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EFFECT OF USED COOKING OIL METHYL ESTER ON COMPRESSION IGNITION ENGINE

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ABSTRACT

Biodiesel is a fuel derived from vegetable oils or animal fats which are basically long chain triglyceride esters with free fatty acids. The long chain triglyceride ester is converted into mono ester by the process called transesterification. In this process the vegetable oils are reacted with methanol or ethanol in the presence of acid or base catalyst producing fatty acids methyl or ethyl ester.

In this study used cooking oil was transesterified using 1% sodium hydroxide and 20 % methanol at the temperature range of 65-69°C. The reaction time was two hours and conversion efficiency was 92.5%. The physical and chemical properties of the biodiesel were determined in accordance with ASTM 6751.

The biodiesel was used as fuel in a four stroke, three cylinder, naturally aspirated engine, in pure as well as in the blended form. Engine performance and emissions were studied. The results showed that specific fuel consumption was increased by increasing the ratio of biodiesel in the blends. However there was notable decrease in CO, CO_2, THC and SO_x emissions and a minor increase in NO_x emission.

Keywords: *Used cooking oil; Biodiesel; Exhaust Emissions; Diesel Engine; Transesterification.*

1) INTRODUCTION

The need of energy is one of the basic necessities of the humanity. Both renewable and non renewable energy resources are widely used but the major consumption is of non-renewable energy resources. Among the non-renewable the significant energy resource is the mineral oil, which is used in power, agricultural, industrial, and transport sectors. The scientific development, better quality of life, and drastic increase in population is gearing up the depletion of mineral oils. So the search of new avenues is mandatory. Biofuels, particularly, use of vegetable oils being renewable fuel, can cope with the shortage of the fuels. They can be used in compression ignition engines to substitute the diesel. No major modifications in engines are required to be made to use these fuels (Hazar, 2009). The lubricant properties of vegetable oils are much better than those of ultra low sulfur diesel. Their use in engines reduces the wear and tear of engine parts and increases the engine life (Geller and Goodrum, 2004).

The use of vegetable oils is also environment friendly. The exhaust emissions of engines, when run on vegetable oils, contain smaller amounts of total hydrocarbons (THC) and carbon dioxide (CO_2), a little amount of carbon monoxide (CO), and negligible amount of oxides of sulfur (SO_x) as compared to the use of diesel. However the oxides of nitrogen (NO_x) emissions are a bit higher than those produced by diesel (Yahya and Marley, 1994).

Straight vegetable oils and animal fats were used to run diesel engines in emergency situations, like World War II (Kim et al., 2004 and Pousa et al., 2007). The straight vegetable oils could be used to cater the temporary situations but their long term use did not show the encouraging results. The molecular weight of vegetable oils is in the range of 850 to 995 that is much higher than the molecular weight of mineral diesel which is 168. The molecular structures of vegetable oils are very complicated with multiple branches. Therefore, their kinematic viscosity is much higher (7-13 times, and in some cases 100 times than that of diesel) and their specific gravity is about 10% higher than that of mineral diesel (Conceição et al., 2007) and (Shahid and Younis, 2011). As a result, the flow rate of vegetable oils is not adequate and their use as fuel creates many problems in fuel pump and injection system. They plug the fuel pump, fuel lines, and fuel injectors, and proper spray pattern is not formed, which ultimately makes the combustion uneven (Engelman et al., 1978). Hence, their chemical structure is required to be modified before using them in the engine as fuel.

2) USED COOKING OIL

Used cooking oil has sufficient potential to fuel the compression ignition engines. It is abundantly available in the local market at cheaper rate as it is not commonly used. A huge quantity of used cooking oil can be collected from restaurants and food item industry.

The kinematic viscosity of used cooking oil (UCO) is about 10 times greater, and its density is about 10% higher than that of mineral diesel. These properties play a vital role in the combustion; therefore these must be modified prior to the use of UCO in the engine. Many techniques have been developed to reduce the kinematic viscosity and specific gravity of vegetable oils, which include pyrolysis, emulsification, leaning and transesterification (Shahid and Younis 2011). Among these techniques, transesterification is the hot favorite. This is because of the fact that this method is relatively easy, carried out at normal conditions, and gives the best conversion efficiency and quality of the converted fuel (Enweremadu et al., 2009).

