# COMPARATIVE STUDIES ON PERFORMANCE PARAMETERS OF LINSEED OIL IN CRUDE FORM AND BIODIESEL FORM IN DIRECT INJECTION DIESEL ENGINE

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**ABSTRACT**

*Investigations were carried out to evaluate the performance parameters of a conventional diesel engine with different operating conditions [normal temperature and pre-heated temperature] of linseed oil in crude form and in biodiesel form with varied injection timing and injector opening pressure. Performance parameters [brake thermal efficiency, exhaust gas temperature, coolant load, sound levels and volumetric efficiency] were determined at various values of brake mean effective pressure of the engine fuelled with diesel, crude linseed oil and linseed oil based biodiesel. Comparative studies on performance were among diesel, crude vegetable oil and biodiesel operation on diesel engine with varied engine parameters. The performance of the engine improved with advanced injection timing and at higher injector opening pressure with test fuels. The optimum injection timing was 31$^o$bTDC with conventional engine with diesel and biodiesel operation, while with crude* vegetable oil, the optimum injection timing was found to be 32$^o$bTDC.

**KEY WORDS**: Need for Alternate Fuels, Vegetable Oil, Biodiesel, LHR combustion chamber, Performance.

## 1. Introduction

The paper is divided into i) Introduction, ii) Materials and Methods, iii) Results and Discussions, iv) Conclusions, Future scope of work, v) Acknowledgements followed by References.

Introduction deals with investigations carried out by researchers in the work related to the authors or brief literature review. .

This section deals with need for alternate fuels in diesel engine, problems with use of crude vegetable oil in diesel engine, advantages of use of preheated vegetable oil in diesel engine, use of biodiesel in diesel engine, effect of increase of injector opening pressure and advanced injection timing on the performance of the diesel engine, research gaps and objectives of the investigations.

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. The fuels of bio origin can provide a feasible solution of this worldwide petroleum crisis(1-2).

It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel and they are renewable and can be easily produced. Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil. Several researchers [3-6] experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. Experiments were conducted [7-10] on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel] and it was reported that preheated vegetable oils improved the performance marginally. The problems of crude vegetable oils can be solved, if these oils are chemically modified to bio-diesel.

Bio-diesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were carried out [11-15] with bio-diesel on direct injection diesel engine and reported performance was compatible with pure diesel operation on conventional engine.

By controlling the injector opening pressure and the injection rate, the spray cone angle is found [16] to depend on injector opening pressure. Few investigators [17-20] reported that injector opening pressure has a significance effect on the performance and formation of pollutants inside the direct injection diesel engine combustion. Venkanna et al.[20] used honne/diesel blend in DI diesel engine with increased injector opening pressure and increased injection rate and reported improved performance and emissions.

The other important engine variable to improve the performance of the engine is injection timing. Performance improved or deteriorated depending on whether injection timing was advanced (injection timing away from TDC) or retarded (injection timing towards TDC). Recommended injection timing was defined by the manufacturer that it is the timing at which maximum thermal efficiency was obtained with minimum pollution levels from the engine.

Investigations were carried out [21-24] on single cylinder water cooled vertical diesel engine with brake power 3.68 kW at a speed of 1500 rpm with varied injection timing from 27-34$^{o}$bTDC and it was reported that performance of the engine improved with advanced injection timing and increased NOx emissions and decreased smoke levels.

Sound levels determine the phenomena of combustion in engine whether the performance was improving or deteriorating. Studies were made [22-24] on sound levels with convention engine with vegetable oils and it was reported from the studies, that performance deteriorated with vegetable oil operation on conventional engine leading to produce high sound levels.

Little literature was available on comparative studies of crude linseed oil and linseed oil based biodiesel with diesel engine. Hence it was attempted here to evaluate the performance of the engine with crude linseed oil and biodiesel at different operating conditions with varied injection timing and injector opening pressure.

**2. Materials and Methods**

This section contains preparation of biodiesel, properties of biodiesel, description of the schematic diagram of experimental set up, specifications of experimental engine, specifications of sound analyzer, and definitions of used values.

The chemical conversion of esterification reduced viscosity four fold. Linseed oil contains up to 72.9 % (wt.) free fatty acids [25].The methyl ester was produced by chemically reacting the linseed oil with an alcohol (methyl), in the presence of a catalyst (KOH). A two-stage process was used for the esterification [26-28] of the waste fried vegetable oil. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in linseed oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. In the second stage (alkali-catalyzed), the triglyceride portion of the linseed oil reacts with methanol and base catalyst (sodium hydroxide-99% pure), in one hour time of reaction at 65°C, to form methyl ester and glycerol. To remove un-reacted methoxide present in raw methyl ester, it is purified by the process of water washing with air-bubbling. The methyl ester (or biodiesel) produced from linseed oil was known as linseed oil biodiesel (LSOBD). The physic-chemical properties of the crude linseed oil and biodiesel in comparison to ASTM biodiesel standards are presented in Table-1.

