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Utilization of Waste Lubricating Oil as a Diesel Engine Fuel

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Abstract. This research work is focused on the regeneration of used lubricating oils which are simply thrown out to the environment. It is evident from the past research outcome that there is an acute shortage of petroleum oils and regeneration of fuels from used lubricating oils can be potential substitute of fossil fuels. But due to some drawback such as higher viscosity and density it cannot be used as a single fuel. In this regard the distillation of used lubricating oil has been carried out with. Further, this distilled used lubricating oil (DULO) was blended in different proportions with Jatropha biodiesel (JB) which has excess oxygen by about 10%. The aim of the current study is to investigate the performance and emission characteristics of a DI diesel engine run on these blends and comparison with base fuel diesel. The behavior of the engine was evaluated in terms of brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, carbon monoxide emission, hydrocarbon, nitric oxide emission and smoke opacity. The test result revealed that, the behaviour of the engine run on the JBDULO20 (i.e. 80% JB and 20% DULO) blend was better than other blends considered in the study.

1. Introduction

Energy is a simple but most powerful word and we can say most important thing in this universe. As we know today world is full of needs, full of machines, human being wants there work to be done without any efforts by them so to make that happen we need energy [1]. Energy can be produced by using various available feedstock such as solar, oil, nuclear, coal, fossil fuels etc. for producing electricity and power [2]. Today world's hot topic is renewable energy and how we can reduce greenhouse gas (GHG) emissions [3]. Need of energy is in every field of life heating, lighting, health, food production and storage, education, mineral extraction, industrial production and transportation etc. Today humankind is facing shortage of energy to fulfill the needs of human being because of rapid increase in population. As population increases, we need more energy to fulfill need of people. In 2016, world population was about 7,466,964,280 and in 2017 this number increase to 7,550,262,101 [4]. There is only solution for this is sustainability of energy.

It is essential to increase the usage of renewable energy and should make a decrement in non-renewable energy usage. In world, human beings are using by about 19% [5-6] of renewable energy in the form of biomass, hydropower, solar energy, geothermal energy etc. The research work is continuing to increase the usage of renewable energy and biomass up to 50% so that we can overcome with energy crisis problem. By using these we can make a diversion of usage of energy for many applications such as for vehicles, electricity etc. We can use solar energy, wind energy, biomass energy, geothermal energy for developing electricity.

Lubricating oil is a significant resource and a petroleum base product [7]. The oil is used for many applications which include reducing friction, as shielding against wear in many rotating equipment's. After some time of usage of these lubricating oils, their properties changes which may affects the operation and life of the rotating parts. The undesirable components which accumulate with the oils during their use and which are generally responsible for deterioration are usually of two kinds of which one is extraneous impurities and other is degradation products of oil. The used lubricating oil contains different kinds of impurities in it and is considered one of the harmful liquids which contaminate the environment is simply disposed off.

It is evident from the past research outcome that there is an acute shortage of petroleum fuels [8-10]. The regeneration of fuels from used lubricating oils can be potential substitute of fossil fuels. In this context, the present research work is aimed on the regeneration of used lubricating oils which are simply thrown out to the environment. But due to some drawback such as higher viscosity and density it cannot be used as a single fuel. In this regard the distillation of used lubricating oil has been carried out. Further, this distilled used lubricating oil (DULO) was blended in different proportions (10-40% at regular intervals of 10% on a volume basis) with Jatropha biodiesel (JB) which has high cetane value which will help for enhancing the combustion process. The aim of the current study is to investigate the performance and emission characteristics of a DI diesel engine run on these blends and comparison with base fuel diesel.

2. Material and methods

For the present investigation, Jatropha oil was selected as a raw material to produce Jatropha Biodiesel (JB). In the present study the JB was produced by transesterification process. The transesterification process to produce JB is given in Figure 1. The optimal inputs for the transesterification of Jatropha oil are identified to be 40% methanol and 1.0% NaOH. The maximum ester yield is achieved after 90 min reaction time at 60^{o}C.

