



INVESTIGATION OF OPTIMUM OPERATING TEMPERATURE RANGE FOR CI ENGINE FUELLED WITH BIODIESEL

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Abstract: *The atmospheric temperature in various regions of India varies from 0°C to 48°C and due to this vast varying temperature range it is difficult for the engine to perform uniformly. Therefore it is essential to investigate the temperature that is most suited for operating parameters of engines and will give the best performance levels. The aim of this study is to analyze the performance of a compression ignition (CI) engine using Jatropha biodiesel and its blends with diesel as fuel on changing engine temperature to obtain best performance levels. It has been tried to investigate the optimum operating temperature of engine that will deliver the best performance level. The blends of Jatropha with diesel in varying proportions (B10, B20 and B40) are prepared and are investigated in single cylinder, four stroke CI engine computerized test rig. The results obtained on engine performance parameters i.e brake power (bp), brake thermal efficiency (η_{th}) and volumetric efficiency (η_v) and presented graphically with respect to the engine coolant temperature at different engine loads. The present study inferred that it is preferable to operate the engine at temperature 65°C-75°C to obtain best performance indicators.*

Keywords: *CI engine, Jatropha biosiesel, diesel, smoke intensity, operating temperature.*

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1. INTRODUCTION

The ongoing diminishing of fossil fuel reserves and consequently dependency on foreign energy resources and also destruction of the environment caused by burning fossil fuels triggered the research of biodiesel as a substitute for petroleum based diesel fuel in the recent years.

Today research and development in the field of internal combustion (IC) engines have to face a double challenge; on the one hand fuel consumption has to be reduced, while on the other hand ever more stringent emission standards have to be fulfilled.. The development of engines with its complexity of in-cylinder processes requires modern development tools to exploit the full potential in order to reduce fuel consumption.

Sharp hike in petroleum prices and increase in environmental pollution jointly have necessitated exploring some renewable indigenous alternatives to conventional petroleum fuels. Also, depletion of fossil fuels, vehicular population, increasing industrialisation, extra burden on home economy, growing energy demand, explosion of population, environmental pollution, stringent emission norms (Euro I, II, III, IV), etc emphasize on the need for alternative fuels. The alternative fuels must be technically feasible, environmentally acceptable, readily available and economically competitive.

Bio-diesel, which can be used as an alternative fuel is made from renewable biological sources such as vegetable oils and animal fats. It is bio-degradable, non-toxic and possesses low emission profiles [1]. Also, the use of bio-fuels is environmental friendly. Significant researches have already been put forward in investigating the performance of biodiesel in diesel engine application.

The researchers have reported varying results on power delivered by diesel engine with the use of biodiesel. Some authors have shown power loss while others have shown an increase in rated power and torque. Cetinkaya et al. in 2005 [2] performed experimentation on a 75 kW four-cylinder common rail engine. They observed that the reduction of torque was only 3 to 5 % with waste oil biodiesel compared to petroleum diesel. Lin et al. in 2006 [3] also carried out experiments on a 2.84 L naturally aspirated engine and they found 3.5% less power using pure palm oil biodiesel than that of petroleum diesel at full load condition. Hansen et al. in 1997 [4] also studied the break torque of test engine by varying viscosity,



density and heating value of the fuel. They have shown that the break torque loss was 9.1% when 100 % bio-diesel was used as fuel instead of petroleum diesel at 1900 rpm.

Many researchers have reported an increase in Brake Specific Fuel Consumption (bsfc) when using biodiesel and its blends compared to petroleum diesel fuel. These increases were basically the result of the loss of heating value in the biodiesel fuel blends. [5, 6, 7, 8, 9]

In the present scenario the designs of CI engine being used in automobiles by various manufacturers are not properly suitable to Indian climate condition. Looking in to the vast varying atmospheric temperature range in the country it is very difficult to say that which temperature is most suited to operating condition of engines and will give the best performance levels as far as η_{th} and bp is concerned.

After reviewing the literature, applying real experiences, in the experimental investigations and observations it is inferred that the engine systems can be optimized and evolved to provide precision cooling with necessary changes in engine cooling system, to reduce excessive heating and irregular temperature gradient for better performance. A lot of work has been done on the study of performance and emission characteristics of alternate fuels in IC engines. Limited amount of work is done related with temperature effect on CI engines running on bio-diesel. As per the author's point of view, it has been observed that no literature is available on the effect of CI engine operating performance parameters for bio-diesel with changing engine operating temperature related to ambient atmospheric temperatures. The authors are in strong opinion to evaluate the research on engine operating temperature with biodiesel and its blends as this would have definite impact on engine performance.