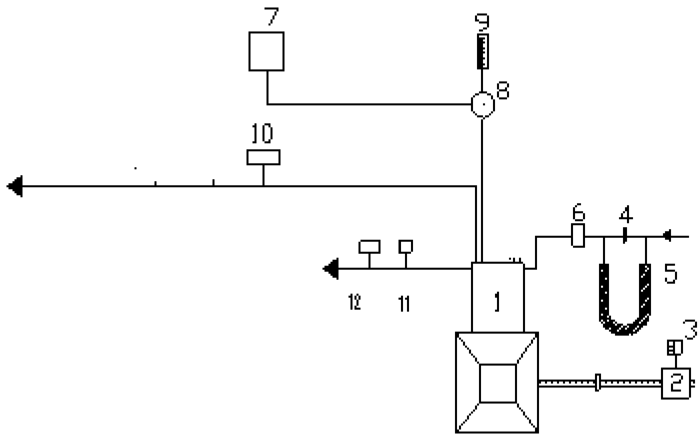
**Table.1. Properties of Test Fuels**

| Property | Units | Diesel | Crude Vegetable oil | Biodiesel | ASTM D 6751-02 |
|---|---|---|---|---|---|
| Carbon chain | -- | $C_8$-$C_{28}$ | $C_{12}$-$C_{20}$ | $C_{16}$-$C_{24}$ | $C_{12}$-$C_{22}$ |
| Cetane Number | | 55 | 48 | 55 | 48-70 |
| Density | gm/cc | 0.84 | 0.92 | 0.87 | 0.87-0.89 |
| Bulk modulus @ 20Mpa | Mpa | 1475 | 2100 | 1850 | NA |
| Kinematic viscosity @ 40$^o$C | cSt | 2.25 | 5.5 | 4.5 | 1.9-6.0 |
| Sulfur | % | 0.25 | 0.4 | 0.0 | 0.05 |
| Oxygen | % | 0.3 | 0.2 | 10 | 11 |
| Air fuel ratio ( stochiometric) | -- | 14.86 | 15.5 | 14.2 | 13.8 |
| Lower calorific value | kJ/kg | 42 000 | 38500 | 38000 | 37 518 |
| Flash point (Open cup) | $^o$C | 66 | 190 | 180 | 130 |
| Molecular weight | -- | 226 | 290 | 280 | 292 |
| Preheated temperature | $^o$C | -- | 85 | 60 | -- |
| Colour | -- | Light yellow | Dark yellow | Yellowish orange | --- |

The test fuels used in the experimentation were pure diesel, linseed oil based biodiesel and crude linseed oil. The schematic diagram of the experimental setup with test fuels is shown in Figure 1. The specifications of the experimental engine are shown in Table-2. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. Air-consumption of the engine was measured by an air-box method (Air box was provided with an orifice meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80$^o$C by adjusting the water flow rate. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan.

**Table.2. Specifications of the Test Engine**

| Description | Specification |
|---|---|
| Engine make and model | Kirloskar ( India) AV1 |
| Maximum power output at a speed of 1500 rpm | 3.68 kW |
| Number of cylinders ×cylinder position× stroke | One × Vertical position × four-stroke |
| Bore × stroke | 80 mm × 110 mm |
| Method of cooling | Water cooled |
| Rated speed ( constant) | 1500 rpm |
| Fuel injection system | In-line and direct injection |
| Compression ratio | 16:1 |
| BMEP @ 1500 rpm | 5.31 bar |
| Manufacturer's recommended injection timing and pressure | $27^o$bTDC × 190 bar |
| Dynamometer | Electrical dynamometer |
| Number of holes of injector and size | Three × 0.25 mm |
| Type of combustion chamber | Direct injection type |
| Fuel injection nozzle | Make: MICO-BOSCH<br>No- 0431-202-120/HB |
| Fuel injection pump | Make: BOSCH: NO- 8085587/1 |



1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice flow meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater, 9.Burette, 10. Exhaust gas temperature indicator, 11.Outlet jacket water temperature indicator, 12. Outlet-jacket water flow meter,

**Figure 1.Schematic Diagram of Experimental Set-up**

Sound intensity was measured with sound analyzer at full load operation of the engine. The specifications of the analyzers were given in Table-3.

**Table 3. Specifications of Analyzers**

| Name of the analyzer | Measuring Range | Precision | Resolution |
|---|---|---|---|
| Sound Analyzer | 0-150 Decibels | 1 decibel | 1 decibel |

Different operating conditions of the biodiesel and crude linseed oil were normal temperature and preheated temperature. Different injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27-34$^{o}$bTDC.

Few definitions of IC engine parameters:

Brake thermal efficiency (BTE); It is the ratio of brake power of the engine to the energy supplied to the engine. Brake power was measured with dynamometer. Energy supplied to the engine is the product of rate of fuel consumed ($m_f$)and calorific value ($c_v$)of the fuel. Higher the efficiency better the performance of the engine is.

$$BTE = \frac{BP}{m_{f \times cv}}$$

Brake specific energy consumption (BSEC): It is measured at full load operation of the engine. Lesser the value, the better the performance of the engine. It is defined as energy consumed by the engine in producing 1 kW brake power. When different fuels having different properties are tested in engine, brake specific fuel consumption is not the criteria to evaluate the performance of the engine. Full BTE and BSEC at full load are important parameters to be considered to evaluate the performance of the engine.

$$BSEC = \frac{1}{BTE}$$

Coolant load: Product of mass flow rate of coolant, specific heat of coolant, rise of temperature of the coolant between inlet conditions and outlet conditions.

Volumetric efficiency: It is the ratio of the volume of air drawn into a cylinder to the piston displacement.

Recommended injection timing: It is the injection timing of the engine with maximum efficiency of the engine with minimum pollution levels.

Calculation of actual discharge of air: By means of water tube manometer and an orifice flow meter, head of air ($h_a$) can be calculated. Velocity of air ($V_a$) can be calculated using the formula $V_a = \sqrt{2gh_a}$ ; Actual discharge of air = $c_d a\sqrt{2gh_a}$, where a= area of an orifice flow meter, $c_d$ = Coefficient of discharge.

### 3. Results and Discussion

Results and discussion were made in two parts such as 1. Determining optimum injection timing with CE with diesel, crude linseed oil and biodiesel, 2. Performance parameters with test fuels

### 3.1 Determination of optimum injection timing with CE with test fuels

From Figure.2, it is noticed that brake thermal efficiency with pure diesel operation increased up to 80% of the full load operation due to increase of fuel efficiency [16] and beyond that load it drops because of reduction of air fuel ratios [29] as oxygen was completely used up. Brake thermal efficiency increased with increase of advancing the injection timings in the diesel engine for entire range of the load, due to early initiation of combustion as delay period increased with advancing of the injection timing. The optimum injection timing was obtained by based on maximum brake thermal efficiency. Maximum brake thermal efficiency was observed when the injection timing was advanced to $31^o$bTDC in diesel engine. Murali Krishna [29] also observed the same trend. Performance was deteriorated if the injection timing was greater than $31^o$bTDC. This was because of increase in ignition delay.