3) TRANSESTERIFICATION

Transesterification is the method in which the vegetable oils or animal fats are reacted with alcohol in the presence of a suitable catalyst at specific temperature. It is a series of reversible reactions in which the triglycerides are converted into diglycerides and diglycerides are converted into monoglycerides as shown below (Neyda et al., 2008).

$$\text{Triglyceride} + \text{Alcohol} \rightleftharpoons \text{Diglyceride} + \text{R'COOR}$$
$$\text{Diglyceride} + \text{Alcohol} \rightleftharpoons \text{Monoglyceride} + \text{R''COOR}$$

Stoichiometricaly, 11.3 ml of methanol is required to transesterify 100 ml of UCO. As the reaction is reversible, so to shift the balance towards the products side and to get better conversion efficiency, higher amount of methanol i.e., about 20% is recommended (Sinha et al., 2008).

3.1) Preparation of Used Cooking Oil Methyl Ester

Two liters of UCO were filtered to remove the solid particles and other impurities. Since the water contents badly affect the transesterification, therefore the oil was heated at 85-90°C in an open lid container for half an hour to vaporize the water contents.

Four hundred ml (20% of UCO) of anhydrous methanol (97% pure of Merc Company) was poured into a flask and 20 grams (1% of UCO w/v) of lye of sodium hydroxide, as catalyst, was put into it and stirred vigorously using magnetic stirrer (Berchmans and Hirata, 2008). This mixture is generally called sodium methaoxide. The filtered oil was poured into the locally developed reactor and mixed with sodium methaoxide. The mixture was agitated continuously for two hours. The mixture container was dipped in a water bath containing a controlled heat source and its temperature was maintained at 67 ± 2°C (Rashid et al., 2008).

The fluid was then poured into a separating funnel and allowed to cool and settle. After about half an hour the fluid started settling. Pale yellow colored fluid named biodiesel or methyl ester started settling above the thick dark brown glycerol or glycerin. The mixture was totally separated into two layers in six hours. To ascertain the separation process the fluids were allowed to remain in the funnel for further two hours. After eight hours, both of the fluids were separated gravitationally, in separate containers. Both of the fluids were poured in two separating funnels and allowed to resettle for one hour. The little traces of glycerin were found in used cooking oil methyl ester (UCOME), which were removed. Similarly a little amount of UCOME was recovered from the glycerin.

3.2) Washing and Neutralization

Since 20% methanol was used whereas stoichiometricaly only 11.3% was required. Therefore extra amount of methanol was present in the UCOME, which was separated by distillation method, for future use.

Sodium hydroxide used in transesterification reaction was found in the UCOME, therefore the PH value of UCOME was as high as 9.20. Warm water was showered into the UCOME and stirred vigorously to mix the water and UCOME homogenously. The mixture was then allowed to settle. From this mixture, NaOH was absorbed by the water, producing soap that was settled in the bottom of the container in foamy form, which was then removed. By this the PH value of UCOME was decreased to 8.10, but still it was higher. The washing process was repeated four times and ultimately the PH value was reduced to 6.98 and crystal clear water was settled, which showed that NaOH had been completely washed away.

3.3) Testing of UCOME

The physical and chemical properties of the UCOME have been tested according to standards ASTM D6751-02 (Peng et al., 2008) and compared with diesel, as shown in Table 1.

Table 1: Properties of Diesel and UCOME

Property	Unit	Diesel	UCOME	ASTM D6751-02
Density at 20°C	Kg/m^3	850	880	870–890
Kinematic Viscosity at 40°C	mm^2/s	3.6	3.95	1.9 to 6.0
Flash Point	°C	68	185	> 120
Pour Point	°C	–6	–9	–15 to 10
Calorific Value	MJ/kg	42	39	--

4) ENGINE PERFORMANCE

4.1) Experimental Setup

The engine performance tests were conducted with a four strokes, three cylinder, direct injection, water cooled, naturally aspirated engine. The engine had necessary controls, i.e. speed, load, and fuel controls and had arrangements of necessary instrumentation, i.e. fuel flow rate, speed, and load measuring system. The engine was connected to a three phase A.C electric generator of 27 KVA with power factor of 0.9 and of efficiency varying from 80 to 85%. The exhaust line of the engine was connected to a five gas exhaust gas analyzer (IMR 3000). Detailed specifications of the engine are given in Table 2.

Table 2: Engine Specifications

Make/Type	Perkins/AD 3.152
Volumetric efficiency	85%
Bore	91.4 mm
Stroke	127.0 mm
Injection Timing	17° BTDC
No. of Nozzle	3
No. of holes of Nozzle	4
Brake mean effective pressure	7.157 bars
Maximum engine power @ 2,250 rpm	36.7 kW
Maximum torque @ 1,400 rpm	173.5 Nm

5) RESULTS AND DISCUSSION

To study the engine performance, tests were conducted at fixed speed of 1500 r.p.m. at different powers varying from no load to 33kW, using pure diesel (B0), pure biodiesel (B100), and blends of diesel and UCOME with different ratios.

