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# Comparision of Diesel Engine Performance and Emissions from Neat and Transesterified Cotton Seed Oil

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**Abstract**

There is an increasing interest in India to search for suitable alternative fuels that are environmental friendly. Environmental concerns and limited amount of petroleum resources have caused interests in the development of alternative fuels for internal combustion (IC) Engines. As an alternative, biodegradable, renewable and sulphur free biodiesel is receiving increasing attention. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock, such as, vegetable oils or animal's fats, for use in compression ignition engines. Therefore, in this study, different parameters for the optimization of biodiesel production were investigated in the first phase, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures was carried out. Biodiesel was made by the well known transesterification process. Cottonseed oil (CSO) was selected for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 76% biodiesel was produced with 20% methanol in presence of 0.5% sodium methaoxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.



Keywords: Bio-Diesel; Transesterification; Cottonseed Oil Methyl Ester; Performance and Exhaust Emissions.

## 1. Introduction

New and renewable alternative fuels as a substitute for petroleum-based fuels have become increasingly important due to environmental concerns, unstable costs and transportation problems. One of the renewable alternative fuels is bio-diesel, which is domestically produced from new or used vegetable oil and animal fat. Oil or fat reacts with alcohol (methanol or ethanol). This reaction is called transesterification. The reaction requires heat and a strong catalyst (alkalis, acids, or enzymes) to achieve complete conversion of the vegetable oil into the separated esters and glycerin [9]. During the transesterification reaction, glycerin is obtained as a by-product. It is used in pharmaceutical, cosmetic and other industries [1, 2]. Not only can bio-diesel be used alone in neat form but it can also be mixed with petroleum diesel fuel in any unmodified diesel engine [3].

Diesel fuel is very important for countries economy because it has a wide area of usage such as long haul truck transportation, railroad, agricultural and construction equipment. Diesel fuel contains different hydrocarbons, sulphur and contamination of crude oil residues [4, 5]. But chemical composition of biodiesel is different from the petroleum-based diesel fuel. Biodiesel hydrocarbon chains are generally 16-20 carbons in length and contain oxygen at one end. Bio-diesel contains about 10% oxygen by weight. Bio-diesel does not contain any sulfur, aromatic hydrocarbons, metals and crude oil residues[10, 6]. These properties improve combustion efficiency and emission profile. Biodiesel fuel blends reduce particulate matter (PM), hydrocarbon, carbon monoxide and sulfur oxides [11]. However, NOx emissions are slightly increased depending on biodiesel concentration in the fuel [12, 13]. Due to the lack of sulfur biodiesel decrease, levels of corrosive sulfuric acid accumulate in engine crank case oil

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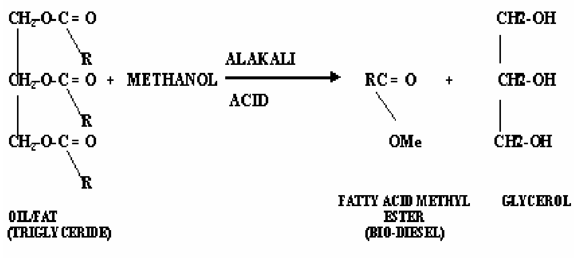
[7]. Using biodiesel is a big advantage for countries where petroleum is imported [14]. Many countries that import crude petrol encourage the production of bio-diesel by reducing taxes and by giving low interest credits.

Vegetable oils, the main source of biodiesel, have considerably higher viscosity and density compared to diesel fuel. Despite transesterification process, which has a decreasing effect on the viscosity of vegetable oil, it is known that bio-diesel still has some higher viscosity and density when compared with diesel fuel [15, 16]. The viscosities of fuels have important effects on fuel droplet formation, atomization, vaporization and fuel-air mixing process, thus influencing the exhaust emissions and performance parameters of the engine. There have been some investigations on using preheated raw vegetable oils such as palm and jatropha oil in diesel engines [8,17]. However, it is known that vegetable oils have considerably higher viscosity compared with diesel fuel. It was declared that CO, HC and particulate matter emission were improved because preheating reduced the viscosity of raw vegetable oil to almost the level of diesel fuel and caused a better combustion [18].