2. ENGINE TEST SET UP AND METHODOLOGY

A computerized C I engine test rig used for present experimental investigation. This experimental test rig consists of a single cylinder, four strokes, constant speed; direct injection diesel engine is used for the experiments having a rated power output of 5.2 kW at a constant speed of 1500 rpm. The test rig also have eddy current dynamometer as loading system, water cooling system, lubrication system and various sensors and instrumentation integrated with computerized data acquisition system for online measurement of load, air & fuel flow rate, instantaneous cylinder pressure, position of crank angle, exhaust emissions and smoke opacity etc. Figure 1 (a) shows the photographic image of the experimental

setup used in the laboratory to conduct the present study and Figure 1 (b) shows the schematic representation of the experimental test setup.

Commercially available lab-view based engine performance analysis software package “Enginesoft” is used for on line performance data storage. The smoke intensity is measured in terms of Hartridge Smoke Unit (HSU in %) or in terms of K (the light absorption coefficient (m^{-1})).

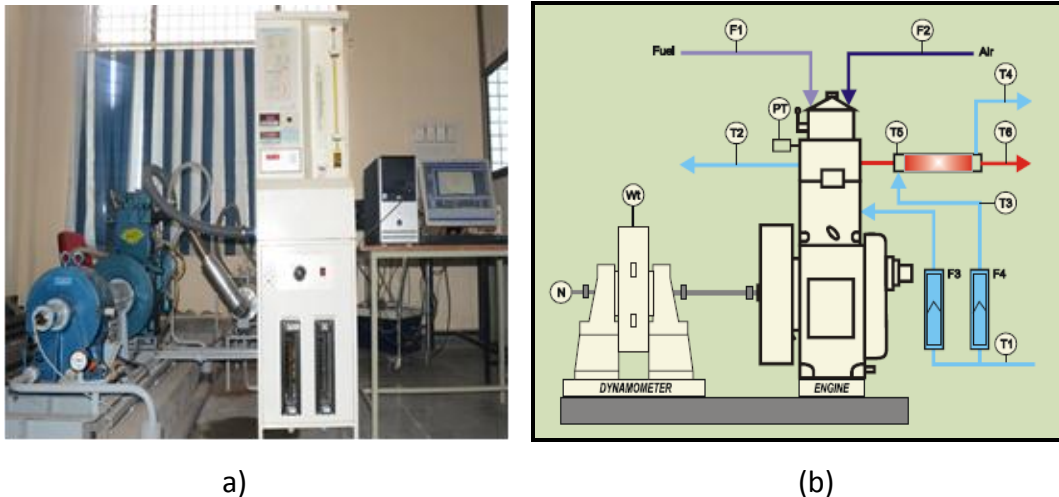


Figure 1. (a) Experimental Set up (b) Schematic representation of set up

2.1 Cylinder Heat Transfer Measurements

There are a wide range of temperature and heat fluxes in an internal combustion engine. The values of local transient heat fluxes can vary by an order of magnitude depending on the spatial location in the combustion chamber and the crank angle. The source of the heat flux is not only the hot combustion gases, but also the engine friction that occurs between the piston rings and the cylinder wall. When an engine is running at steady state, the heat transfer through out most of the engine structure is steady.

The maximum heat flux through the engine components occurs at fully open throttle and at maximum speed. Peak heat fluxes are in order of 1to10 MW/m.2 the heat flux increase with in increases with increasing engine load and speed. The heat flux is largest in the centre of the cylinder head, the exhaust valve seat and the centre of the piston. About 50% of the heat flow to the engine coolant is through the engine head and valve seats, 30% through the cylinder sleeve or walls and remaining 20% through the exhaust port area



2.2 Effect of Engine Temperature

Temperature control is very important for combustion engines as temperature is a critical; factor both for chemical reactions and mechanical stresses. Traditionally, temperature control is performed by feedback of a global quantity, the coolant temperature, which however is a poor indicator of specific temperatures. The use of pumps opens new possibilities for thermal control, in particular in terms of efficiency, but also of pollution, especially in the cold start phase. It shows that predictive control and the use of coolant pumps allow to regulating specific temperatures. [11].

2.3 Heat Release and Component Temperature in CI Engines

The heat flux to the combustion chamber walls varies with engine design and operating condition. Also the heat flux to the various parts of the combustion chamber is not the same. As a result of this nonuniform heat flux and the different thermal impedances between locations on the combustion chamber surface and the cooling fluid, the temperature distribution within engine components is nonuniform. [11].

