>HC</td>
<td>+44%</td>
<td>+122%</td>
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<tr>
<td>4</td>
<td>Smoke</td>
<td>-51%</td>
<td>-47%</td>
<td>-55%</td>
<td>-55%</td>
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</tbody>
</table>
for unheated tested fuels compared to diesel oil but decreased for preheated tested fuels.

6. There were decreases in air-fuel ratios for all fuels compared to diesel oil but increased for preheated jatropha oil at 90°C.

7. Higher performance was observed for preheated jatropha oil compared to other fuels. Specific fuel consumption decreased by up to 2%, thermal efficiency increased by up to 10%, exhaust gas temperature decreased by up to 41%, and air-fuel ratio increased by up to 7%.

8. Preheated jatropha oil produced lower emissions compared to other fuels. CO2 emission decreased by 45%, CO emission decreased by 51% and decrease of smoke emission was up to 55% compared to diesel fuel.

9. Preheated jatropha oil is environmentally friendly, economical, results in engine improved performance and lower emissions. Using of cheaper and easy produced preheated oil as fuel rather than biodiesel fuel is recommended. Preheating is free of charge as it utilizes the enthalpy of the engine exhaust gases. These achievements demand the design of new biodiesel engines with exhaust preheating facility.

10. Preheating of bio-oil and biodiesel proved to be a good technique to obtain improvement in engine performance and emissions reduction. Therefore, fuel preheating is necessary when burning jatropha oil or biodiesel.

**REFERENCE**


