“EXPERIMENTAL STUDY OF PERFORMANCE-EMISSION CHARACTERISTICS OF CI ENGINE FUELED WITH COTTON SEED OIL METHYL ESTER BIODIESEL AND OPTIMIZATION OF ENGINE OPERATING PARAMETERS”

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ABSTRACT

Nowadays biomass derived fuels are preferred as alternative fuels for IC engines due to its abundant availability, environmental friendly and renewable nature. The objective of the present work is to investigate the performance – emission characteristics of diesel engine fueled with cotton seed oil methyl ester (CSOME) as a potential substitute fuel. In the present work, experiments were conducted on 5.2 KW(7 HP) single cylinder, four stroke, water cooled, direct injection, naturally aspirated diesel engine by using fuels like diesel, biodiesel and their blends. The experimental investigation revealed that the optimized operating parameters for cotton seed oil methyl ester (CSOME) are 19° bTDC start of injection, 230 bar injection opening pressure, 17.5 compression ratio and 4 hole nozzle geometry of Ø = 0.3 mm. Thermal efficiency for optimized parameters was ~17.7% higher than the baseline operating parameters of engine at full load condition. The hydrocarbon and carbon monoxide emission were showed decreasing trend while NOx emission are significantly increased depending on biodiesel concentration in the fuel. Hence it is recommended to use BD 20 CSOME as substitute fuel with optimized operating parameters like 19° bTDC start of injection, 230 bar injection opening pressure and 4 hole nozzle geometry of Ø = 0.3 mm for optimum performance-emission characteristics of diesel engine.

Keywords: Biomass, cotton seed oil methyl ester, performance, emission, optimum.

INTRODUCTION

One prominent key on liquid fuel was given by Rudolf Diesel. He used peanut oil as fuel for demonstration on CI Engine, and suggested it as an alternative fuel option. However, he quoted very true predicting fact as, “the use of vegetable oil for engine fuels may seem
insignificant today. But such oils may become, in course of time, as important as petroleum and the coal tar products of the present time”- Rudolf Diesel, 1912. After eight decades, the awareness about environment rose among the people to search for an alternative fuel that could burn with less pollution. Rudolf Diesel’s prediction is becoming true today with more and more bio-diesel being used all over the world[1]. ASTM D6751 definition of biodiesel states that biodiesel is composed of mono-alkyl esters of long chain fatty acids, oxygenated fuel derived from plant oils or animal fats. The term mono-alkyl ester indicates that biodiesel contains only one esters linkage in each molecule. Biodiesel is a clean burning alternative fuel, produced from domestic, renewable resources. It can be used in CI Engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics. However, biodiesel minimizes CO, HC, and CO2 to large extent but increases NOx and PM because of presence of more O2 molecules. Use of biodiesel can extend life of CI Engine because it is more lubricating and energy secure source than petroleum diesel fuel. Owing to this, bio-diesel with NOx emission reduction techniques in CI Engine will not only solve energy crises but also bring vital revolution in CI Engine development. [2] Sing S. P., et al., (2010) [3], Murugesan A., et al., (2009) [4] have put forth exhaustive review of biodiesel as an alternative to diesel. Also, mentioned biodiesel merits, demerits, government polices etc. They reported that the major difference between diesel fuel and vegetable oil included, for the later, the significantly higher viscosities and moderately higher densities, lower heating values, rise in the stoichiometric fuel/air ratio due to the presence of molecular oxygen and the possibility of thermal cracking at the temperatures encountered by the fuel spray in the naturally aspirated diesel engines. These differences contribute to the poor atomization, coking tendencies, carbon deposition and wear that generally experienced and which adversely affect the durability of the engine. Banapurmath N. R. and Tiwari P. G., (2010) [5] investigated characteristics of a single cylinder CI Engines operated on ethanol-biodiesel blends. The break thermal efficiency values at all injection timing were lower for biodiesel, and biodiesel ethanol blends than diesel fuel. The decrease in break thermal efficiency for Hong oil methyl ester (HOME) and Jathropa oil methyl ester (JOME) were might be due to lower energy content of fuel, and higher viscosity of biodiesel (HOME/JOME). The ethanol blend with 15% ethanol shows better performance than 5% or 10% ethanol. The blended fuel with ethanol showed better performance compared to neat biodiesel of JOME operation. Ethanol not only reduces petroleum/oil consumption in diesel engine but also increases oxygen content for alternative fuel. Ethanol has some obstacles to overcome such as separation of ethanol in diesel/biodiesel blends when blending ratio exceeds than 10%. In addition, it has corrosive effect on engine mechanical component as well as on rubber material of fuel pipe may cause jamming of fuel flow.