2.4 Effect of Engine Variables

The following variables affect the magnitude of the heat flux to the different surfaces of the engine combustion chamber and the temperature distribution in the components that comprise the chamber, engine speed, engine load, overall equivalence ratio, compression ratio, injection timing, swirl motion, wall material, mixture inlet temperature, coolant temperature and composition. These variables with speed and load have the greatest effect. [11].

2.5 Engine Cooling Systems

There are two types of engine cooling systems used for heat transfer from the engine block and head; liquid cooling and air cooling. With a liquid coolant, the heat is removed through the use of internal cooling channels within the engine block. Liquid systems are much quieter than air systems, since the cooling channel absorbs the sounds from the combustion process. However, in this experimentation the engine temperature was artificially maintained by controlling the flow rate of coolant to the required fixed temperature.



3. RESULTS AND DISCUSSION

The performance parameters considered in the present study are bp , η_v and η_{th} responding to coolant temperatures considered as engine operating temperature. Thermal Performance Evaluation is carried out in following three different experimental stages;

1. Diesel as fuel at different coolant temperatures and loads.
2. Jatropha bio-diesel as fuel at different coolant temperatures and loads.
3. Blends of Jatropha biodiesel and diesel as fuel at different coolant temperatures and loads.

The blend proportions used to conduct the experiments are B10, B20 and B40. The blends are prepared by direct mixing of both the fuels in required proportions. Mixing is done with the help of a magnetic mixer. Blends used are as follows;

- B10: 10% biodiesel and 90% diesel
- B20: 20% biodiesel and 80% diesel
- B40: 40% biodiesel and 60% diesel

Figure 2 shows graph between brake power (bp) and coolant water temperature (T_2) at part load. It is seen from the graph that bp tends to increase with temperature from 50°C . This is because the higher wall temperature delays flame quenching on the wall as the quench layer thickness gets reduced and hence the bp increases. The maximum bp occurs at around 65°C - 75°C for all test fuels considered. With diesel the maximum bp is 2.36 kW at 65°C and at 75°C while with biodiesel the maximum bp is 2.18 kW at 75°C . Beyond 75°C the bp reduces. This is attributed to the fact that volumetric efficiency (η_v) reduces with increase in operating temperature due to the decrease in air density at higher temperature [11]. It is also seen from the figure that the increase of biodiesel percentage in the blends (B40 and B100) resulted in a decrease of bp over the entire temperature range. This is due to the fact that the higher viscosity and lower heating value of biodiesel reduces bp . The higher viscosity results in power losses, because the higher viscosity decreases combustion efficiency due to poor fuel injection atomization. It was also found that the B20, B10 and B0 have almost similar bp values. This could be attributed to additional lubricity and presence of oxygen provided by the biodiesel in blends B20 and B10 resulting improved combustion and mitigates the effect of higher viscosity and lower heating value of biodiesel.

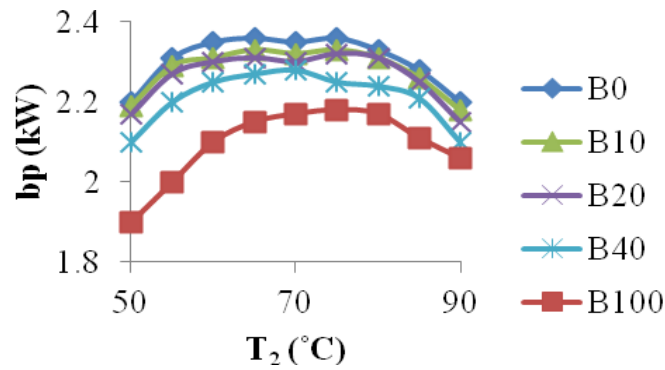


Figure 2. Brake power (bp) of B0, B10, B20, B40 and B100 with different coolant temperatures (T₂) at part load on engine

Figure 3 shows graph between volumetric efficiency (η_v) and coolant water outlet temperature (T₂) at part load on engine. It is seen from the graph that η_v reduces with increase in coolant temperature. This is attributed to the fact that there is decrease in air density with increase in operating temperature due to which the η_v decreases (Heywood 1988[11]).