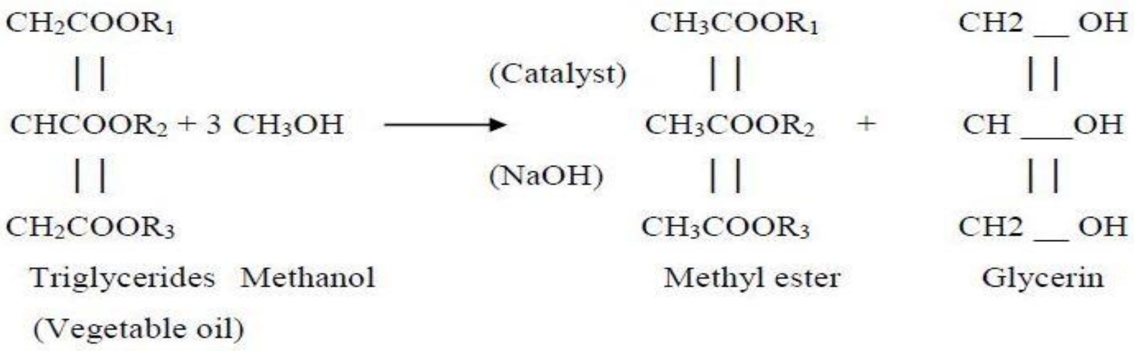

Figure 1. The transesterification process

The purification of used lubricating oil (ULO) was done using atmospheric distillation process. The ULO was heated with a mantle from 160 °C to 180 °C under atmospheric pressure, for an hour. Further, the JB and distilled used lubricating oil (DULO) at low percentages (10-40% at regular intervals of 10% on a volume basis), was blended with the JB at 90 to 60% respectively, to get the fuel blends for the investigation.

3. Experimental setup

The present work was done on a, single cylinder, direct injection diesel engine with a rated power of 4.4 kW at a constant speed of 1500 rpm. The test was started with diesel fuel to record base data and then switched over with JBDULO blends. The designations of the test fuels and their compositions used in this test are provided below in Table 1.

Table 1. Percentage of fuel available in different blends

Blends	JB	DULO
JBDULO10	90%	10%
JBDULO 20	80%	20%
JBDULO 30	70%	30%
JBDULO 40	60%	40%

Cylinder pressure inside the combustion chamber was measured by using piezoelectric pressure transducer connected to piezocharge amplifier. All the sensors were attached with a control panel, which communicate all the results to the computer. All the inputs such as engine brake power, air and fuel consumption were recorded by data acquisition system, stored in computer and displayed in the monitor. The schematic diagram of the experimental setup and specification are given in figure 2 and Table 2 respectively.

Table 2. Technical Specifications of Test Engine

Engine Manufacturer/Model	**Kirloskar/** TAF 1
Bore and Stroke	87.5 mm and 110 mm
Compression ratio	17.5:1
Number of cylinder	1
Piston Type	Bowl-in-piston
Maximum power output	4.4 kW
Maximum speed	1500 rpm (Constant)
Type of fuel injection	Pump-line-nozzle injection system
Nozzle type	Multi hole (3 hole)
Start of fuel injection	23 ^{o} CA bTDC
Fuel injection pressure	200 bar
Type of Cooling	Air cooled with radial fan

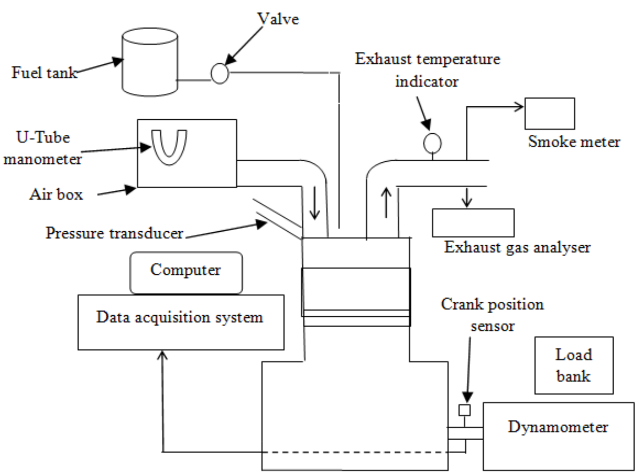

Figure 2. Schematic representation of test setup

4. Results and discussions

4.1. Performance analysis
The important performance terms of a diesel engine are discussed in following section.

4.1.1. Brake thermal efficiency. The variation of brake thermal efficiency (BTE) with respect to brake power for all the test fuels is shown in figure 3.