MATERIALS AND METHODS

- **Cotton Seed Oil Methyl Ester**

India is the fifth largest cotton producing country in the world today, the first-four being the U.S, china, Russia and Brazil. Our country produces about 8% of the world cotton. Cotton is a tropical plant. Cottonseed oil is a vegetable oil extracted from the seeds of the cotton. After being freed from the linters, the seeds are shelled and then crushed and pressed or treated with solvents to obtain the crude cotton seed oil. Cotton seed oil is one of the most widely available oils and it is relatively inexpensive. Different parameters for the optimization of biodiesel production were investigated and suggested that a maximum of 77% biodiesel was
produced with 20% methanol in presence of 0.5% sodium hydroxide [8]. Fuels are used in the single mode of operation includes of diesel, cotton oil methyl ester and its blend with diesel. Biodiesel-diesel blend was done on percent volume basis of diesel and biodiesel for net unit volume. The combinations of blends studied were very in logical manner selected i.e. biodiesel (BD) 10%, 20%, 40% and 80%. Whereas the number signifies, percent volume of biodiesel in diesel fuel at unit volume.

<table>
<thead>
<tr>
<th>Sr.</th>
<th>Property</th>
<th>Units</th>
<th>Diesel</th>
<th>COME</th>
<th>COME</th>
<th>COME</th>
<th>COME</th>
<th>COME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density at 15 °C</td>
<td>Kg/m³</td>
<td>832</td>
<td>834</td>
<td>835</td>
<td>839</td>
<td>845</td>
<td>848</td>
</tr>
<tr>
<td>2</td>
<td>Kinematic viscosity at 40 °C</td>
<td>Cst. or mm²/sec</td>
<td>4.78</td>
<td>4.89</td>
<td>5.0</td>
<td>5.24</td>
<td>5.7</td>
<td>5.92</td>
</tr>
<tr>
<td>3</td>
<td>Calorific value at 40 °C</td>
<td>kJ/kg</td>
<td>42.496</td>
<td>39858</td>
<td>39.355</td>
<td>39979</td>
<td>38610</td>
<td>38.050</td>
</tr>
<tr>
<td>4</td>
<td>Flash point</td>
<td>°C</td>
<td>53</td>
<td>68</td>
<td>80</td>
<td>90</td>
<td>120</td>
<td>167</td>
</tr>
<tr>
<td>5</td>
<td>Fire point</td>
<td>°C</td>
<td>58</td>
<td>72</td>
<td>86</td>
<td>97</td>
<td>127</td>
<td>178</td>
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<td>6</td>
<td>Cloud point</td>
<td>°C</td>
<td>-2</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>7</td>
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<td>7</td>
<td>Pour point</td>
<td>°C</td>
<td>-5</td>
<td>-2</td>
<td>-1</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Carbon residue</td>
<td>% mass</td>
<td>0.01</td>
<td>---</td>
<td>---</td>
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<td>0.016</td>
</tr>
</tbody>
</table>

**Table 1.1 Properties of fuel studied**

**EXPERIMENTAL SET-UP AND METHODOLOGY**

The engine selected for conducting tests is Kirloskar TV1, four-stroke, single-cylinder, water-cooled, naturally aspirated, DI (open chamber), diesel engine. Eddy current dynamometer has been used for loading the engine. The engine setup is checked for proper connections. Then the engine is started and run the engine at 1500 rated RPM for 17.5:1 compression ratio. Moreover, all tests were conducted and parameters were measured under steady state operation. Optimization of CI Engine parameters for cotton oil methyl ester (COME) biodiesel was done experimentally by conducting series of tests on experimental set-up shown in Fig.1 and 2. Initially engine was operated at various engine operating parameters such as SOI, IOP, nozzle holes etc.