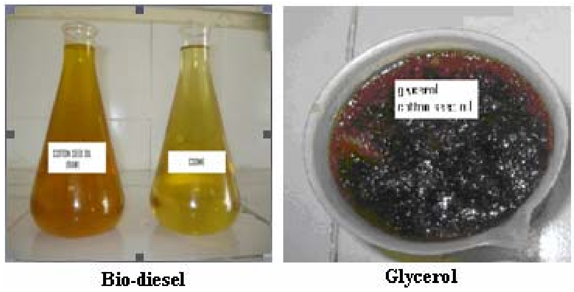
In the present investigation different parameters for biodiesel production have been investigated and the effects of viscosity of cottonseed oil methyl ester (CSOME), which is decreased by means of preheating process, on the performance parameters and exhaust emissions of a diesel engine. For this aim, CSOME was produced by transesterification method, using cottonseed oil and methyl alcohol, and its effect of reaction temperature, catalyst percentages, alcohol percentages and reaction time for optimum biodiesel production have been studied, and its properties were determined. Finally, the results for CSOME were compared with those for diesel fuel.

## 2. Production of Cottonseed oil Methyl Ester

The Transesterification process of cottonseed oil was performed using 5g Sodium methaoxide as catalyst and 100ml methyl alcohol per 1 litre pure cotton seed oil. First, the cottonseed oil was heated to about 65-70$^0$C in a reactor with a capacity of about 40 litres. Then, the catalyst was mixed with methyl alcohol to dissolve and added to the heated cotton seed oil in the reactor. After the mixture was stirred for 1 h at a fixed temperature of about 70$^0$C, it was transferred to another container and the separation of the glycerol layer was allowed. Once the glycerol layer was settled down, the methyl ester layer, formed at the upper part of the container, was transferred to another vessel. After that, a washing process to remove some unreacted remainder of methanol and catalyst was carried out, using distilled water and blown air. Then, a distillation process at about 110$^0$C was applied for removing the water contained in the esterified cottonseed oil. Finally, the produced cottonseed oil methyl ester (CSOME) was left to cool down. The Chemical Equation of Transesterification Process, Crude, Transesterified (Biodiesel) of Cottonseed Oil and its by-product, and the Production Process of CSOME are presented in Figure1a, Figure1b and Figure1c respectively.




(a)

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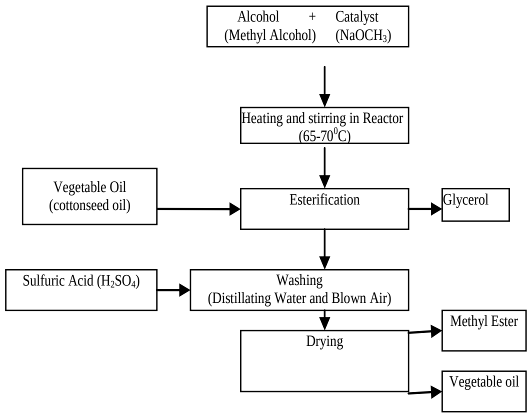



(c)

Figure 1. (a) Chemical Equation of Transesterification Process, (b) Crude, Transesterified (Biodiesel) Cotton Seed Oil and its by-product, (c) The flowchart of the cotton seed oil methyl ester (CSOME) production processes

## 3. Experimental Setup

A single cylinder 4-stroke water cooled diesel engine developing 5.2 KW at 1500 rpm was used. Engine details are given in Table 1. The schematic of the experimental setup is shown in Figure 2 An eddy current dynamometer was used for loading the engine. The fuel flow rate was measured on the volumetric basis. Experiments were initially carried out on the engine at all loads using diesel to provide base line data. The engine was stabilized before taking all measurements. Various blends of different proportions of CSOME and diesel were used to run a single cylinder CI engine.