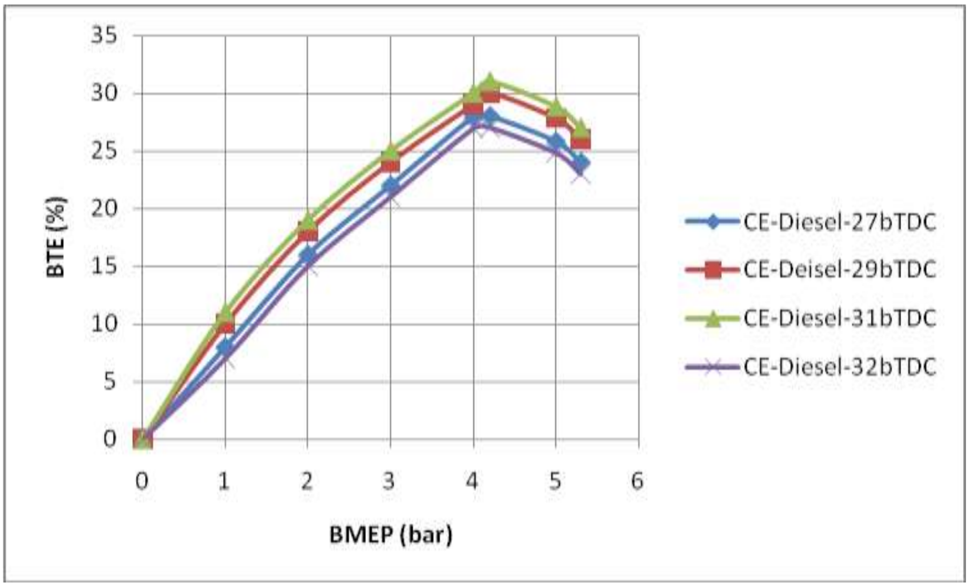



**FIGURE.2.Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE) with pure diesel, at various injection timings at an injector opening pressure of 190 bar.**

Curves from Figure. 3 indicate that at recommended injection timing, conventional engine with crude vegetable oil showed the deterioration in the performance at all loads when compared with the pure diesel operation. Higher density of crude vegetable oil caused higher mass injection, for the same volume. In addition, the heating value of crude vegetable oil was lower than diesel fuel. Higher viscosity of crude vegetable oil leads to reduced fuel losses, leakage past the injector needle for lubrication purpose, during injection process, to faster evolution of pressure, again resulting in more fuel charge entering the combustion chamber. Brake thermal efficiency increased with the advanced injection timing at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment [29] in fuel spray giving higher brake thermal efficiency. Brake thermal efficiency increased at all loads when the injection timing was advanced to 32$^o$bTDC in the engine at the normal temperature of vegetable oil. Increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with vegetable oil could be attributed to its longer ignition delay and combustion duration. Similar trends were observed with preheated vegetable oil also. The performance improved further with the preheated crude vegetable oil for entire load range when compared with normal vegetable oil.

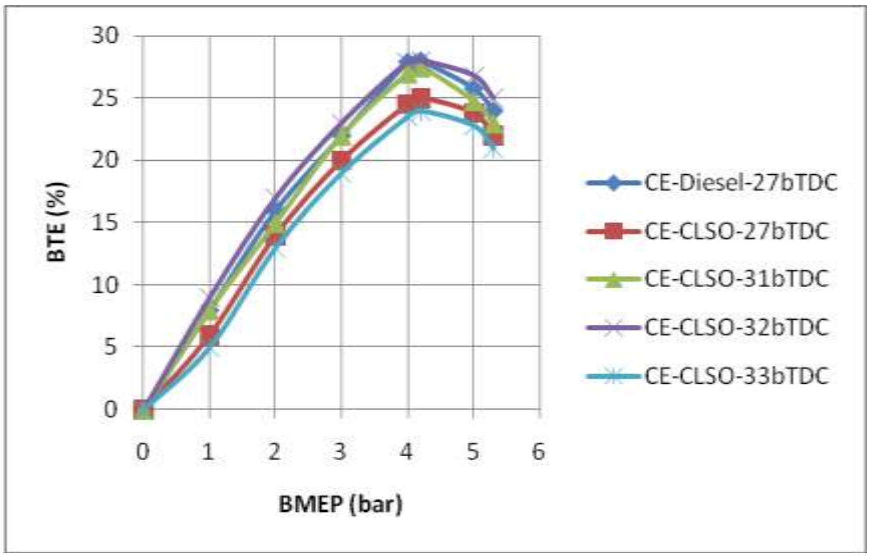



**FIGURE 3. Variation of brake thermal efficiency (BMEP) with brake mean effective pressure (bmep) in conventional engine (CE) at different injection timings with crude vegetable oil (CLSO) operation.**

Preheating of the crude linseed oil reduced the viscosity, which improved the spray characteristics of the oil and reduced the impingement of the fuel spray on combustion chamber walls, causing efficient combustion thus improving brake thermal efficiency.

Curves from Figure 4 indicate that at recommended injection timing, engine with biodiesel showed the compatible performance for entire load range when compared with the pure diesel operation. This may be due to the difference of viscosity between the diesel and biodiesel and calorific value of the fuel. The reason might be due to (1) higher initial boiling point and different distillation characteristics, (2) higher and (2) higher density and viscosity leads to narrower spray cone angle and higher spray penetration tip, leading to inferior combustion compared to neat diesel [26]. However, higher density of biodiesel compensates the lower value of the heat of combustion of the biodiesel thus giving compatible performance with engine. Biodiesel contains oxygen molecule in its molecular composition. Theoretical air requirement of biodiesel was low and hence lower levels of oxygen were required for its combustion. Brake thermal efficiency increased with the advanced injection timing with conventional engine with the biodiesel at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment in fuel spray giving higher brake thermal efficiency. Brake thermal efficiency increased at all loads when the injection timing was advanced to 31$^{o}$bTDC with the engine at the normal temperature of biodiesel. The increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with biodiesel with conventional engine could be attributed to its longer ignition delay and combustion duration [29]. Similar trends were noticed with preheated biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil, causing efficient combustion thus improving brake thermal efficiency. Ignition delay with biodiesel was less due to its high cetane number hence injection advance was less with biodiesel operation(31$^{o}$bTDC) than crude vegetable oil operation(32$^{o}$bTDC)