<table>
<thead>
<tr>
<th>Sr.</th>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CR &amp; Speed</td>
<td>17.5:1 @ 1500 rpm.</td>
</tr>
<tr>
<td>2</td>
<td>SOI</td>
<td>19⁰ bTDC (COME) &amp; 23⁰ bTDC (Diesel &amp; 20% COME)</td>
</tr>
<tr>
<td>3</td>
<td>IOP</td>
<td>230 bar (COME) &amp; 205 bar (20% COME &amp; Diesel)</td>
</tr>
<tr>
<td>4</td>
<td>Nozzle hole &amp; dia.</td>
<td>4 hole nozzle (100% COME), 3 hole nozzle (20% COME &amp; Diesel); Ø = 0.3 mm (all nozzles)</td>
</tr>
<tr>
<td>5</td>
<td>Fuel studied</td>
<td>100 % COME, 20% COME, Diesel</td>
</tr>
<tr>
<td>6</td>
<td>Load</td>
<td>Zero to full load (0 to 12.6 kg) in steps of 20%</td>
</tr>
</tbody>
</table>

**Table: 1.2 Operating parameter & test conditions**
RESULTS AND DISCUSSION

1. EFFECT OF VARYING INJECTION TIMING ON ENGINE PERFORMANCE & EMISSIONS CHARACTERISTICS

1.1 Brake thermal efficiency (BTE)

Influence of varying injection timing (19° to 27° in step of 4°) on BTE has been shown in Fig. 1.1 with 100% COME. The rise in BTE of 9% was noticed with retarded injection timing. Due to retarded injection timing (19° bTDC) with biodiesel delay period was decreased; hence, combustion phase may be shifted away from TDC. Also, heat release rate may be increased due to improved combustion. Thus, retarded injection may show improved pre-mixed and rapid consumption which was responsible for increase in thermal efficiency. The need of retarded injection with biodiesel may be due to its higher viscosity and density. Consequently higher viscosity, density and lower heating value of biodiesel were responsible for lower BTE compared to diesel at all injection timings studied.
1.2 Brake specific fuel consumption (BSFC)

Influence of load and injection timing on BSFC is represented in Fig. 1.2. Brake specific fuel consumption (0.29 kg/kWh) was lower with diesel compared to biodiesel. This trend is observed with all types of biodiesel. The reason may be attributed to higher calorific value and volatility (flash point) compared to biodiesel. However, with biodiesel, at 27° bTDC injection timing, higher BSFC (0.49 kg/kWh) was observed. This may be due to increase in delay period with injection advance [4]. Also, at 19° bTDC injection timing and full load operation, lowest BSFC of 0.44 kg/kWh were observed. Retarded injection showed lower fuel consumptions compared to advancing at all loads. Decrease in delay period improves combustion quality due to proper mixing of air-fuel.

![Fig. 1.2 Effect of injection timing on brake specific fuel consumption](image1)

1.3 Exhaust gas temperature (EGT)

Fig. 4.3 shows that exhaust gas temperature increases with increase in load at all injection timing with biodiesel and diesel. It was found that, exhaust gas temperature (EGT) was higher for advanced injection timing with biodiesel. This may be due to increase in delay period which delays combustion process. As a consequence, there is increase in NO emission with small drop in efficiency. It was noticed from Fig. 1.3 at full load operations with 100% COME biodiesel, higher EGT 458 °C at advanced injection timing of 27° bTDC followed by 23° and 19° bTDC EGT 443 °C and 429 °C respectively. Further, the lowest EGT of 412 °C was observed with diesel.

![Fig. 1.3 Effect of injection timing on exhaust gas temperature](image2)
1.4 NO emission

Oxidation of nitrogen (NO) soars at peak combustion temperature. Effect of varying injection timing on NO emission is as showed in Fig. 1.4. Generally, retarded injection results in substantial reduction in NO emission. When the injection timing was retarded, reduction in delay period was observed. This may be due to higher peak pressure and temperature of compressed air at retarded injection. The number signifies that, NO emission was increased with increase in load. Also, NO emission, 601 ppm was found to be higher with diesel at full load. Due to standard operating condition for IOP at 205 bars with diesel may be sufficient, whereas same may be not enough with biodiesel. However, lower NO emission 478 ppm was found at 100% COME biodiesel with retarded injection timing of 19° bTDC.

Fig. 1.4 Effect of varying injection timing on NO emission

1.5 HC & CO emission

HC and CO emission due to varying injection timing are shown in Figs. 1.5 and 1.6 respectively. HC emission in CI Engines was caused due to lean mixture during delay period and under mixing of fuel leaving fuel injector nozzle at lower velocity. General trend of increased HC and CO emission was observed for all injection timings compared to diesel fuel. This may be attributed to decreased combustion efficiency resulting from poor spray characteristic and heat release rate of biodiesel. We know that, CO emission is a toxic by product and a clear indication of incomplete combustion of the pre-mixed mixture. The amount of CO emission was decreases at part load and increased at higher load for all injection timing operation. The lowest CO emission 0.16 % vol. was noticed at part load application with diesel fuel compared to other operations with biodiesel. However, higher CO 0.71 % vol. was observed at full load operation with biodiesel at advanced injection timing.