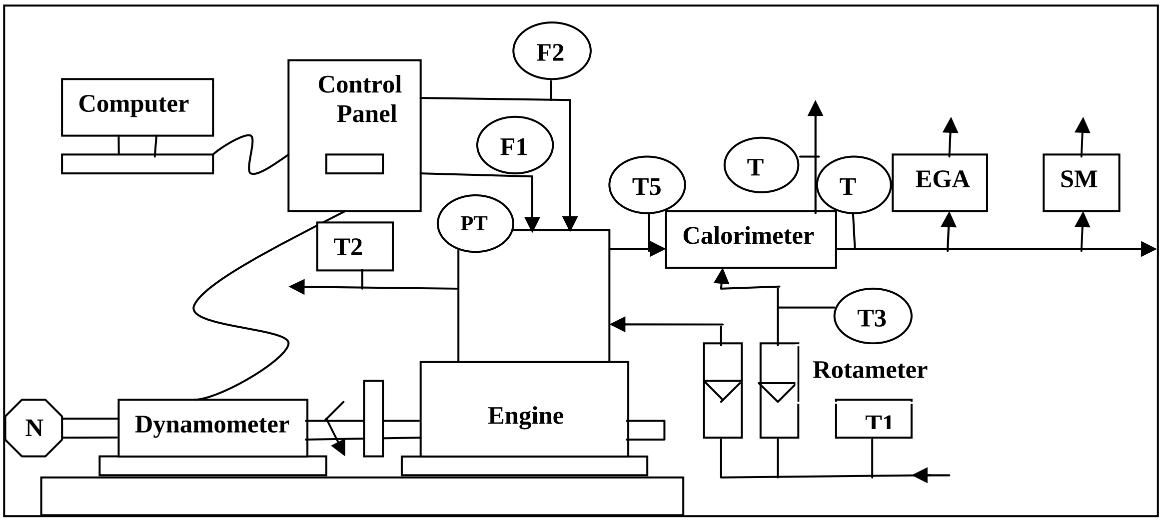



Figure 2. Experimental Setup with main parts

Where,

| | | | |
|---|---|---|---|
| T1, T3 | Inlet Water Temperature 0C | F2 | Air Intake DP unit |
| T2 | Outlet Engine Jacket Water Temperature $^0$C | PT | Pressure Transducer |
| T4 | Outlet Calorimeter Water Temperature $^0$C | Wt | Load kg |
| T5 | Exhaust Gas Temperature before Calorimeter $^0$C | N | RPM Decoder |
| T6 | Exhaust Gas Temperature after Calorimeter $^0$C | EGA | Exhaust Gas Analyzer (5 gas) |
| F1 | Fuel Flow DP (Differential Pressure) unit | SM | Smoke meter |

## 4. Results and Discussions

### *4.1. Optimization of Different Parameters for Biodiesel Production*

The rate of conversion from CSO to CSOME depends upon the different parameters like oil temperature, reaction temperature, catalyst percentage, methanol percentage, purity of reactants, etc. In this work, reaction temperature, catalyst percentage and methanol percentage have been investigated.

#### *4.1.1. Reaction Temperature and Biodiesel Production*

Figure 3. shows the effect of methanol percentages on biodiesel production. The volumetric percentages of methanol were varied from 15% to 25%. The weight percentage of catalyst ($NaOCH_3$) was fixed at 0.5%. The reaction temperature was varied from 45 to 60$^0$C. The maximum bio-diesel yield was noticed at 20% methanol. This was due to the fact that the 20% methanol has a favorable influence on maximum bio-diesel production. A maximum of 76% biodiesel production was observed at 20% methanol and at a temperature of 55$^0$C.

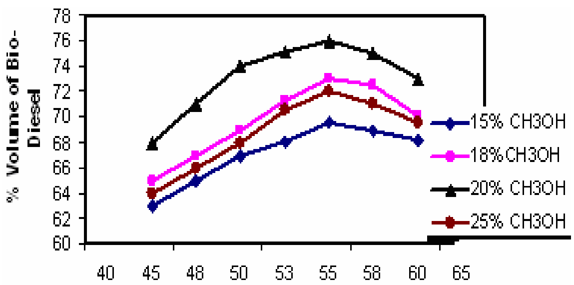



Figure 3. Effect of Temperature on Bio-Diesel Production ($NaOCH_3$=0.5%)

Table 1. Experimental Setup Specifications.

| | |
|---|---|
| Engine | Four-stroke, single cylinder, constant speed, water cooled Diesel engine |
| Maximum Power/ HP | 5.2 KW @ 1500 RPM/ 7.2 HP |
| Bore x Stroke | 87.5 x 110 mm |
| Compression Ratio | 17.5:1 |
| Dynamometer | Eddy current dynamometer with loading unit |

#### *4.1.2. Influence of Catalyst Percentage and Biodiesel Production*

Figure 4. Depicts the influence of catalyst percentages on bio-diesel production. The weight percentages of catalyst were varied from 0.5 to 0.75%. The optimum methanol percentage was kept