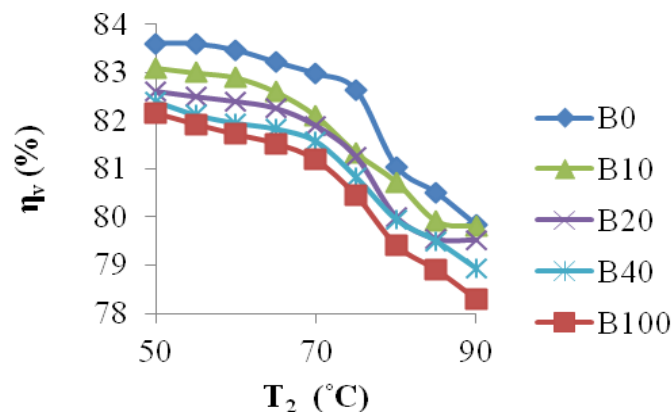


Figure 3. Volumetric efficiency (η_v) of B0, B10, B20, B40 and B100 with different coolant temperatures (T₂) at part load

Figure 4 presents the variation of brake thermal efficiency (η_{th}) for biodiesel and its blends with diesel with different operating temperatures (T₂) at part load on test engine. It can be observed that η_{th} increases continuously with increase in T₂ for all the fuels. The increasing trend is due to higher temperature results in better combustion of fuel. It is also observed that η_{th} is decreased with increase in biodiesel content in the blend at a constant T₂. The decrease may be due to higher viscosity of biodiesel which hinders the fuel evaporation due to poor atomization during combustion process. The maximum η_{th} for B0, B10, B20, B40 and



B100 are 30%, 29%, 28%, 25% and 24% respectively. Beyond 80 °C the η_{th} reduces. This is attributed to the fact that bp and volumetric efficiency (η_v) reduces with increase in operating temperature due to the decrease in air density at higher temperature.

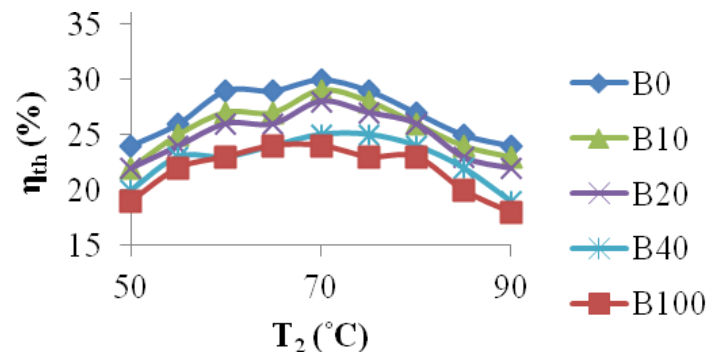


Figure 4 Brake thermal efficiency (η_{th}) of B0, B10, B20, B40 and B100 with different coolant temperatures (T_2) at part load

Figure 5 shows the graph of bp versus coolant temperature (T_2) at full load on test engine. It is observed that bp increase with the increase in load as expected. As the load increases from part load to full load the approximate percentage increase in bp for all test fuels is approximately 22 - 25 %. With diesel the maximum bp is 4.54 kW at 65 °C while with biodiesel the maximum bp is 4.3 kW at 65 °C. The minimum bp occurs at temperature 90°C for all fuels tested. It is also seen from the figure that the increase of biodiesel percentage in the blends resulted in a decrease of power over the entire temperature range.

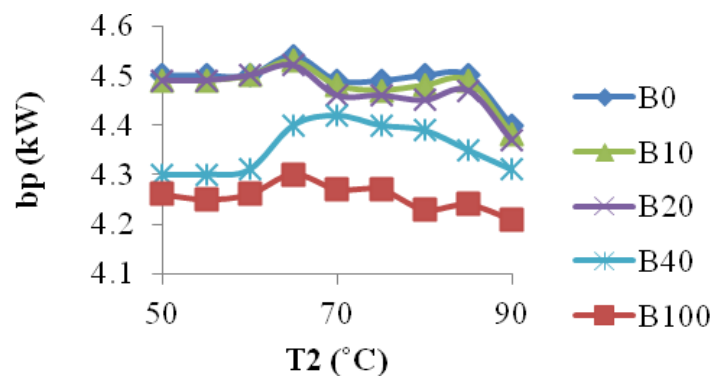


Figure 5. Brake power (bp) of B0, B10, B20, B40 and B100 with different coolant temperatures (T_2) at full load on engine



Figure 6 shows the graph of variation of η_v of diesel and biodiesel with different operating temperatures at full load on test engine. As the load increases from part to full the approximate percentage decrease in η_v for all test fuels is approximately 1 - 3 %. It is also seen from the graph that η_v reduces with increase in coolant temperature due to decrease in air density.