Fig. 1.5 Effect of varying injection timing on HC emission
2. EFFECT OF VARYING INJECTION OPENING PRESSURE (IOP) AND NOZZLE HOLE GEOMETRY ON ENGINE PERFORMANCE & EMISSIONS CHARACTERISTICS

2.1 Brake thermal efficiency (BTE)

Effect of nozzle hole geometry for nozzle hole, 3, 4, and 5 on brake thermal efficiency is as shown in Figs. 2.1.1-2.1.3 respectively. It was found that, nozzle hole geometry has significant influences on droplet size penetration (spray penetration). From Figs 2.1.1-2.1.3 at corresponding IOP say 210 bar, it was noticed that, rise in thermal efficiency with increase in nozzle hole. This was due to; increase in nozzle hole was responsible to rise in air fuel mixing, fuel vaporization and improved combustion and heat release rate. Thus, in view of this BTE rises with number of hole. However, more nozzle hole will lead to over penetration gives impingement of liquid fuel on cool surfaces (wall) leaving incomplete combustion and lower thermal efficiency. From the Figs. 2.1.2 below, it was observed that BTE 25.96% and 24.9% was higher at 4H nozzle, 230 bar IOP, and 100% and 80% load respectively. Increase in IOP has promising influence on engine characteristics. Figs. 2.1.1-2.1.3 showed that, for fixed hole operation say 4H, with increase in IOP from 210 bars to 230 bar thermal efficiency was increased from 22.7% to 25.96% at full load operation. The possible reason may be stated as, increase in IOP leads to better atomization of fuel, improved spray characteristics and reduced physical delay period; which improved premixed combustion and rapid combustion rate. Owing to this, increase in brake thermal efficiency was observed. However too high IOP will lead to delayed injection, negating gain due to high IOP. Also, too high IOP may responsible to higher velocity of droplet which will pass away without mixing air properly and lower thermal efficiency due to improper combustion. One notable point was observed that BTE 28.88% with diesel was highest compared to biodiesel.
Fig. 2.1.1 Effect of brake thermal efficiency on 3-hole nozzle with varying pressure

Fig. 2.1.2 Effect of brake thermal efficiency on 4-hole nozzle with varying pressure

Fig. 2.1.3 Effect of brake thermal efficiency on 5-hole nozzle with varying pressure
2.2 NO emission

Effect of nozzle hole geometry and injector opening pressure on NO emission as shown in Figs., 2.2.1-2.2.3. NO emission is result of oxidation of nitrogen at peak combustion temperature. At any nozzle hole operation with increase in IOP, NO emission was found to be increasing. This may be attributed to better atomization and improved mixing rate of fuel responsible to reduce delay period, and combustion duration, corollary it results in improved heat release rate, peak combustion and temperature. It was also noticed that, with increase in IOP, for 4H nozzle NO emission with biodiesel was higher than diesel fuel. Reason may be justified as, with increase in IOP produces faster combustion and higher temperature in cycle. Also, biodiesels are oxygenated fuel. This brings more or rapid oxidation of nitrogen at peak temperature.

![Fig. 2.2.1 Effect of NO emission on 3 hole nozzle and varying injection opening pressure](image)

![Fig. 2.2.2 Effect of NO emission on 4 hole nozzle and varying injection opening pressure](image)
NO emission for 3H and 4H nozzle, at 80% load and lower IOP 210 bar, was 472 ppm and 521 ppm, lower among all NO emission. This may be due to lower combustion phase and incomplete combustion caused by poor atomization, sprays characteristics and increased ignition delay.