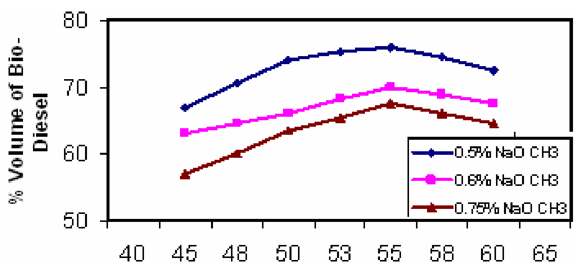



Figure 4. Effect of Catalyst ($NaOCH_3$) Precentages on Bio-Diesel ($CH_3OH$=20%).

constant to 20%. It can be seen from the figure that with the increase in lye catalyst, bio-diesel yield decreases. This may be associated with the increase in the formation of wax. The vegetable oil used in transferification process contains many free fatty acids. The catalyst reacts with these free fatty acids and produces wax. A maximum of 76% bio-diesel yield was found at 0.5wt%. Catalyst and at a reaction temperature of 55°C. If the weight percentage of catalyst is used below 0.5% the bio-diesel production was found minimum. Thus 20% methanol and 0.5% $NaOCH_3$ were chosen as the optimum percentages for biodiesel production.

### *4.1.3. Influence of Reaction Time on Biodiesel Production*

Figure 5 shows the effect of reaction time on bio-diesel production. The catalyst percentage was set to 0.5. The reaction temperature was kept at 55°C. It was found that when reaction time increases, the bio-diesel production increases and reaches maximum at about 8hrs. Then bio-diesel production decreases with the increase in reaction time. When the mixture of CSO, methanol and catalyst was kept for 24hrs, the bio-diesel production was reduced to 70%. This was due to the fact that the tendency of soap formation increases with the increase in reaction time. It was found that for 8hrs the maximum bio-diesel production was 76.5%.


Figure 5. Effect of Reaction Time on Bio-Diesel Production ($CH_3OH$=20%$NaOCH_3$=0.5%, Reaction Temperature 60°c).

### *4.2. Properties of Neat Diesel Fuel and Biodiesel Mixtures.*

Performance of CI engine greatly depends upon the properties of fuel, among which viscosity, density, cetane number, volatility, lubricity, calorific value, etc are very important. In this work the effect of temperature on viscosity with neat diesel fuel and different biodiesel mixtures have been investigated.
Viscosity and other properties of neat diesel fuel and CSOME were determined by the authors and shown in Table 2. Regarding volatility, there are no direct volatility data for bio-diesel, but it can be explained with the help of distillation temperature. Since diesel fuel (90% = 326°C, table 2) has lower distillation temperature than that of biodiesel (90% = 361°C, table 2), neat biodiesel has low volatility.

### *4.2.1. Viscosity as a Function of Temperature*

One of the major interests of this work is bio-diesel viscosity. Viscosity plays an important role of diesel combustion and exhaust emissions. Figure 6 Shows the variation of absolute viscosity of diesel and different bio-diesel mixtures with respect to temperatures. It is clear from the figure that absolute viscosities of neat diesel fuel and different bio-diesel mixtures decrease with increased temperature and vise versa. By increasing the temperature of the fluid, the inter molecular attraction between different layers of the fluid decreases, thus viscosity decreases.

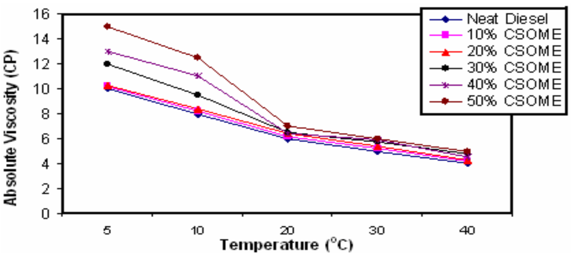



Figure 6. Variation of Absolute Viscosity of different Diesel-Biodiesel blends with respect to Temprature.

The figure also indicates that viscosity increases with the increase of bio-diesel percentages. For proper functioning of the engine, it is necessary to reduce the viscosity of a fuel. Fuel with relatively higher viscosity will not break into fine particles when sprayed. Large particles will burn slowly resulting in poor engine performance. On the other hand, if the viscosity is too low, the fuel will not lubricate the moving parts of the injection pump and injection nozzle. This causes rapid wear of those parts. For operating, a temperature range of 20-40°C up to B50 (50% CSOME) can be effectively used. For temperature range below 20°C, it is necessary to keep the bio-diesel percentages as low as possible.