5.1) Engine Performance Characteristics

5.1.1) Fuel Consumption

The rate of fuel consumption increases with the increase of load for pure diesel as well as for all of its blends, as shown in Figure 1. It is obvious, as more energy is required to generate more power.

The trend shows that there is a rapid increase in fuel consumption up to 10 kW power, after which this increase is moderate up to 28 kW. However a rapid increase is observed for further increase in load. Therefore, it can be concluded that the combustion efficiency improves from 10 kW to 28 kW, and declines for higher loads. Hence, it may be considered that the optimum range of load is 10 kW to 28 kW.

It can also be observed from Figure1 that for the same load, more fuel is required with increased percentage of UCOME in the blends of diesel and UCOME. The reason of this increase is that the heating value of UCOME is lower than that of diesel. The difference in fuel consumption is not very high up to B20, but the rate of increase is more visible for higher ratios of UCOME, particularly when higher power is generated.

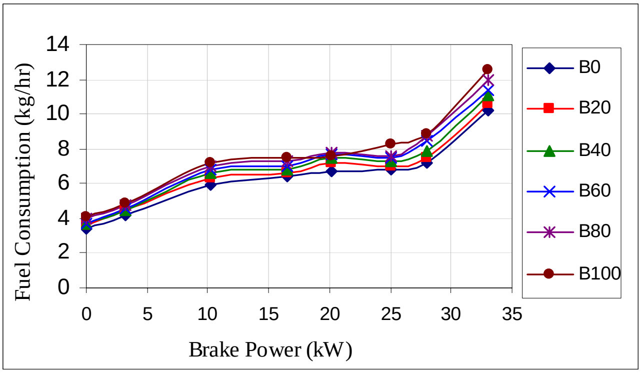

Figure 1: Effect of brake power on fuel consumption for various blends of diesel and UCOME

The specific gravity and kinematic viscosity of UCOME are higher than those of diesel, which disturbs the spray pattern when higher amount of UCOME passes through the fuel injector. This may also be the reason of consumption of more fuel. Fortunately, the affected range is not the normal performance range of the engine. Similar trends have been shown by (Nabi et. al., 2009).

5.1.2) Brake Thermal Efficiency

The brake thermal efficiency (BTE) is increased with the increase of load up to 28 kW and dropped abruptly for higher loads for pure diesel and for all of its blends, as shown in Figure 2. It also shows that BTE improves for higher power up to 28 kW for B0 and up to 30 kW for B100. For higher power the combustion time and heat transfer time becomes insufficient as more fuel enters the combustion chamber which results in lower BTE.

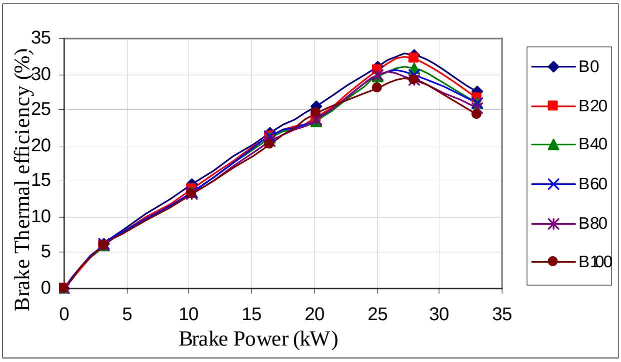

Figure 2: Effect of brake power on brake thermal efficiency for various blends of diesel and UCOME

Although BTE decreases by increasing the ratio of UCOME in the blends, yet this decrease is very small up to 21 kW power. The BTE is lower because the heating value of UCOME is lower as compared to mineral diesel. Certainly the difference in BTE between B0 and B20 is negligible, hence it can be concluded that B20 can be safely used for the normal range of load. Similar types of results were shown by (Gumus, 2008).

5.2) Engine Emissions

5.2.1) Carbon dioxide

The major portion of emissions consists of carbon dioxide (CO_2), which causes green house effect and global warming. It causes health hazardous e.g. skin diseases, eye irritations etc., and affects the human respiratory and nervous systems.

It can be observed from Figure 3 that the amount of CO_2 increases with the increase of power which is due to the fact that more fuel is consumed for higher power, which consequently produces more carbon dioxide.

