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Production of Biodiesel from Vegetable Oil Using CaO Catalyst & Analysis of Its Performance in Four Stroke Diesel Engine

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Abstract- The production of biodiesel from vegetable oils stands as a new versatile method of energy generation in the present scenario. Biodiesel is obtained by the transesterification of long chain fatty acids in presence of catalysts. Transesterification is an attractive and widely accepted technique. The purpose of the transesterification process is to lower the viscosity of the oil. The most important variables affecting methyl ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil, reaction temperature, catalyst amount and time. Biodiesel is renewable, biodegradable, non-toxic, and essentially free of sulfur and aromatics. It can be used in diesel engines by blending with conventional diesel in various proportions. Biodiesel seems to be a realistic fuel for future. It has become more attractive recently because of its environmental benefits.

This paper discusses the production of biodiesel from coconut oil by transesterification with methanol using Calcium Oxide catalyst. The effect of various reaction parameters on the yield is studied and the variables were optimized experimentally. The optimized conditions for CaO sample was found to be 4hrs, 600C, 4:1 methanol to oil ratio and catalyst amount was 0.6% of oil. Also studied the influence of various biodiesel blends on four stoke diesel engine. The engine characteristics like specific fuel consumption and total fuel consumption, the brake and indicated thermal efficiencies of the engine with various biodiesel blends were investigated. The blends used for analysis includes B10, B20, B30.The experiment was conducted using conventional diesel as well. The results obtained with biodiesel are compared to those obtained with conventional diesel. Thus by the comparative study efficiency of using the biodiesel blends in diesel engines was analyzed. The experimental results proved that the use of biodiesel blends in 4 stoke diesel engines is a viable alternative to diesel.

Index Terms- Biodiesel, Fatty Acid Methyl Ester, Four stroke diesel engine, Transesterification

I. INTRODUCTION

Energy consumption is inevitable for human existence. Man relies immensely on it for various sectors of life like transportation, power generation, industrial processes, and residential consumption. World energy consumption doubled between 1971 and 2001 and the world energy demand will increase 53% by the year 2030. It is estimated that petroleum consumption will rise from 84.4 to 116 million barrels per day in USA until year 2030[1].Petroleum-based fuels are limited reserves concentrated in certain regions of the world. These sources are on the verge of reaching their peak production. The fossil fuel resources are shortening day by day. At the same time its consumption rate is pacing on an alarming rate. The world currently faces an energy crisis. The global fossil fuel prices have been increasing dramatically way beyond the imaginations of common men. The scarcity of known petroleum reserves will make renewable energy sources more attractive. Also the extensive use of fossil fuels has led to various environmental problems including pollution, increase in the amount of CO_2 and other greenhouse gases in the atmosphere, global warming etc.

The depletion of fossil fuel has forced the mankind to find alternate ways of energy generation which is renewable, environmental friendly and technically suitable in conventional engines without any modifications. Among the various alternatives biofuels especially biodiesel stands out as promising method. Biodiesels are esters of long chain fatty acids derived from vegetable oils or animal fats. They are produced by the transesterification reaction of long chain fatty acids by alcohols, primarily methanol or ethanol, in presence of catalysts [2]. The direct use of alcohols as fuel causes corrosion of various parts in the engine. The transesterification process solves this problem.

Biodiesel fuels are attracting increasing attention worldwide as a blending component or a direct replacement for diesel fuel in vehicle engines. Biodiesel is a vegetable oil which can be used in diesel engines after some adjustments and modifications. Vegetable oils are the primary source of biodiesel. They can be of edible or non edible nature. Edible oils like coconut oil, soybean oil, sesame oil, palm oil, sunflower oil can be used. Non edible oils include algal oil, rubber seed oil, Jatropha curcas, rape seed oil, canola oil etc. In addition to these used oils can also be used for biodiesel production which is more economical. Oils of animal origin derived from sheep and beef tallow, fish oil etc also serves as source of biodiesel. Vegetable oils contain saturated hydrocarbons (triglycerides) which consist of glycerol and esters of fatty acids. In addition, fatty acids have different numbers of bonds and carbon chain lengths.

The utilization of biofuels or vegetable oil in internal combustion engines was reported during 1920–1930 and Second World War from all around the world. Germany, Argentina, Japan, Belgium, Italy, France, the United Kingdom, Portugal, and China have tested and used different types of biofuels [3]. The investigation of vegetable oils as fuel started in 1978 and 1981 in the United States and South Africa, respectively. In 1982, methyl ester was produced in Germany and Austria from rapeseed oil, and a small pilot plant was built in Austria at 1985.