Table 2. Properties of neat diesel fuel and CSOME.

| Properties | Neat diesel fuel | CSOME | ASTM Method |
|---|---|---|---|
| Chemical formula | $C_{14.09}H_{24.78}$ | $C_{54}H_{101}O_6$ | - |
| Kinematic viscosity ($mm^2/s$) at 40°C | 3.8 | 6.1 | D445 |
| Density ($kg/m^3$) at15°C | 836 | 848 | D 1298 |
| Higher calorific value (KJ/Kg) | 43,850 | 40,610 | D 5865 |
| Flash point (° C) | 55 | 200 | - |
| Cetane number | 49 | 53 | D613 |
| Cloud point (° C) | -20 | -2 | D2500 |
| Pour point (° C) | -24 | -5 | D97 |
| Carbon mass (wt %) | 84.6 | 76.0 | D3176 |
| Hydrogen (wt %) | 12.8 | 11.9 | D3176 |
| Oxygen (wt %) | 0.00 | 10.36 | D3176 |
| C/H ratio | 6.32 | 6.11 | D3176 |
| Sulfur (wt %) | 0.038 | <0.004 | D3176 |
| Distillation (° C) | - | - | D86 |
| 10% | 225 | 238 | - |
| 50% | 268 | 290 | - |
| 90% | 326 | 361 | - |

### *4.3. Optimization of Engine Speed*

Figure 7. shows the brake thermal efficiency (BTE) with neat diesel fuel at different engine speeds. To optimize the engine speed, BTE versus engine speed curve has been drawn. The BTE is defined as the actual brake work per cycle divided by the amount of fuel chemical energy as indicated by the lower heating

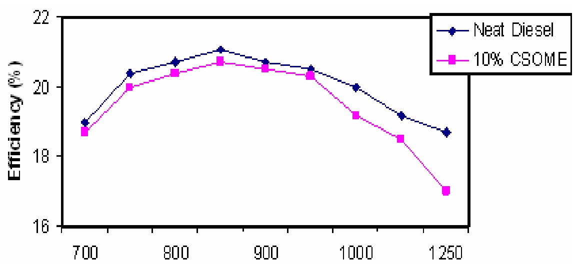
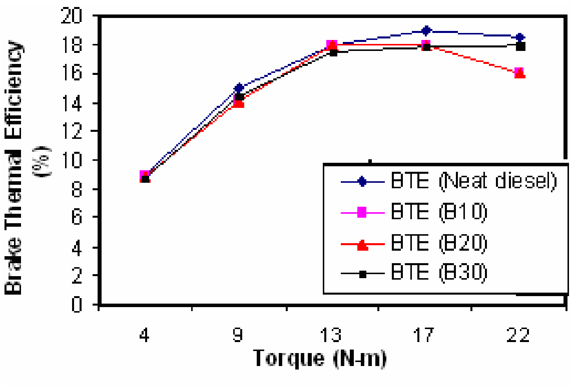


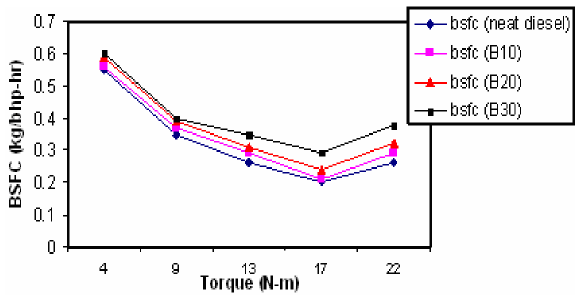

Figure 7. Effect of Engine Speed on Brake Thermal Efficiency (Load = 49N).

value of fuel. As can be seen in the figure, with the increase in engine speed up to 850 rpm, the BTE increases. This was due to the fact that with the increase in engine speed, the output power of the engine increases. As power increases, the engine BTE increases as well. The BTE of the engine decreases when the engine was run at a speed above 850 rpm.