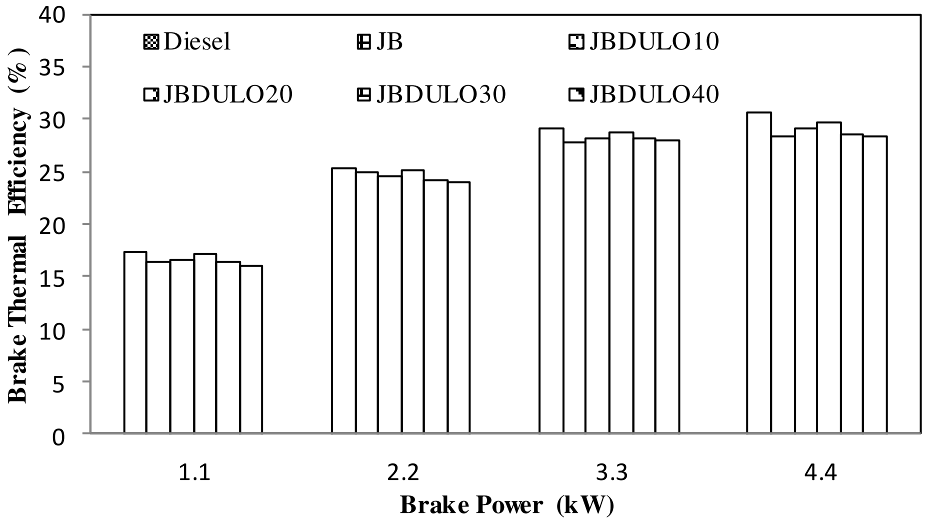

Figure 3. Variation of brake thermal efficiency with brake power

The brake thermal efficiency is the ratio of power output or work done by the engine with respect to heat supplied to it [11]. It is also called as fuel conversion efficiency. The thermal efficiency of the engine increases with increase in brake power for all the fuel operations [12-13]. This is because, while increasing the load, both the brake power (BP) and fuel flow rate increases and reduction in heat loss occur at higher loads. It is highly depending on some parameters like calorific value, fuel consumption. The BTE values for diesel, JB, JBDULO10, JBDULO20, JBDULO30, and JBDULO40 are 30.6%, 28.4%, 29.13%, 29.4%, 28.42% and 28.12% respectively at full load condition. Figure 3 clearly says that the higher brake thermal efficiency for diesel is 30.6% and JBDULO20 is 29.4%, which is 7% maximum brake thermal efficiency when compared with the neat Jatropha biodiesel. The BTE of the engine depends primarily on the calorific value of the fuel used [14]. The decrease of DULO concentration BTE also increases due to high level oxygen content in JB; it increases the better atomization, maximum heat release rate, higher pressure and better performance [15].

4.1.2. Brake specific energy consumption. The BSFC is the mass of fuel consumed per unit power output in a diesel engine. It is correlated with viscosity, CV, CN, heating content and specific gravity [16-17]. The figure 4 represents the variation of BSEC with brake power in the diesel engine with four different DULO percentages test fuel are, JB+DULO10%, JB+DULO20%, JB+DULO30%, and JB+DULO40% and compared with diesel.