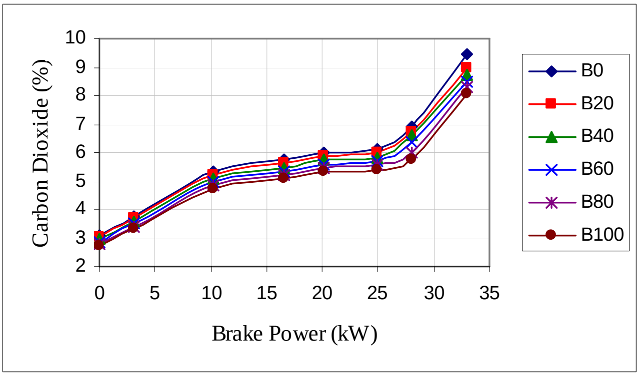

Figure 3: Effect of brake power on CO_2 emission for various blends of diesel and UCOME

Fortunately less amount of CO_2 is produced when the engine is fueled with UCOME compared to the use of diesel for same power. The reason of this fact is that diesel has 85% carbon atoms while biodiesel has about 76%, hence the combustion of UCOME produces less carbon dioxide.

Figure 3 also shows that, at optimum power, the decrease in CO_2 is 2 % with the use of B20 and 22% with the use of B100 compared to B0. Carbon dioxide is health hazardous but its production is unavoidable when the carbon containing fuel is burnt. However it is the beauty of biodiesel that the amount of CO_2 produced by burning the biodiesel is almost the same as absorbed by the plants. Therefore it is claimed that the global production of CO_2 is zero, when engines are fueled with biodiesel.

5.2.2) Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, and highly hazardous pollutant emission which affects the human lungs, heart, brain, and nervous system (Aerias, 2008). Moreover the presence of CO in the exhaust emissions shows that there is an incomplete combustion of fuel in the engine.
The percentage of CO in the exhaust increases with the increase of load for diesel and all of its blends with UCOME as shown in Figure 4. The reason can be that air fuel ratio decreases for higher loads, since the amount of intake air remains constant due to constant speed of engine and amount of fuel continuously increases. Forson et al. also reported similar results (Forson et al., 2004).

The trends show that the amount of CO decreases with the increase of ratio of UCOME in the blends of fuel for the same power. Similar trends have been shown by (Gumus, 2008).

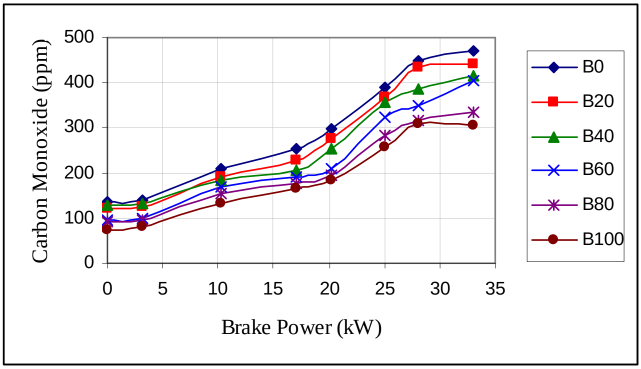

Figure 4: Effect of brake power on CO emission for various blends of diesel and UCOME.

It can also be observed that the difference of CO increases with the increase of power. Murillo et al., reported that CO emission in the exhaust was lowered by using biodiesel up to 18 kW but it increased slightly up to 27 kW power and then again decreased (Murillo et al., 2007).

Scientists are continuously trying to reduce CO emission of the engines using various techniques, such as, by modifying the design of combustion chamber and fuel injection system, by using catalysts, by changing the fuel properties etc. Fortunately, UCOME is an oxygenated fuel, which provides the excessive amount of oxygen; hence the production of CO is reduced. Moreover due to higher specific gravity of UCOME than pure diesel, early injection of fuel elongates the combustion time therefore less amount of CO is produced by using UCOME.

5.2.3) Total Hydrocarbon

The excessive amount of total hydrocarbon (THC) in the exhaust emissions is not only the health hazardous but it also indicates the wastage of fuel because of incomplete combustion. It can be seen from Figure 5 that total hydrocarbon decreases with the increase of power, up to 30 kW, after which it increases with the increase of power, for pure diesel and all of its blends with UCOME.

It validates the earlier conclusion that the combustion efficiency improves with the increase of power up to optimum power. As the power crosses the optimum limit, higher amount of fuel is injected and combustion time becomes insufficient, resulting in the emission of higher amount of THC.

It is also interesting to note that the amount of THC decreases by increasing the ratio of UCOME in the blends.