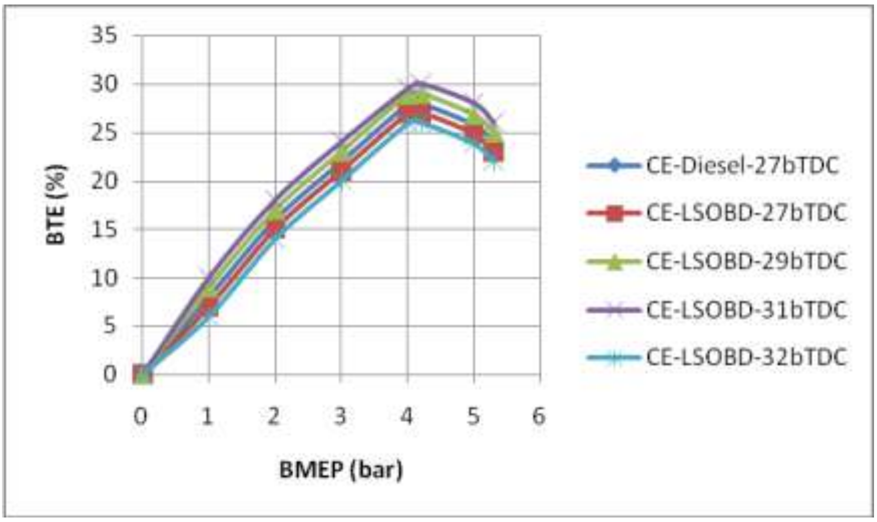



**FIGURE 4. Variation of brake thermal efficiency (BTE) with brake means effective pressure (BMEP) in conventional engine (CE) at different injection timings with biodiesel (LSOBD) operation.**

Part load variations were very small and minute for the performance parameters and exhaust emissions. The effect of varied injection timing (advanced injection timing) on the performance with test fuels was discussed with the help of bar charts, while the effect of increase of injector opening pressure was discussed with the help of Tables. Injector opening pressure was varied from 190 bar to 270 bar to improve the spray characteristics and atomization of the test fuels and injection timing is advanced from 27 to 34$^{o}$bTDC for CE.

From Figure.5, it was noticed that full brake thermal efficiency was higher for diesel operation at its optimized injection timing followed by biodiesel operation in comparison with crude vegetable oil operation. This was due to higher calorific value and improved cetane rating of diesel causing efficient combustion leading to produce higher brake thermal efficiency.

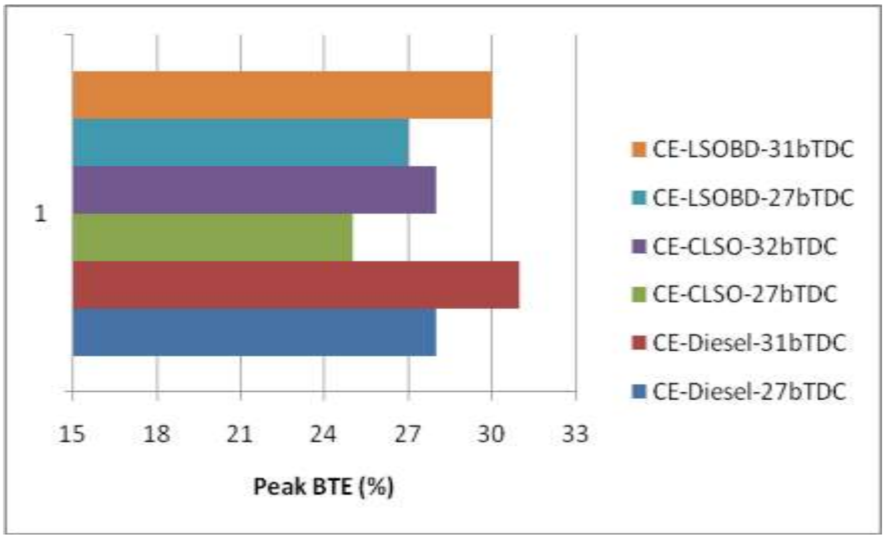



**FIGURE. 5. Bar charts showing the variation of full brake thermal efficiency (BTE) with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

As it is observed from Table.4, full brake thermal efficiency increased with increase in injector opening pressure at different operating conditions of the vegetable oil in crude form and in biodiesel form along with diesel fuel.

For the same physical properties, as injector opening pressure increased droplet diameter decreased influencing the atomization quality, and more dispersion of fuel particle, resulting in turn in better vaporization, leads to improved air-fuel mixing rate, as extensively reported in the literature [30-32]. In addition, better combustion leads to less fuel consumption. The performance improved further with the preheated vegetable oil (s) when compared with normal vegetable oil(s). Preheating of the vegetable oil(s) reduced the viscosity, which improved the spray characteristics of the oil causing efficient combustion thus improving brake thermal efficiency. The cumulative heat release was more for preheated biodiesel [28] than that of biodiesel and this indicated that there was a significant increase of combustion in diffusion mode [28]. This increase in heat release [28] was mainly due to better mixing and evaporation of preheated biodiesel, which leads to complete burning. The heat released [28] by the biodiesel was less due to poor mixing of biodiesel with the surrounding air because of its high viscosity.

Optimum injection timing changed with increase of injector opening pressure for both crude vegetable oil and biodiesel. The optimum injection timing was 32$^{o}$bTDC at an injector opening pressureof 190 bar, 31$^{o}$bTDC at 230 bar and 30$^{o}$bTDC at 270 bar with crude vegetable oil operation. Similarly optimum injection timing was 31$^{o}$bTDC at an injector opening pressureof 190 bar, 30$^{o}$bTDC at 230 bar and 29$^{o}$bTDC at 270 bar with biodiesel and diesel operation. This was due to change of ignition delay with the change of injector opening pressure. Full brake thermal efficiency was higher for diesel fuel, followed by biodiesel and crude vegetable oil. This was because of high calorific value and less viscous nature of diesel fuel.