2.3 HC emission

We know that, HC emission is caused due to low velocity of fuel which is not sufficient to penetrate air spray and induced improper air-fuel mixing or lower equivalence ratio (Ø). Also, more emission is found due to lack of fuel atomization or vaporization. As cited in Figs.2.3.1-2.3.3, for all nozzle hole operation HC emission was decreased with increase in IOP. The decrease in HC emission ~16% was promising outcome of increasing IOP with addition of gain in BTE. Diesel fuel operation showed lowest HC emission compared to biodiesel under all operation. With biodiesel as higher viscosity and density are responsible to undergo for less atomization, fuel velocity and vaporization compared to diesel. Thus, leaving the fuel unburned during combustion.
In general, HC emission 79 ppm was found to be lowest at 4H nozzle, 230 bar IOP. This was credited to large pressure difference across injection nozzle geometry was required to enter injected liquid jet to combustion chamber at high velocity to atomize into small sized droplets to enable rapid evaporation and travel chamber in time available and fully utilize air charge. As shown in Fig. 4.15 percent decrease in HC emission was 12.2% at full load operation for increase in IOP from 210 bars to 230 bars.

![Fig. 2.3.2 Effect of HC emission on 4 hole nozzle and varying injection opening pressure](image1)

![Fig. 2.3.3 Effect of HC emission on 5 hole nozzle and varying injection opening pressure](image2)
2.4 CO emission

As we know CO emission is nothing but behavior of incomplete combustions due to rich air-fuel mixture. Thus, due to increase in load from 80% to 100% CO emission for all tests was found to be increased. In addition, CO emission was found to be decreased with increase in nozzle hole and IOP. This adds merits of increasing IOP and nozzle hole upto certain limit. Further, as expected CO emission was lowest 0.1 % vol at 80% load with diesel fuel. As diesel fuel is highly volatile, less viscous and dense compared to biodiesel. Beside, biodiesel are oxygenated fuel, premixed combustion and rapid combustion are eventually lower compared to diesel. Higher viscosity and density of biodiesel lower vaporization and air mixing rate cause to rich fuel air mixing zones in chamber. This is responsible to higher CO emission.

![Fig. 2.4.1 Effect of CO emission on 3 hole nozzle and varying injection opening pressure](image1)

![Fig. 2.4.2 Effect of CO emission on 4 hole nozzle and varying injection opening pressure](image2)
The lowest CO emission was found at 220 bars for 5H nozzle as shown in Fig 4.19. This is so because, for 5H nozzle it seems 220 bars pressure was sufficient for proper combustion phase and maximum heat release rate. Beyond this to both sides will lead to produce higher CO emission.

![Graph showing CO emission vs Injection Opening Pressure](image)

Fig. 2.4.3 Effect of CO emission on 5 hole nozzle and varying injection opening pressure

Hence, it is recommended from performance and emissions characteristics of CI Engine using 100% COME with varying IOP and nozzle hole study that, 4H nozzle and 230 bar IOP @ 19° bTDC showed optimum results.

3. EFFECT OF CSOME BIODIESEL BLENDS ON ENGINE PERFORMANCE & EMISSIONS CHARACTERISTICS

3.1 Brake thermal efficiency (BTE)

The BTE 25.96% with biodiesel operated engine was lowest compared to diesel BTE 28.88% at full load operation as seen from Fig. 3.1.1. This trend may be attributed to low volatility, high viscosity and density responsible for shorter combustion phase, lower heat release rate, and peak pressure. Thus, thermal efficiency was found to be 10% less with biodiesel compared to diesel mode operation. Rise in diesel content within biodiesel by volume i.e. from BD80 to BD10 (rise in diesel value) it was noticed that, thermal efficiency increases consistently. In addition, BD20 showed instinct in raised performance. The BTE was found to be 28.0% which was very closer to diesel mode operation. The decrease in BTE with BD20 was very low to ~3% compared to diesel fuel. Whereas percent rise in BTE 8% with BD20, was promising outcome concerned to reference fuel (BD100 COME).
3.2 Exhaust gas temperature

As expected exhaust gas for raise in biodiesel blend showed higher value due to increased ignition delay and combustion duration reduced peak combustion temperature but, increased after burning phase. Exhaust gas temperature 440 °C was found highest at full load and biodiesel application, compared to diesel 412 °C EGT. This may be due to biodiesel as oxygenated fuel may show longer after burning of fuel. Owing to this EGT and NO emission are increased with biodiesel.
3.3 NO emission

NO emission is cause of oxidation of nitrogen at higher temperature. Owing to this, and as seen from Fig. 3.3 biodiesel BD 100 showed higher NO emission according to increasing load. Also, addition of diesel reduces oxygen from fuel and increases combustion duration. As, diesel has higher ignition delay owing to smaller cetane number compared to biodiesel, diesel operation showed lower NO emission due to longer duration, and very small after combustion or re-burning phase hence lower exhaust gas temperature causing lower NO emission. NO emission 842 ppm was highest at full load biodiesel operation followed by higher biodiesel blends. In addition, NO emission with diesel and BD20 fuel were almost closer except at full load. This is so, due to combustions characteristics with BD20 and diesel may be closer.