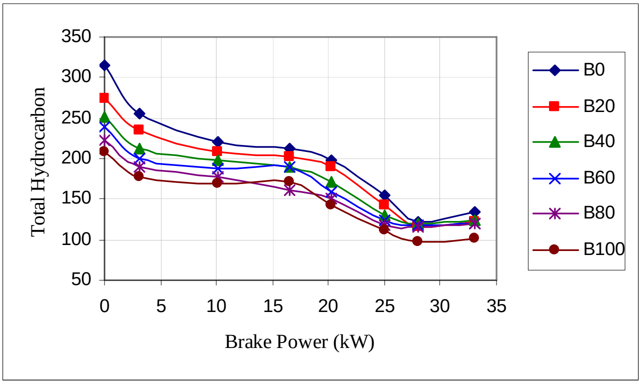

Figure 5: Effect of brake power on THC emission for various blends of diesel and UCOME

This may be due to the fact that the UCOME is an oxygenated fuel which results in better utilization of fuel. These results are similar to those of (Najafi et al., 2007).

5.2.4) Oxides of Nitrogen

Different types of oxides of nitrogen (NO_x) are produced when oxygen reacts with nitrogen at temperatures higher than 1600°C. These gases are dangerous for human and horticulture, and also contribute to weaken the ozone layer. It can be observed from Figure 6 that the amount of NO_x increases as power increases. The reason is very simple i.e., the engine temperature increases with the increase of power due to more fuel consumption. The trend in the increase of NO_x is almost smooth up to 27 kW of power. After that the rate of NO_x decreases up to 30 kW, and then it increases again. Many techniques have been developed to control the level of NO_x in the emissions, like exhaust gas recirculation, water spray, and use of after combustion catalysts, etc.

Oxides of nitrogen become a serious challenge when the biodiesel is used in the engine. It can be seen from Figure 6 that the amount of NO_x increases with increase in the ratio of UCOME in the blends of diesel and UCOME. As the specific gravity of UCOME is about 3.5% higher than that of diesel so the injection process starts earlier providing elongated combustion time which results in the higher amount of NO_x emission. Fortunately, there is a negligible increase in its amount (2%) with B20 but it increases rapidly for higher ratios of UCOME in the blends. Other scientists also showed similar type of results Yage et al., (2009) and Kegl (2008).

Cetane number is a property of fuel which explains the ignition delay in the combustion chamber.

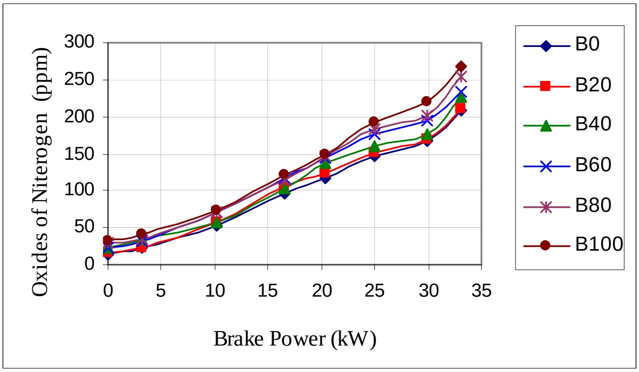

Figure 6: Effect of Brake Power on NO_x Emission for various blends of diesel and UCOME

The Cetane number of UCOME is 54 as compared to 47 for diesel (Yao et al. 2008). Higher Cetane number of UCOME reduces ignition delay period, hence ignition starts earlier. It also affects the combustion phenomenon. Premix combustion also takes place due to higher cetane number of UCOME, which may also be responsible for producing more NO_x. George et. al. reported that soot radiates away the heat and reduces the temperature in the combustion chamber (George et al. 2007). The improved combustion efficiency with UCOME produces less soot, resulting in less reduction in temperature. Consequently higher temperature in the cylinder may cause the formation of higher amount of NO_x. However, Gumus reported that the amount of NO_x is lower when the engine is fueled with biodiesel and its proportion is inversely proportional to the ratio of biodiesel in the blends of fuel (Gumus 2008).

6) CONCLUSIONS

Used cooking oil can be successfully used as an alternative fuel in diesel engines after converting it into ethyl or methyl esters. It can be converted into UCOME by reacting it with 20% methanol, in the presence of 1% NaOH at 65-69°C. Within two hours one liter of oil can be converted into 925 ml of UCOME. Although B100 can be used in an engine, yet B20 is more acceptable, as in this case, the results obtained are very much close to those obtained by using pure diesel. When the engine was fueled with B20 there was just 10% increase in fuel consumption and 10% decrease in BTE. In this case, at optimum range of load, about 8% decrease in CO_2, 4% decrease in CO, 12% decrease in THC, and 2% increase in NO_x was observed in the exhaust.

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