**Table.4 Data Of Full Brake Thermal Efficiency (BTE) and Brake Specific Energy Consumption at Full Load Operation**

| Injection Timing ($^{o}$ bTDC) | Test Fuel | Peak BTE (%) | | | | | | Brake Specific Energy Consumption at full load operation ( kW/kW) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Injector opening pressure(Bar) | | | | | | Injector opening pressure(Bar) | | | | | |
| | | 190 | | 230 | | 270 | | 190 | | 230 | | 270 | |
| | | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT |
| 27 | DF | 28 | -- | 29 | --- | 30 | -- | 4.0 | | 3.96 | | 3.92 | |
| | CLSO | 25 | 25.5 | 25.5 | 26 | 26 | 26.5 | 4.88 | 4.84 | 4.84 | 4.8 | 4.8 | 4.76 |
| | LSOBD | 27 | 27.5 | 27.5 | 28 | 28.5 | 29 | 4.02 | 3.96 | 3.96 | 3.94 | 3.94 | 3.96 |
| 31 | DF | 31 | | 31.5 | | 32 | | 3.6 | -- | 3.5 | -- | 3.4 | --- |
| | LSOBD | 30 | 30.5 | 30.5 | 31 | 31 | 31.5 | 3.82 | 3.78 | 3.86 | 3.82 | 3.90 | 3.86 |
| 32 | CLSO | 28 | 28.5 | 28.5 | 29 | 29 | 29.5 | 3.96 | 3.92 | 3.98 | 3.96 | 4.00 | 3.98 |

DF- Diesel fuel, TSOBD Biodiesel, CLSO- Crude vegetable oil, NT- Normal temperature , PT- Preheated temperature

Generally brake specific fuel consumption, is not used to compare the two different fuels, because their calorific value, density, chemical and physical parameters are different. Performance parameter, BSEC, is used to compare two different fuels by normalizing brake specific energy consumption, in terms of the amount of energy released with the given amount of fuel. Brake specific energy consumption of biodiesel is almost the same as that of neat diesel fuel as shown in Figure.6. Even though viscosity of biodiesel is slightly higher than that of neat diesel, inherent oxygen of the fuel molecules improves the combustion characteristics. This is an indication of relatively more complete combustion [10,26]. Crude vegetable oil showed higher BSEC compared to normal diesel at the full load operation as observed from the same figure. The reason may be due to higher viscosity, poor volatility and reduction in heating value lead to their poor atomization and combustion characteristics.

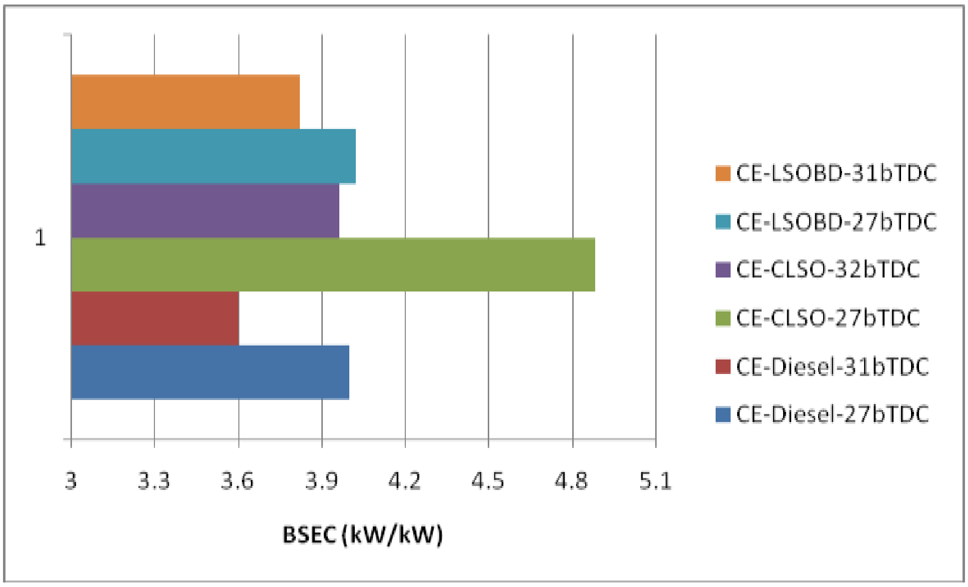



**FIGURE. 6. Bar charts showing the variation of brake specific energy consumption (BSEC) at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

From the same Figure and Table.4 it is noticed that Brake specific energy consumption (BSEC) at full load operation decreased with the advanced injection timing and increase of injector opening pressure with different operating conditions of crude vegetable oil and biodiesel. This was due to initiation of combustion at earlier period and efficient combustion with the increase of air entrainment in fuel spray giving lower BSEC. Different operating conditions of biodiesel showed improved performance over the crude vegetable oil operation. Esterification reduced the viscosity, molecular weight of the fuel and improved the cetane number, which reduced the ignition delay thus improving the performance of the engine, when compared to the crude vegetable oil. BSEC at full load operation decreased with increase in injector opening pressure. BSEC decreased with the preheated vegetable oil (s) at full load operation when compared with normal vegetable oil(s). Preheating of the vegetable oil reduced the viscosity, which improved the spray characteristics of the oil. BSEC was lower with diesel operation followed by biodiesel and crude vegetable oil at recommended and optimized injection timings. This was due to high calorific value and improved spray characteristics of the diesel fuel with high cetane value of the fuel.

From the Figure.7, it is observed that at recommended and optimized injection timings, crude vegetable oil operation recorded drastically higher value of exhaust gas temperature while biodiesel produced marginally higher value of exhaust gas temperature at full load operation in comparison with pure diesel operation. Though the calorific value (or heat of combustion) of fossil diesel is more than those of vegetable oil (s); the density of these vegetable oils were higher therefore greater amount of heat was released in the combustion chamber leading to higher exhaust gas temperature. Also, there was an advanced combustion of diesel due to its cetane number, when compared to vegetable oil (s). Therefore, the heat released by vegetable oil (s) combustion is late by few degrees and thus more heat gets exhausted. Exhaust gas temperature decreased with advanced injection timings with test fuels, which confirmed the decrease of brake specific energy consumption at full load with test fuels. Similar findings were obtained by other studies [21].