Commercial production of methyl ester first began in Europe in 1990. More than 2.7 million tones biodiesel was produced in Europe in 2003, but their target is around 20% total diesel market in 2020. In addition, the USA future plan for biodiesel production is around 3.3 million tons in 2016 [4].

Detailed studies were made in several papers for the selection of catalyst needed for the process. There are two kinds of catalysts typical to any biodiesel process: homogeneous and heterogeneous. If the catalyst remains in the same (liquid) phase to that of the reactants during transesterification, it is homogeneous Catalytic transesterification. On the other hand, if the catalyst remains in different phase (i.e. solid, immiscible liquid or gaseous) to that of the reactants the process is called heterogeneous catalytic transesterification. The heterogeneous catalytic transesterification is included under Green Technology due to the following attributes: (1) the catalyst can be recycled (reused), (2) there is no or very less amount of waste water produced during the process and (3) separation of biodiesel from glycerol is much easier [5].

The inventor of biodiesel engines, Rudolf Christian Karl Diesel (1858–1913) demonstrated the use of vegetable oils as a substitute for diesel fuel in the 19th century. He believed the utilization of biomass fuel will become a reality as future versions of his engine are designed and developed [6].In recent years, lots of studies are being done to determine the suitability of vegetable oil and its derivatives as fuel or additives to the diesel. Transesterification followed by blending with conventional diesel is the commonly adoptable way to use the vegetable oil as fuel in diesel engines. Christopher [7] conducted some tests in Chicago using biodiesel as the alternative fuel for in-service motor coaches. This was an exploratory investigation to determine the effect of fuel on the engine performance characteristics and infrastructure needed to use this fuel. This testing proved that the biodiesel could easily be used as a feasible alternative fuel. Choi [8] conducted tests on biodiesel blended with diesel fuel in the concentration of 20 and 40% by volume on a single cylinder caterpillar engine, using both single and multiple injection strategies. The experimental results of these researchers support the use of biodiesel as a viable alternative to the diesel oil for use in the internal combustion engines.

In this study biodiesel is produced from coconut oil by transesterification with methanol in presence CaO catalyst. Coconut oil can be used for the production of biodiesel in a simpler and easier way. The advantage of using this crop is due to its high abundance in south East Asia especially in India. In India kerala stands first in the production of coconut. Kerala is called as the land of coconuts. So the production of biodiesel from coconut oil stands as a promising way of energy utilization in our perspective. The crop is cultivated in hectares of areas in kerala as well as other states of India. Apart from India countries like Thailand, Malaysia and Indonesia are also leading producers of coconut. The advantage of this crop is its resistance to sustain in temperate climates and also the poor soil conditions. Each coconut tree can bear about 14 coconuts per month for 65 years .That comes to about 6000 coconuts per acre. This natural sustainability and abundance of coconut makes it popular. And also if we compare the properties of coconut oil it is also significant while we chose it for FAME production. The specific energy and other properties of coconut oil is comparably good than other oils. The values are closer to petroleum diesel. Heterogeneous transesterification was selected since catalyst can be recycled, reused after reaction. Hence powdered CaO which is a heterogeneous catalyst was employed. Also it makes the separation of ester and glycerol layer is comparatively easier. Methanol which is less commercially important and cheaper than ethanol was used.

This paper discusses the influence of the various reaction parameters like temperature, time, Methanol to oil ratio and catalyst amount were studied. These variables were optimized experimentally. Also various blends were prepared by mixing conventional diesel and biodiesel in different proportions. The trials were run on conventional diesel, pure biodiesel and blends of biodiesel blended with conventional diesel in different proportions .Biodiesel can be blended in many proportions with conventional Diesel. B100 is pure biodiesel. B10 blend is 10 volume percentage pure biodiesel blended with 90 volume percentage of conventional Diesel. Similarly other blends were also prepared containing 20% and 30% biodiesel proportions. It was tested in four stroke diesel engine and performance characteristics were analyzed.

II. Experiment

A. Materials & Reagents

Dried coconut shells (copra) were collected from various locations. Oil from shells was extracted using mechanical press. The extracted oil was collected and stored. 98% methanol, CaO powder was purchased from chemind.

B. Reactor Set Up

The reactor unit was setup consisting of stirrer and a water bath which gives a provision for heating up to 100^0C. It has volume of about 3 liters approximately.