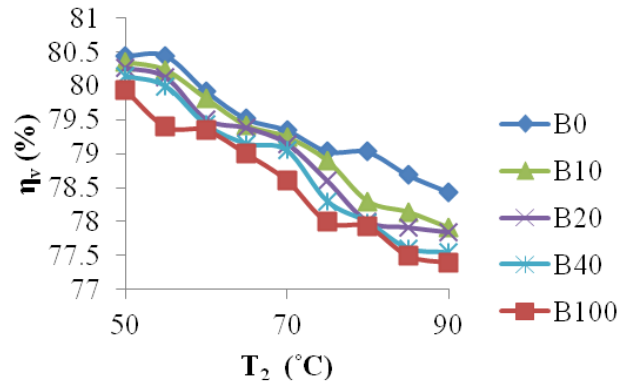


Figure 6 Volumetric efficiency (η_v) of B0, B10, B20, B40 and B100 with different coolant temperatures (T_2) at full load

Figure 7 shows the graph of variation of η_{th} of diesel and biodiesel with different operating temperatures at full load on test engine. It is observed that η_{th} increases with increase in load for all the blends tested. The trend may be due to the reason that relatively less portion of power is lost with increasing load. It can be observed that η_{th} decreases with the increase in blend proportion at constant temperature. The reduction in η_{th} can be attributed to lower heating value of the blends. Also, the higher viscosity of the blend may result in slightly reduced atomization and poorer combustion. The early initiation of combustion for biodiesel and early pressure rise before TDC contributes to increased compression work and heat loss resulting in a decrease in η_{th} .

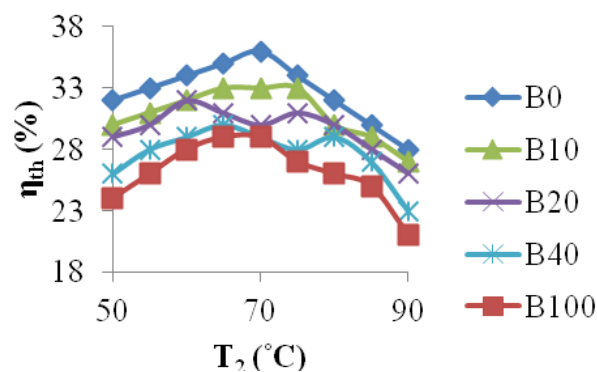


Figure 7 Brake thermal efficiency (η_{th}) of B0, B10, B20, B40 and B100 with different coolant temperatures (T_2) at full load



4. CONCLUSIONS

The experimental study is conducted on a single cylinder, four stroke, constant speed, water-cooled, direct injection diesel engine using Jatropha biodiesel and its blends with diesel. The thermal performance and smoke characteristics were evaluated by running the engine at different combinations of preset engine loads, ranging part to full load, with various coolant temperature at exit from 50°C to 90°C in steps of 10°C.

From the experimental investigation on CI engine following conclusions can be drawn;

1. A single cylinder, four stroke, constant speed, water-cooled, direct injection CI engine originally designed to operate on diesel as fuel can also be operated on pure jatropha biodiesel without any system hardware modifications.
2. Based on the observation of graphs of bp versus coolant temperature, it can be concluded that with the increase in coolant temperature, the bp of diesel engine operated using diesel, biodiesel and its blends tends to increase with temperature from 50°C. This is because the higher wall temperature delays flame quenching on the wall as the quench layer thickness gets reduced. With diesel the maximum bp is 2.36 kW at 65°C and at 75 °C while with biodiesel the maximum bp is 2.18 kW at 75 °C. Beyond 75 °C the bp reduces due to reduction in volumetric efficiency (η_v).
3. The increase of biodiesel percentage in the blends resulted in a decrease of bp over the entire temperature range attributed to the fact that the higher viscosity and lower heating value of biodiesel reduces bp.
4. Based on the observation of graphs of η_v versus coolant temperature, it can be concluded that η_v tends to reduce with temperature due to decrease in air density.
5. The η_{th} increases continuously with increase in T_2 due to higher temperature results in better combustion of fuel but beyond 80 °C the η_{th} reduces due to the fact that bp and volumetric efficiency (η_v) reduces.

Based upon the performance characteristics of CI engine under investigation it is inferred that engine should operate at coolant temperature of 65°C-75°C. This experimental result shows that there is a requirement to think about modifications in existing engine cooling system design as per India's climatic condition.



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