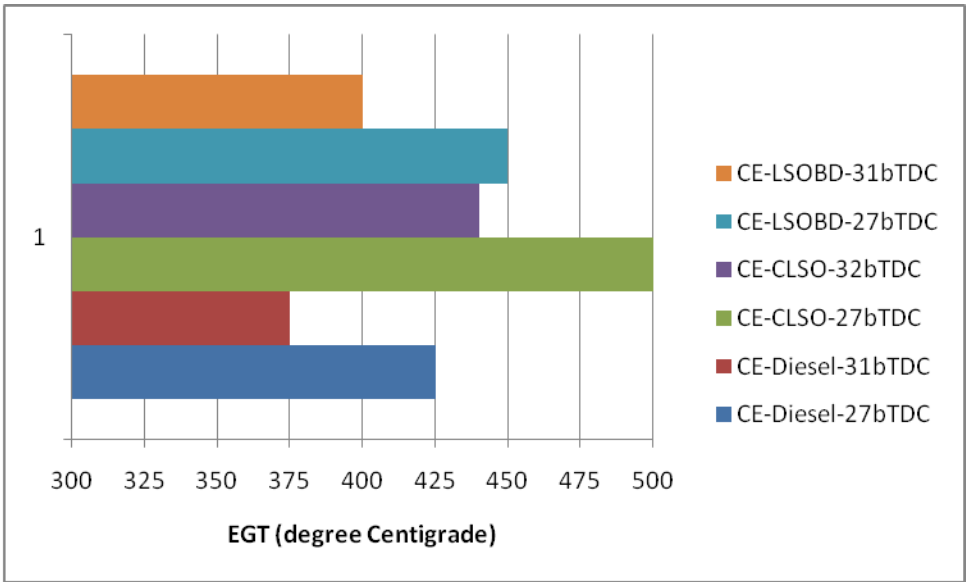



**FIGURE. 7. Bar charts showing the variation of exhaust gas temperature (EGT) at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

From the Table.5, it is noticed that the exhaust gas temperatures of preheated vegetable oil (s) were higher than that of normal vegetable oil (s), which indicates the increase of diffused combustion [28] due to high rate of evaporation and improved mixing between methyl ester and air. Therefore, as the fuel temperature increased, the ignition delay decreased and the main combustion phase (that is, diffusion controlled combustion) increased [28] , which in turn raised the temperature of exhaust gases. The value of exhaust gas temperature decreased with increase in injector opening pressure with test fuels as it is evident from the Table.5. This was due to improved spray characteristics of the fuel with increase of injector opening pressure.

Exhaust gas temperature was lower with biodiesel operation when compared with crude vegetable oil operation. This was due to improvement of cetane number of the vegetable oil with the esterification, which leads to improved combustion and reduced exhaust gas temperature, as crude vegetable oil operation causes wastage of exhaust gas enthalpy instead of actual conversion of heat into work.

**Table.5. Data Of Exhaust Gas Temperature (EGT) And Coolant Load At Full Load Operation**

| Injection Timing ($^o$ bTDC) | Test Fuel | EGT at full load operation (degree centigrade) | | | | | | Coolant load at full load operation (kW) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Injector Opening Pressure (Bar) | | | | | | Injector Opening Pressure (Bar) | | | | | |
| | | 190 | | 230 | | 270 | | 190 | | 230 | | 270 | |
| | | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT |
| 27 | DF | 425 | -- | 410 | --- | 395 | -- | 4.0 | --- | 4.2 | -- | 4.4 | --- |
| | CLSO | 500 | 540 | 460 | 500 | 420 | 460 | 4.6 | 4.4 | 4.8 | 4.6 | 5.0 | 4.8 |
| | LSOBD | 450 | 490 | 410 | 450 | 370 | 410 | 4.2 | 4.0 | 4.4 | 4.2 | 4.6 | 4.4 |
| 31 | DF | 375 | --- | 350 | --- | 325 | -- | 4.2 | -- | 4.4 | -- | 4.6 | --- |
| | LSOBD | 400 | 440 | 420 | 460 | 440 | 420 | 4.4 | 4.2 | 4.6 | 4.4 | 4.8 | 4.6 |
| 32 | CLSO | 440 | 480 | 460 | 500 | 480 | 520 | 4.8 | 4.6 | 5.0 | 4.8 | 5.2 | 4.0 |

DF- Diesel fuel, TSOBD Biodiesel, CLSO- Crude vegetable oil, NT- Normal temperature , PT- Preheated temperature

By observing lower value of exhaust gas temperature, it established a fact that the performance of the engine improved with the biodiesel, compared with crude vegetable oil. Exhaust gas temperature was lower with pure diesel operation followed by biodiesel and crude vegetable oil. This was due to clean combustion of diesel with improved cetane rating.

From the Figure.8, it is noticed that coolant load increased with crude vegetable oil operation at recommended injection timing in comparison with pure diesel operation. This was due to concentration of un-burnt fuel at the walls of combustion chamber. However, at 27$^o$bTDC, biodiesel operation showed compatible value of coolant load when compared with pure diesel operation. This was because of efficient combustion of biodiesel with improved cetane rating. Coolant load increased with advanced injection timing with linseed oil operation in crude form and biodiesel along with diesel fuel. This was due to due to increase of gas temperatures with improved combustion. However, the improvement in the performance of the conventional engine was due to heat addition at higher temperatures and rejection at lower temperatures.