C. Procedure

Coconut oil was preheated to the reaction temperature. Lye was prepared by mixing methanol with catalyst CaO. Then the mixture was stirred well and then allowed to settle. Two separate layers will be formed, upper layer consists of fatty acid methyl ester (FAME) and lower layer consists of glycerol. The procedure was repeated for various combinations of temperature, alcohol to oil ratio, catalyst amount at different reaction times. Optimization of the parameters was made experimentally.

D. Engine Testing

A single stage cylinder, constant speed, 4-stroke water cooled diesel engine developing 8 HP at 850 rpm was used for the engine test which is shown figure 1. The detailed specification is given in table 1.

Fig.1: Four Stroke Diesel Engine

Type of stroke	4 stroke
Engine make	Anil Engine
BHP	8 HP
Speed	850 rpm
Bore	114.3
Diameter of rope	20 mm
Diameter of brake drum	320 mm

Table I: Engine Specifications

The fuel tank is connected to a graduated burette to measure quantity of fuel consumed in unit time. The thermal energy generated is known as the calorific value of the fuel. A part of this energy alone gets converted into mechanical power of the piston movement, known as the indicated power (I.P). A little amount of indicated power is used to overcome the frictional losses of the engine known as frictional power (F.P) and the remaining is delivered as the useful power output of the engine known as Brake power (B.P). Experiments were carried out initially using conventional diesel fuel to generate the base line data for various loads. After recording the base line Data, tests were carried out using B10, B20, B30 biodiesel blends .The engine tests were conducted at various loads by increasing the load on the brake drum and the parameters related to performance characteristics such as specific fuel consumption (SFC), total fuel consumption (TFC), brake thermal efficiency (BTE) and indicated thermal efficiency (ITE) were recorded. The experimental data generated are documented and presented using appropriate graphs.

III. Result and Discussions

Each parameter that depend the reaction was optimized. The results were tabulated and graphs were plotted.

A. Optimization of Reaction Time

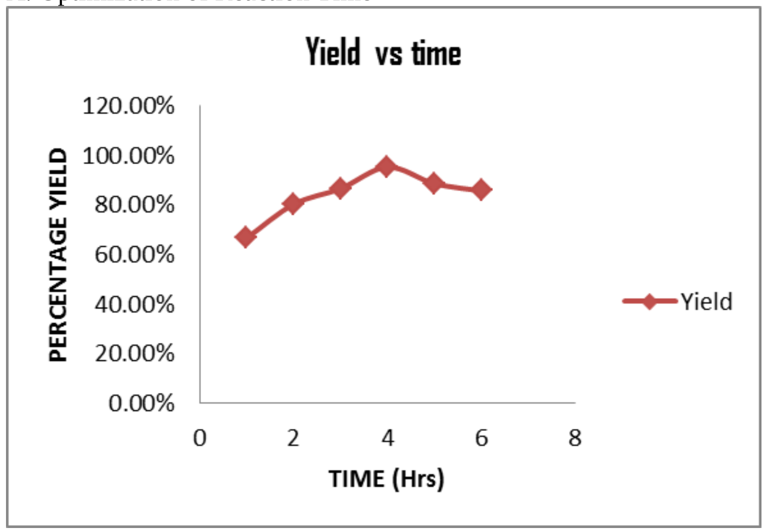

Fig.2: Optimization of Reaction Time for CaO Sample

The optimization of reaction time was done by keeping all other parameters as constant and by conducting the experiments for various reaction times. The optimum value was found at the time were maximum yield was obtained. The optimum time required for the reaction was about 4hrs for with CaO catalyst. Initially the yield was less when time was low since the reaction requires more time to complete while using heterogeneous catalyst. Gradually as the time increased the yield also increase and reached a maximum at 4hrs .At 4hrs the yield was 95.33%.Then the yield declined as the time increased the percentage yield was only 88.66%. So the optimum was taken at 4hrs.

B. Optimization of Reaction Temperature

The experiment was carried up to 70^0C for finding the optimum required temperature for the reaction. The maximum yield was obtained at 60^0C. For temperatures higher than 60^0C, the yield was less because it exceeds the boiling point of methanol which results in evaporation of alcohol during the reaction.