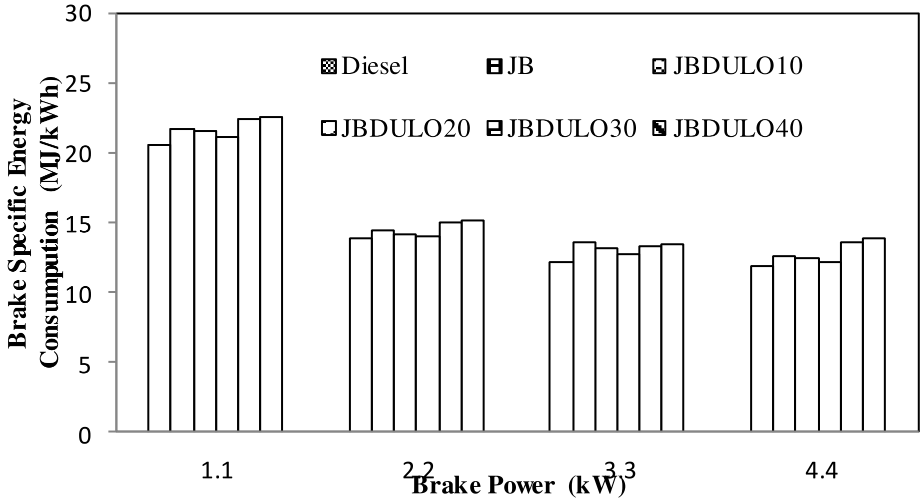

Figure 4. Variation of brake specific energy consumption with brake power

The BSEC changes from 0.391 kg/kW h at low load to 0.263 at high load condition for normal diesel fuel, and its changes from 0.413 kg/kW h at low load condition to 0.266 at high load condition for JBDULO10, 0.423 kg/kW h at low load to 0.278 g/kWh at high load condition for JBDULO20, 0.441 kg/kW h at low load to 0.291 high load condition for JBDULO30%, 0.541 kg/kW h at low load to 0.391 for JBDULO40%, respectively. From the figure 4 it says that as the DULO concentration increases, the BSFC also increased from zero to full load condition. This is due to the low heating value of DULO fuel and low cetane number, to main the same power output during power stroke more fuel is required [18]. The CV, latent heat of evaporation, flash point is plays major part in combustion, performance characteristics [19].

4.1.3. Exhaust gas temperature. Figure 5 shows the deviation of exhaust gas temperature (EGT) with respect to brake power for different fuels used in this test. The EGT increases with increase in brake power for all the test fuels. The analysis of EGT is important as it describes about those heat which are not utilized for producing power [20]. The highest EGT value with respect to all the powers was recorded for the blend which has higher percentage of DULO. This result is expected due to present of moisture content in DULO. But up to 20% DULO in blend, the value of EGT of JBDULO20 blend is close to diesel reading.

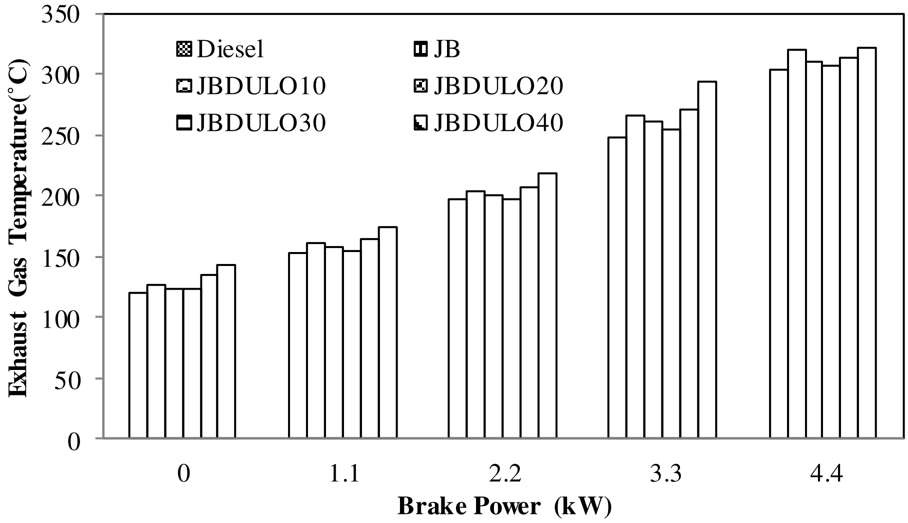

Figure 5. Variation of exhaust gas temperature with brake power

This is due to the availability of oxygen content in the JB which enhances the combustion process which resulted in lower EGT. At a brake power of 4.4 kW (maximum load condition), the EGT of JBDULO40 is 8% higher than neat diesel fuel respectively.

4.2 Emission analysis

4.2.1. Carbon monoxide emission. The chemical reaction takes place between oxygen molecule and carbon molecule during the combustion process the intermediate combustion product is called as CO [21]. It is produced due to insufficient air flow, rich air fuel mixture, etc. The figure 6 shows the development of CO emissions at different brake power for different test fuels and compared with diesel.