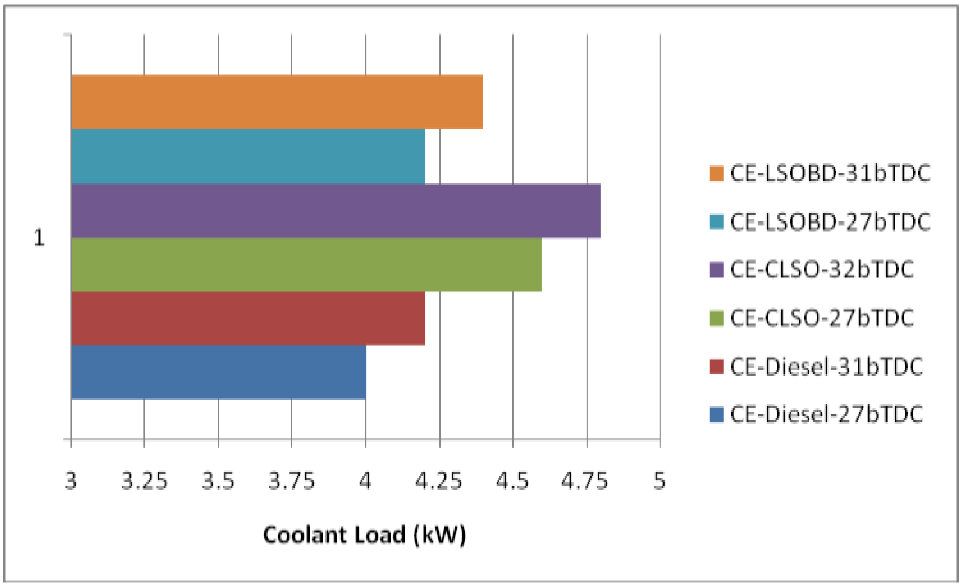



**Figure. 8. Bar charts showing the variation of coolant load at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

From Table.5, it is noticed that coolant load increased with increase of injector opening pressure with test fuels. This was due to the fact with increase of injector opening pressure with conventional engine, increased nominal fuel spray velocity resulting in better fuel-air mixing with which gas temperatures increased. However, coolant load decreased with preheated condition of vegetable oil in crude and biodiesel form in comparison with normal vegetable oil. This was due to improved air fuel ratios with improved spray characteristics. This was also due to decrease of bulk modulus and density with increase of temperature of the fuel. Coolant load was found to be marginally higher with crude vegetable oil than biodiesel at different operating conditions of the vegetable oil (s). This was due to higher concentration of un-burnt fuel at the combustion chamber walls. Cooling load was found to be lower with pure diesel operation followed by biodiesel and crude vegetable oil. This was because of clean combustion with diesel fuel with improved cetane number and reduction of un-burnt fuel concentration at combustion chamber walls. Coolant load was lower with diesel fuel followed by biodiesel and crude vegetable oil. This was due to less concentration of un-burnt fuel at combustion chamber walls.

Figure 9 indicates at recommended injection timing, sound levels drastically increased with vegetable oil (s) operation in comparison with pure diesel operation. This was due to deteriorated performance because of high viscosity, poor volatility and high duration of combustion caused moderate combustion of crude vegetable oil leading to generate high sound levels.

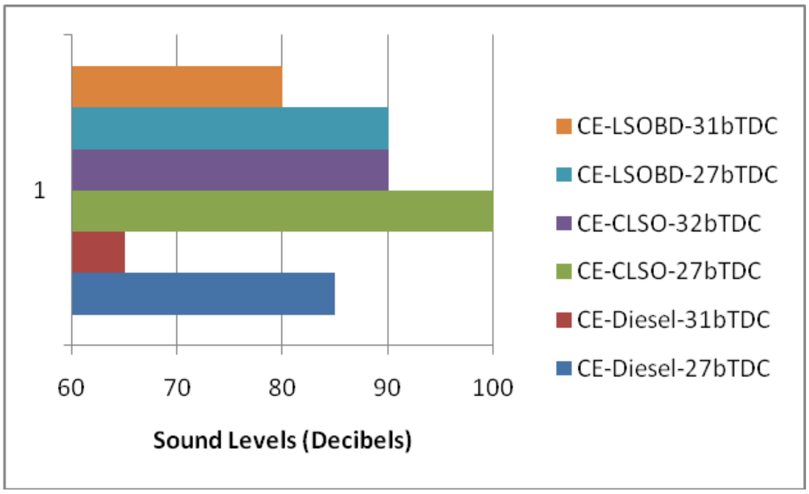



**FIGURE. 9. Bar charts showing the variation of sound levels at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

However, sound levels were observed to be moderate with biodiesel operation in comparison with pure diesel operation at recommended injection timing. When injection timings were advanced to optimum, sound levels decreased with test fuels due to early initiation of combustion.

Table 6 denotes that the Sound levels decreased with increase of injector opening pressure with the test fuels. This was due to improved spray characteristic of the fuel, with which there was no impingement of the fuel on the walls of the combustion chamber leading to produce efficient combustion. Sound levels were higher with crude vegetable oil than biodiesel at different operating conditions of the vegetable oil. This was due to increase of fuel deposits with crude vegetable oil operation in comparison with biodiesel. Sound intensities were lower at preheated condition of crude vegetable oil and biodiesel when compared with their normal condition. This was due to improved spray characteristics, decrease of density and viscosity of the fuel. Sound levels were lower with diesel operation followed by biodiesel and crude vegetable oil operation. This was due to the low viscosity and density of diesel fuel.

**Table.6. Data Of Sound Levels And Volumetric Efficiency With Test Fuels At Full Load Operation.**

| Injection Timing (° bTDC) | Test Fuel | Sound Levels at full load operation (Decibels) | | | | | | Volumetric Efficiency (%) at full load operation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Injector Opening Pressure (Bar) | | | | | | Injector Opening Pressure (Bar) | | | | | |
| | | 190 | | 230 | | 270 | | 190 | | 230 | | 270 | |
| | | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT |
| 27 | DF | 85 | -- | 80 | -- | 95 | -- | 85 | -- | 86 | -- | 87 | -- |
| | CLSO | 100 | 95 | 95 | 90 | 90 | 85 | 81 | 80 | 82 | 81 | 83 | 82 |
| | LSOBD | 90 | 85 | 85 | 80 | 80 | 70 | 83 | 82 | 84 | 83 | 85 | 84 |
| 31 | DF | 65 | -- | 60 | -- | 55 | -- | 89 | -- | 90 | -- | 91 | -- |
| | LSOBD | 80 | 75 | 85 | 80 | 90 | 85 | 87 | 88 | 87 | 89 | 88 | 87 |
| 32 | CLSO | 90 | 85 | 95 | 90 | 100 | 95 | 85 | 84 | 86 | 85 | 87 | 86 |

DF- Diesel fuel, TSOBD Biodiesel, CLSO- Crude vegetable oil, NT- Normal temperature , PT- Preheated temperature

Volumetric efficiency depends on density of the charge which intern depends on temperature of combustion chamber wall. Figure.10 indicates that at the recommended injection timing, volumetric efficiency with vegetable oil (s) operation (particularly with crude vegetable oil) decreased at full load, when compared with pure diesel operation.