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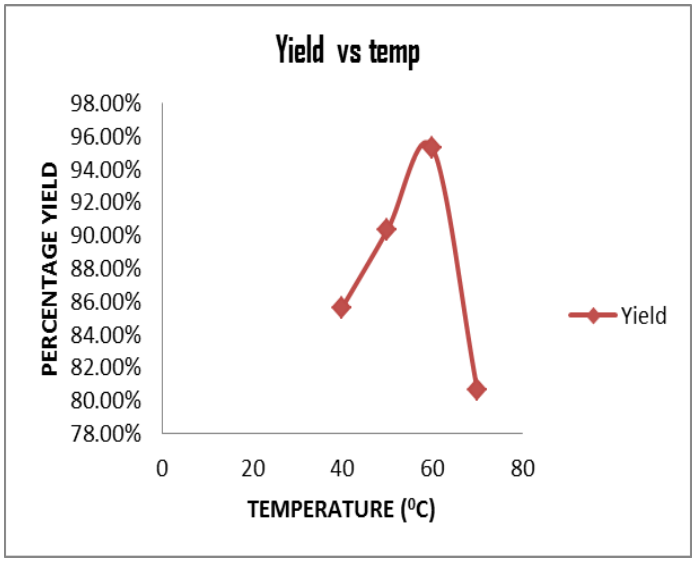

Fig. 3: Optimization of Reaction Temperature for CaO Sample

C. Optimization of methanol to oil ratio

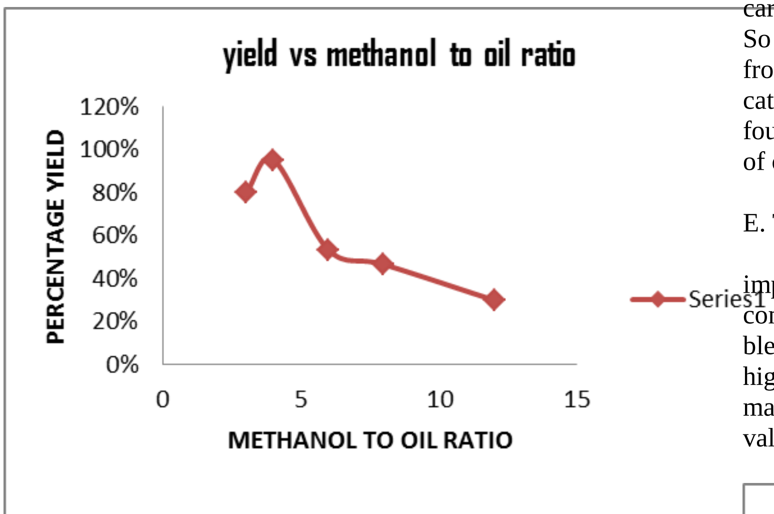

Fig. 4: Optimization of methanol to oil ratio for CaO Sample

The amount of alcohol needed for is an important factor that determines the rate of formation of ester or biodiesel product. Experiments with methanol to oil ratio starting from 3:1 to 12:1 were done and the optimum was found at 4:1.

D. Optimization of catalyst amount

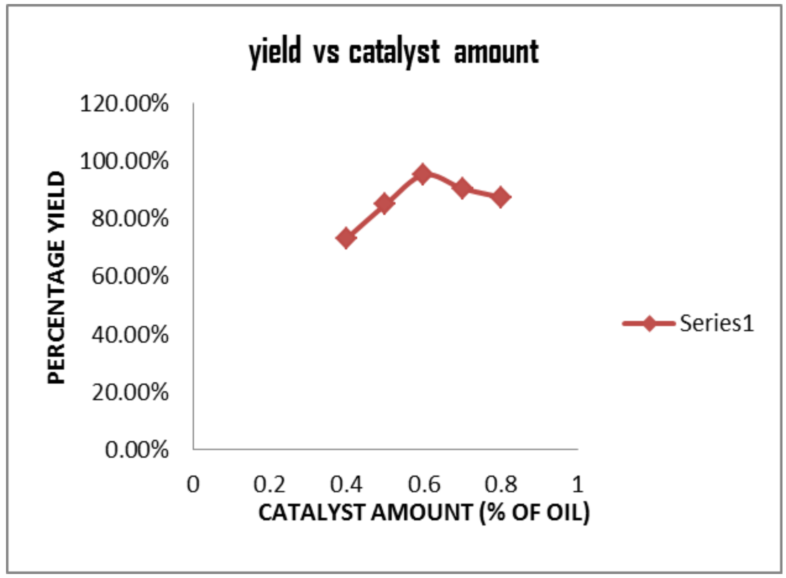

Fig.5: Optimization of catalyst amount for CaO Sample

Normally the amount of catalyst required is less when we carry out the experiment with a heterogeneous catalyst like CaO. So a lesser range was chosen for doing the experiment starting from 0.4% to 0.7%. However the yield was very low when catalyst amount was less than 0.4%. From the experiment it was found that the optimum amount of catalyst required is only 0.6% of oil used.