*4.3.1. Brake Thermal Efficiency and Brake Specific Fuel Consumption.*




(a)




(b)

Figure 8. (a) Effect of Engine Torque on Brake Thermal Efficiency (Engine speed 850rpm), (b) Effect of Engine Torque on Brake Specific Fuel Consumption (Engine speed 850rpm).

Figure 8 (a) and (b). Illustrate the variation of BTE and brake specific fuel consumption (BSFC) with engine torque using neat diesel fuel and bio-diesel mixtures. Figure8-a. shows that the efficiency increases with the increase in engine torque and, after reaching maximum value, efficiency decreases with the increase of torque. On the other hand, according to Figure8-b., BSFC decreases with the increase in engine torque and becomes minimum and then increases again. It can be seen from the figure that in case of biodiesel mixtures, the BSFC values were determined to be higher than those of neat diesel fuel, and thus more biodiesel mixtures were required for the maintenance of a constant power output. It is well known that BSFC is inversely proportional with the BTE. From the figure, it was learned that BTE with biodiesel mixtures was little lower than that of neat diesel fuel. The slight reduction of BTE with biodiesel mixtures was attributed to poor spray characteristics, poor air fuel mixing, higher viscosity, higher volatility and lower calorific value.

*4.4. Exhaust Emissions with Neat Diesel Fuel and Biodiesel Mixtures.*

*4.4.1. CO Emissions.*

Figure 9. Shows the CO emissions of the neat diesel fuel and the biodiesel mixtures. CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to $CO_2$. If the combustion is incomplete due to shortage of air or due to low gas temperature, CO will be formed. Usually high diesel CO emissions are formed with fuel-rich mixtures, but as diesel combustion is occurred with lean mixture and has an abundant amount of air, CO from diesel combustions is low. The comparative analysis of CO is shown in Figure9. For bio-diesel mixtures CO emission was lower than that of diesel fuel, because biodiesel mixture contains some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to $CO_2$. Compared to neat diesel fuel, 30% bio-diesel mixtures reduced CO emissions by 24%.

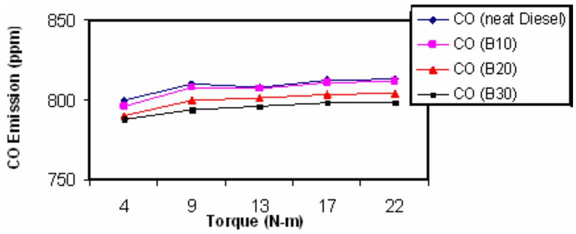



Figure 9. Variation of CO emission with Engine Torque for Neat Diesel and Bio-Diesel Mixture (engine speed 850rpm).

*4.4.2. $No_x$ Emissions.*

Figure 10. shows the effect of engine torque on $NO_x$ emission. Naturally $NO_x$ emission increases with the increase in engine torque. It is well known that nitrogen is an inert gas, but it remains inert up to a certain temperature (1100°C) and above this level it does not remain inert and it participates in chemical reaction. At the end of the combustion, gas temperature inside cylinder arises around 1500°C. At this temperature oxidation of nitrogen takes place in presence of oxygen inside the cylinder. On the other hand, since the formation of nitrogen oxides do not attain chemical equilibrium reaction, then after the end of expansion stroke when the burned gases cool and the formation of $NO_x$ freeze, the concentration of the formed $NO_x$ in the exhaust gas remain unchanged. Figure10. also shows that $NO_x$ level was higher for biodiesel mixtures than conventional diesel fuel at the same engine torque. This occurs due to the presence of extra oxygen in the molecules of Bio-diesel mixtures. This additional oxygen was responsible for extra $NO_x$ emission. Approximately 10% increase in $NO_x$ emission was realized with 30% biodiesel mixtures. Reduction of $NO_x$ with biodiesel may be possible with the proper adjustment of injection timing and the introduction to exhaust gas recirculation. (EGR).

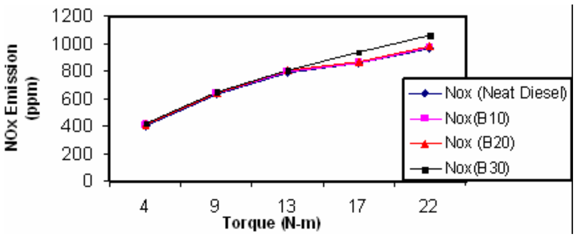



Figure 10. Variation of NOx emission with Engine Torque for Neat Diesel and Bio-Diesel Mixture (engine speed 850 rpm).