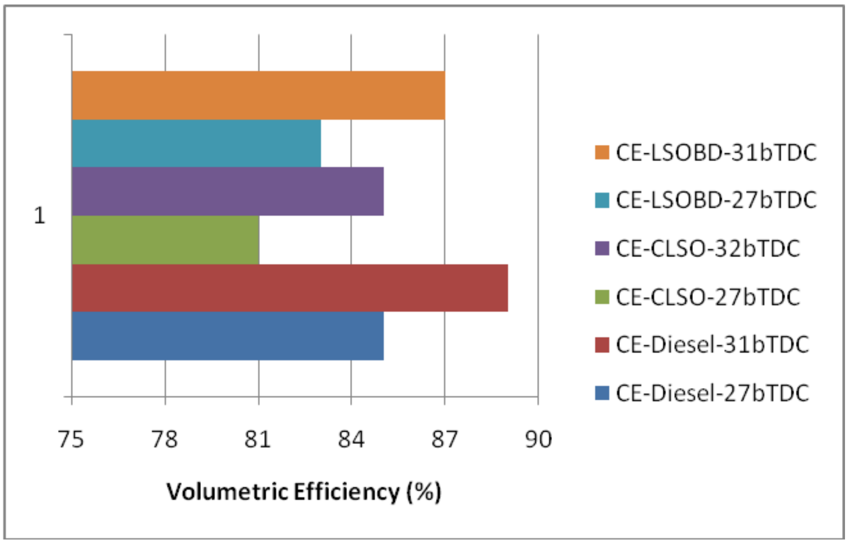



**FIGURE. 10. Bar charts showing the variation of volumetric efficiency at full load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.**

This was due to increase of combustion chamber wall temperatures with vegetable oil (s) operation due to accumulation of un-burnt fuel concentration with vegetable oil (s) operation. This was also because of increase of combustion chamber wall temperature as exhaust gas temperatures increased with vegetable oil operation in comparison with pure diesel operation. Volumetric efficiency increased marginally at optimized injection timings when compared with recommended injection timing with test fuels. This was due to decrease of un-burnt fuel fraction in the cylinder leading to increase in volumetric efficiency. This was also due to decrease of exhaust gas temperatures and hence combustion chamber wall temperatures with advanced injection timing with vegetable oil operation.

From Table-6, it is evident that volumetric efficiency increased with increase of injector opening pressure with test fuels. This was due to improved fuel spray characteristics and evaporation at higher injection pressures leading to marginal increase of volumetric efficiency. This was also because of decrease of exhaust gas temperatures and hence combustion chamber wall temperatures. This was also due to the reduction of residual fraction of the fuel, with the increase of injector opening pressure. Preheating of the linseed oil in crude and biodiesel form marginally decreased volumetric efficiency, when compared with the normal temperature of the test fuels, because of reduction of bulk modulus, density of the fuel and increase of exhaust gas temperatures. Volumetric efficiency was higher with diesel operation followed by biodiesel and crude vegetable oil. This was due to clean and efficient combustion with high cetane value of diesel. Also exhaust gas temperatures were lower with pure diesel operation in comparison with vegetable oil (s).

**4. Conclusions**

At recommended injection timing and pressure, when compared with pure diesel operation,

1. Full brake thermal efficiency relatively decreased by 11% with crude vegetable oil operation, while biodiesel operation showed compatible thermal efficiency.
2. Brake specific energy consumption at full load operation increased by 22% with crude vegetable oil operation, while biodiesel operation showed compatible values.
3. Exhaust gas temperature at full load operation increased by 75$^{o}$C, while biodiesel operation showed compatible value.
4. Coolant load at full load operation increased by 15%, while biodiesel operation showed compatible value
5. Sound levels at full load operation increased by 18%, while biodiesel operation increased sound levels by 6%
6. Volumetric efficiency at full load operation decreased by 5%, while biodiesel operation showed compatible value.

At the respective optimized injection timing and an injector opening pressure of 190 bar, when compared with pure diesel operation,

1. Full brake thermal efficiency decreased by 10% with crude vegetable oil operation, while biodiesel operation showed compatible thermal efficiency.
2. Brake specific energy consumption at full load operation increased by 10% with crude vegetable oil operation, while biodiesel operation increased it by 6%.
3. Exhaust gas temperature at full load operation with crude vegetable oil operation increased by 65$^{o}$C, while biodiesel operation showed compatible value.
4. Coolant load at full load operation with vegetable oil operation increased by 15%, while biodiesel operation showed compatible value.
5. Sound levels at full load operation with crude vegetable oil operation increased by 38%, while biodiesel operation increased it by 23%.
6. Volumetric efficiency at full load operation with crude vegetable oil operation increased by 5% and biodiesel operation showed compatible values.

With increase of injector opening pressure

Full brake thermal efficiency increased, at full load operation- brake specific energy consumption decreased, exhaust gas temperature decreased, volumetric efficiency increased, coolant load increased with test fuels.

With preheating

Full brake thermal efficiency increased, at full load operation- brake specific energy consumption decreased, exhaust gas temperature increased, volumetric efficiency decreased, coolant load decreased, sound levels decreased with test fuels.

### 4.1 Research Findings and Suggestions

Investigations on study of performance parameters with conventional engine were systematically carried out with varied injector opening pressure and injection timing with different operating conditions of the test fuels.

The vegetable oil (s) requires hot combustion chamber as they are highly viscous, and non-volatile. Hence a low heat rejection diesel engine can be employed in order to burn them effectively and hence study in this direction is necessary.

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