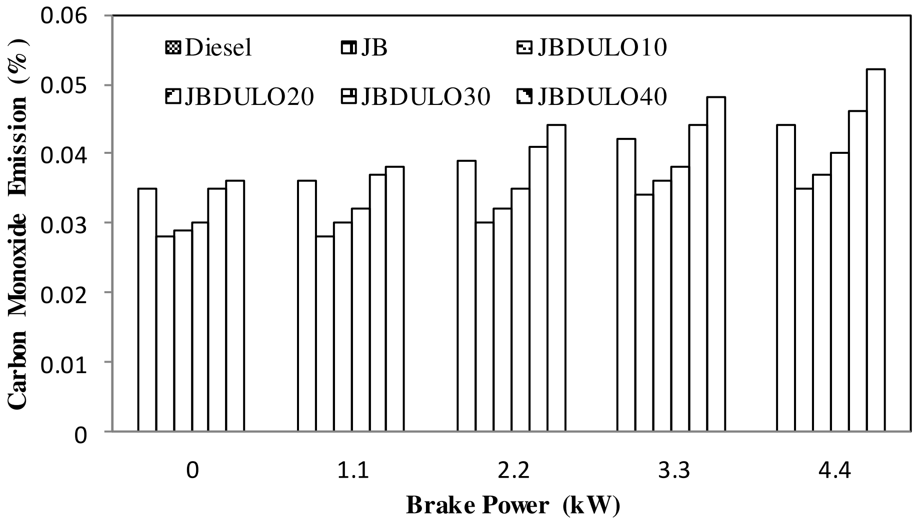

Figure 6. Variation of CO emission with brake power

The value of CO emission changes from 4.96 g/kW h at low load to 3.61 g/kWh at high load condition for normal diesel fuel, and its changes from 5.12 g/kW h at low load condition to 3.85 at high load condition for JBDULO10, 5.49 g/kW h at low load to 3.92 g/kWh at high load condition for JBDULO20%, 5.84 g/kW h at low load to 4.16 at high load condition for JBDULO20, 6.84 g/kW h at low load to 5.16 at high load condition JBDULO40 respectively. The lower CO emissions are liberated at 50% load condition and the values are 1.68 g/kW h for diesel. From the above graph clearly understood that CO emissions increased simultaneously low load condition by 3.22%, 10.68 %, 17.74% and 21.23 to final load condition by 6.6%, 8.5%, 15.23% and 18.2% compared with diesel fuel. The biodiesel has higher lower heat of evaporation decreased the heat transfer, which cause the low cooling effect on the combustion chamber [22]. The overall efficiency is increased, and CO emission is decreased. The reason is rapid addition of DULO in the Jatropha biodiesel blends reduces the overall cetane number when compared with diesel fuel [23-24].

4.2.2. Unburned hydrocarbon emission. The UHC emission shows the quality of the combustion process and amount of oxygen percentages available in the entire conversion of fuel into water vapour and carbon dioxide. The fuel properties, operation condition, incomplete combustion (rich or lean fuel mixture), heat losses around the cylinder, and flame quenching are the important parameters for the formation of UHC emissions [25-26]. The figure 7 shows the formation of UHC at different brake power for different test fuels used in this investigation. The value of UHC emission changes from 2.21 g/kWh at low load to 0.91 g/kWh at high load condition for normal diesel fuel, and its changes from 2.38 g/kW h at low load condition to 0.96 g/kWh at high load condition for JBDULO10, 2.54 g/kW h at low load to 1.05 g/kWh at high load condition for JBDULO20, 2.96 g/kW h at low load to 1.16

g/kWh at high load condition for JBDULO30 and 3.96 g/kW h at low load to 2.16 g/kWh JBDULO40 respectively. From the figure 7, it is observed that UHC increased simultaneously from low load condition by 7.6%, 14.93 % to final load condition by 5.4%, 15.38%, 20.87% compared with diesel fuel. Basically, the UHC emissions are maximum at low load condition than full load condition due to air fuel mixture, minimum cylinder surrounding temperature.