*4.4.3. PM Emissions.*

Figure 11. Shows the PM emission with neat diesel fuel and 20% biodiesel mixtures. The primary reason of the particulate emission from CI engine is improper combustion and combustion of heavy lubricating oil. Diesel PM (some times also called diesel exhaust particles (DEP)), is the particulate component of diesel exhaust, which includes diesel soot and aerosols such as ash particulates, metallic abrasion particles, sulfates, and silicates. When released into the atmosphere, PM can take the form of individual particles. In this experiment, PM was measured by

filter cloth method. It was found that particulate emission with 20% biodiesel mixture was lower than that of neat diesel fuel because neat biodiesel contains 10-12% extra oxygen, which resulted in better combustion, lowers PM emission. With 20% biodiesel mixtures, PM emission was reduced by 24% compared with neat diesel fuel.

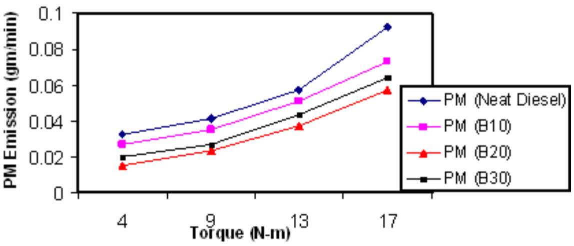



Figure 11. Variation of Particulate Matter Emission with Torque (engine speed 850 rpm).

*4.4.4. Smoke Emission.*

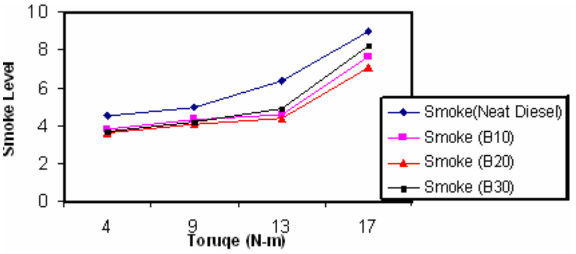



Figure 12. Variation of Smoke Emission with Torque (Engine Speed 850rpm).

The variation of smoke emission with engine torque for neat diesel fuel and 10% mixture was shown in Figure12. For 10% biodiesel mixtures, smoke emission was less, compared to neat diesel fuel. The maximum reduction of smoke emission with 10% biodiesel mixtures was observed by 14%. Because of the heterogeneous nature of diesel combustion, fuel-air ratio, which affects smoke formation, tends to vary within the cylinder of a diesel engine. Smoke formation occurs primarily in the fuel-rich zone of the cylinder, at high temperatures and pressures. If the applied fuel is partially oxygenated, locally over-rich regions can be reduced and primary smoke formation can be limited.

## 5. Conclusions

Cottonseed oil methyl ester (CSOME) was produced by means of transerterification process using cottonseed oil, which can be described as a renewable energy sources. The viscosity of CSOME was reduced by preheating it before supplying it to the test engine. After the fuel properties of CSOME have been determined, various performance parameters and exhaust emission of the engine were investigated and compared with those of diesel fuel. The experimental conclusions of this investigation can be summarized as follows.

- Kinematics viscosity and flash point of CSOME are higher than those of diesel fuel.
- A maximum of 76% BD production was found at 20% methanol and 0.5% $NaOCH_3$ at $55^0$C reaction temperature.
- Thermal efficiency with biodiesel mixtures was slightly lower than that of neat diesel fuel due to lower heating value of the mixtures. However, volatility, higher viscosity, higher density may be additional reasons for efficiency reduction with biodiesel mixtures.
- Biodiesel mixtures showed less CO, PM, smoke emission than those of neat diesel fuel.
- NOx emission with biodiesel mixtures showed higher values when compared with neat diesel fuel.
- Compared to the neat diesel fuel, 10% BD mixtures reduced PM, smoke emission by 24% and 14% respectively.
- Biodiesel mixtures (30%) reduced CO emission by 24%, while10% increase in the NOx emission was experienced with the same blend. The reason for reducing three emissions (PM, smoke and CO) and increasing NOx emission with biodiesel mixtures was mainly due to the presence of oxygen in their molecular structure. Also low aromatics in the biodiesel mixtures may be an additional reason for reducing these emissions.

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