![Fig. 3.3 Effect of Blends on NO emission](image)

3.4 HC emission

HC emission is significance of incomplete combustion of operation. As seen from Fig. 3.4 HC emission with biodiesel is more due to high viscosity and density of fuel. Also, HC emission for BD 20 and BD10 are showing trends, very closer HC emission to diesel fuel. This may be attributed to complete combustion of oxygenated biodiesel fuel. HC emission was found to be increase with rise ignition delay and less IOP with biodiesel. Hence at higher blends of biodiesel trends are showing rise in HC emission. For 100% COME biodiesel at full load highest HC emission was observed to be 83 ppm.
3.5 CO emission

CO emission for blends shows similar trends as seen for HC emission. However, biodiesel blend at BD20, CO emission were very close to emission at diesel mode operation. This lower may be distinguished due to oxygenated fuel of biodiesel and higher volatile, less viscous diesel fuel formed good mixture for combustion.
A CO emission 0.39% vol. for BD 100 was observed to maximum. This may be described because of ignition delay, less atomization and poor spray lead to rich fuel mixture. In view of this, fuel droplet velocity was lower which could not impede air velocity properly and failed to higher air mixing rate. Thus, rich zones in chamber increase CO with rise in biodiesel blends.

**CONCLUSIONS**

- **Properties of Biodiesel**
  It was found that the properties of cotton oil methyl esters (COME) biodiesel were closer to the specifications of biodiesel given in ASTM standard D6751-06. The heating value of reference biodiesel cotton oil methyl ester (COME) biodiesel was 10.4% lower compared to diesel. In addition, kinematic viscosity 5.96 Cst was found to be marginally higher but within acceptable limit of 2-6 Cst. Thus, in developing nations CSO is available in ample quantity, if it is processed as per the fuel requirements in mass production then there is a chance for reducing its overall cost. Then it will become a renewable source of energy in the case of diesel fuel scarcity.

- **Optimization of Injection Timing**
  It is concluded that CI Engine operating on 100% CSOME, it was observed that retarded injection timing of 19° bTDC gives better performance and emission characteristics. This may be attributed to lower ignition delay of biodiesel which results in higher value of cetane number. At 19° bTDC retarded injection timing, BTE was observed to be 21.4% compared to 19.3% at 27° bTDC at full load operation. Moreover, HC, CO, & NO emission were observed lower for retarded injection timing owing to reduced ignition delay period, complete combustions. Thus, 19° bTDC retarded injection timing for cotton oil methyl ester is optimum.

- **Optimization of injection opening pressure and number of holes on nozzle**
  It is concluded that CI Engine operating on biodiesel with 4-hole nozzle and 230 bar IOP, has given highest value of BTE of 25.96% at full load condition due to improved atomization and better spray characteristics. However, HC and CO emission were showed decreasing trend with increase in IOP and nozzle holes compared to baseline parameters 19° bTDC, 205 bar IOP and 3H nozzle at full load. Besides, significant NO penalty from 478 ppm to 842 ppm (~43% rise) for biodiesel was noticed with respect to baseline parameters.

- **Optimization of CSOME with % blends**
  While conducting the tests to optimize for optimum percentage of blend, it was noticed that BD20 has shown best results. With increase in % of biodiesel in blend thermal efficiency was decreased compared to diesel under same operating conditions. The hydrocarbon and carbon monoxide emission were showed decreasing trend while NOx emission are significantly increased depending on biodiesel concentration in the fuel.

Hence it is recommended to use BD 20 CSOME as substitute fuel with optimized operating parameters like 19° bTDC start of injection, 230 bar injection opening pressure and 4 hole nozzle geometry of Ø = 0.3 mm for optimum performance-emission characteristics of diesel engine.
Future Scope

- 1000 hrs durability tests may be conducted on diesel engines and the wear associated with the engine moving parts may be analyzed.
- Instead of modifying the existing engine, new designs of engines may be attempted keeping in mind comprehensive combustion optimization.
- The studies on future biodiesel and biodiesel – diesel blends fuels may be carried out in order to reduce its viscosity and NOx formation as well as improve spray characteristics of non-edible vegetable oils.

REFERENCES