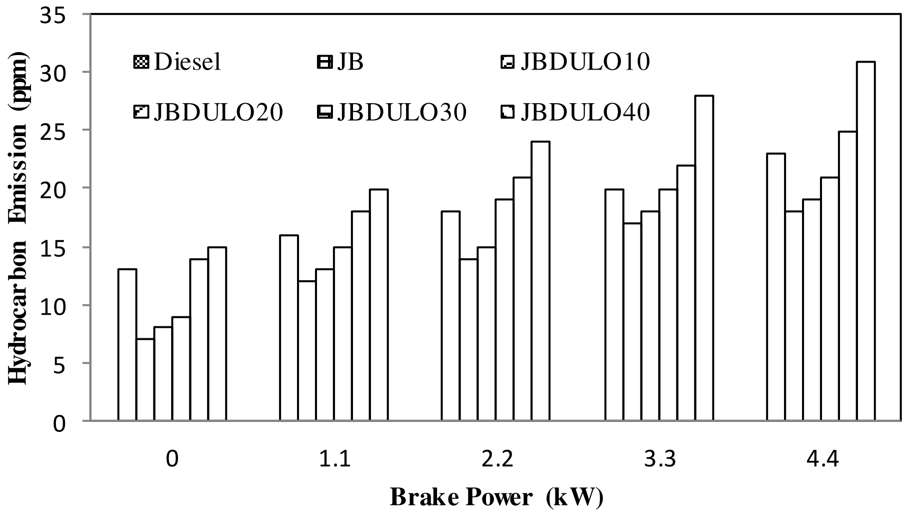

Figure 7. Variation of HC emission with brake power

The addition of DULO percentages with Jatropha biodiesel blend the UHC also increased entire load condition, this is because of low cetane number of DULO reduced their self-ignition properties, higher latent heat of vaporization, more cooling effect are the main reason for incomplete combustion and higher UHC emission [27-28].

4.2.3. Nitric oxide emission. Oxides of nitrogen emission levels are produced when the inert nitrogen molecules react with oxygen molecule at maximum temperature above 1700 K and pressure. Basically, these liberated NOx particles are splits into some wings such as nitric oxide (NO) contain 90%, NO_2 and N_2O at 5% and N_2O_3 and N_2O_5 [29]. Figure 8 compares the variation of NO_x emissions with engine load for JBDULO blends.

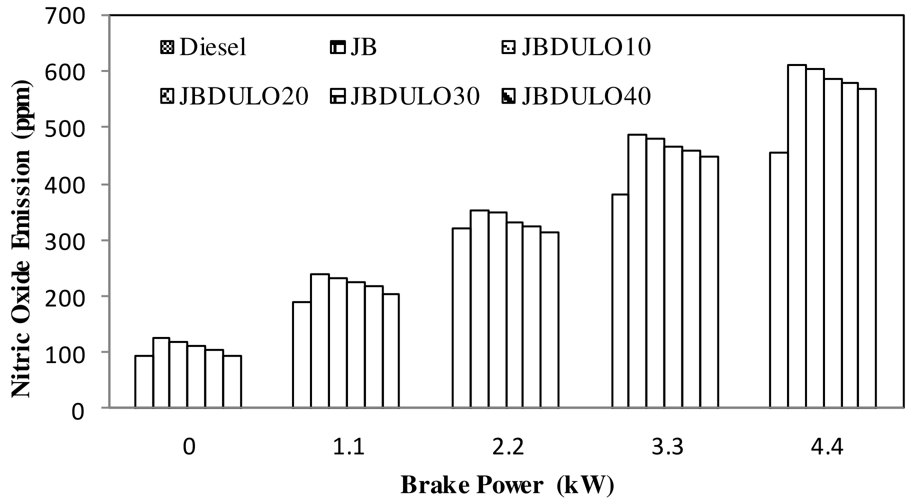

Figure 8. Variation of NO emission with brake power

The value oxides of nitrogen emission changes from 91 ppm at low load to 460 ppm at high load condition for normal diesel fuel, and its changes from 120 ppm at low load condition to 583 ppm at high load condition for JBDULO10, 117 ppm at low load to 570 ppm at high load condition for JBDULO20, 115 ppm at low load to 561 ppm at high load condition for JBDULO20, respectively. The NOx emissions are reduced by 17.31% at JBDULO20, at full load condition compared with JB. By increases of DULO concentration with JB brings down the oxides of nitrogen emissions upto JBDULO20 compare with diesel. This is due to the higher cooling effect liberated by latent heat of vaporization of DULO; it is highly useful to reduce development of oxides of nitrogen emissions [30]. Further increases the DULO concentration in JB causes high cylinder pressure, cylinder temperature increases the NOx formation.

4.2.4 Soot concentration. The results of smoke opacity for different test fuels with respect to brake power is shown in Fig. 9. It is the fact that smoke formation depends upon the load of the engine. Hence, smoke density increases with an increase in load of the engine. The minimum and maximum smoke densities produced during the test for diesel, JB and JBDULO blends were in the range of 4% and 65% respectively. At full load condition, the maximum increase of smoke density was observed for diesel. It is perceived from the figure that the smoke density value increases with the increase in the percentage of DULO in the JB-DULO blends, which is higher than the smoke density of pure JB [31]. The smoke density of diesel and JB is recorded as 65% and 54.5% at rated load. In case of DULO10, DULO20, DULO30 and DULO40 blends the values are 55.2%, 57.4%, 60.4% and 64.9% at full load. The increase in smoke emission is caused by poor atomization of the DULO molecule present in the blend. The factors which cause higher amount of smoke emission are the higher viscosity, bulk fuel molecules, low volatility and presence of aromatic of waste plastic oil constituted in reduced atomization of fuel.

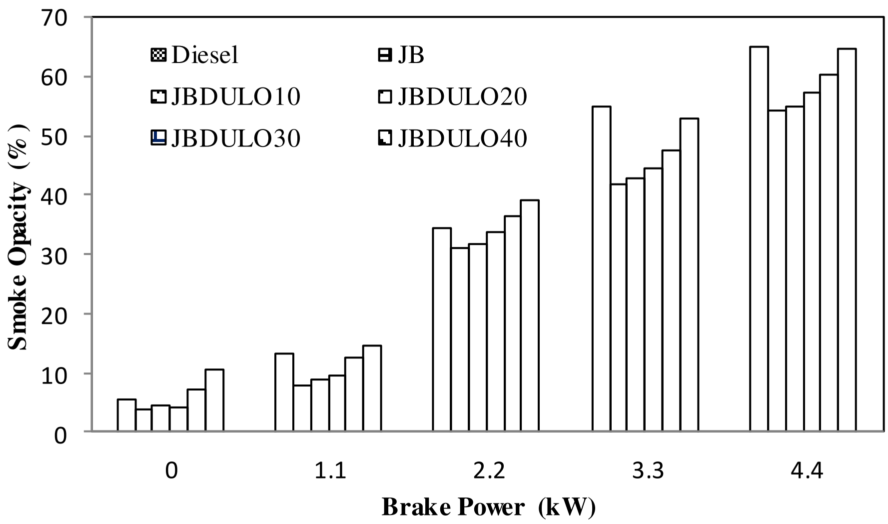

Figure 9. Variation of smoke density with brake power

5.Conclusion

The main aim of this study is to improve the performance of a diesel engine when distilled used lubricant oil (DULO) is used as partial replacement of diesel/biodiesel fuel. In this regard behaviour of a single cylinder, diesel engine fuelled with JBDULO blend as a fuel were tested and results obtained were equated with base line reading of diesel. The conclusions of this study are given in this section.

- The BTE value of the JBDULO20 blend was 29.1% while for diesel was 30.5% at full load.
- The energy losses in the form of EGT were higher for JBDULO20 blend in comparison with diesel operation.

- The value of BSEC for diesel was 11.7 MJ/kWh at full load. The increase in 4.3% of BSEC was recorded for JBDULO20, than that of diesel reading.
- The CO, HC and smoke emissions were reduced by 8.7%, 7.3% and 12.4% respectively for JBDULO20 blend, compared to diesel.
- The NO emission was recorded extra by about 15.3% for JBDULO20, in comparison with diesel.
- By considering the above results, it can be summarised that the JBDULO20 blend revealed better engine results compared to those of other JBDULO20 blends. Overall it can be suggested that this blend can be used as a replacement of diesel fuel in a diesel engine.

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