E. Total Fuel Consumption (TFC)

Accurate measurement of fuel consumption is very important in engine testing work. The figure 6 shows the comparison between the fuel consumed by various biodiesel blends and conventional diesel. The amount of fuel required is higher as the amount of biodiesel in the blend increases. This may be due to the lower calorific value of biodiesel. However the values are comparable with that of conventional diesel.

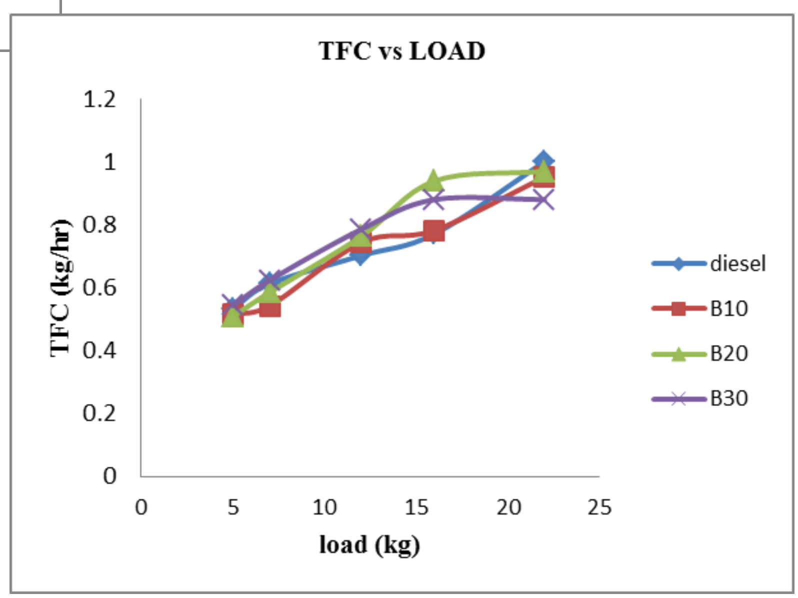

Fig. 6: Variation of TFC with Load

F. Effect of Load on Specific Fuel Consumption

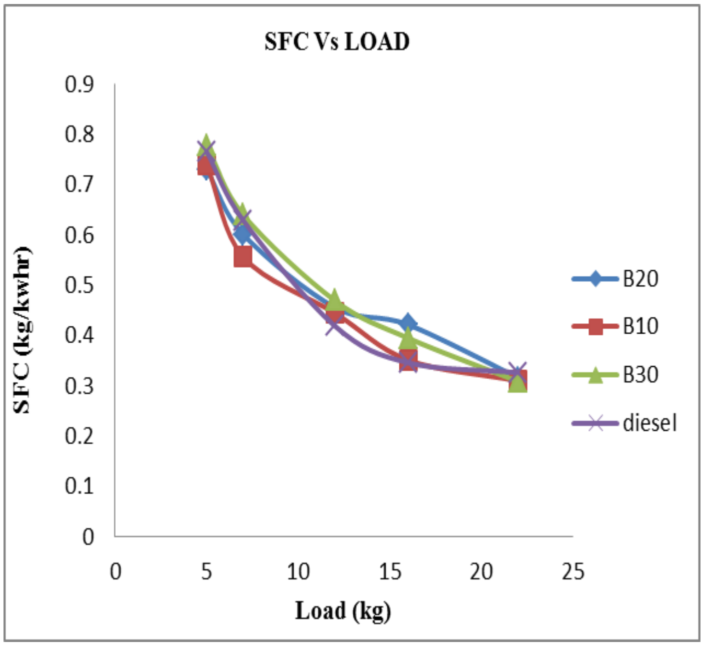

Fig.7: Variation of Specific Fuel consumption with Load

Specific Fuel Consumption (SFC) is a measure of the efficiency of the engine in using the fuel supplied to produce work. It is desirable to obtain a lower value of SFC indicating that the engine used less fuel to produce the same amount of work. Fig. 7 gives a comparison of SFC of various blends of biodiesel with that of conventional diesel. The specific fuel consumption keeps on decreasing with increasing load. Fuel consumption is more for biodiesel blends since the calorific value of biodiesel is lesser than conventional diesel. However the value of SFC of biodiesel blends are not very high when compared to pure diesel. This shows that the using of blended biodiesel is economically acceptable.

G. Effect of Load on Brake Thermal Efficiency

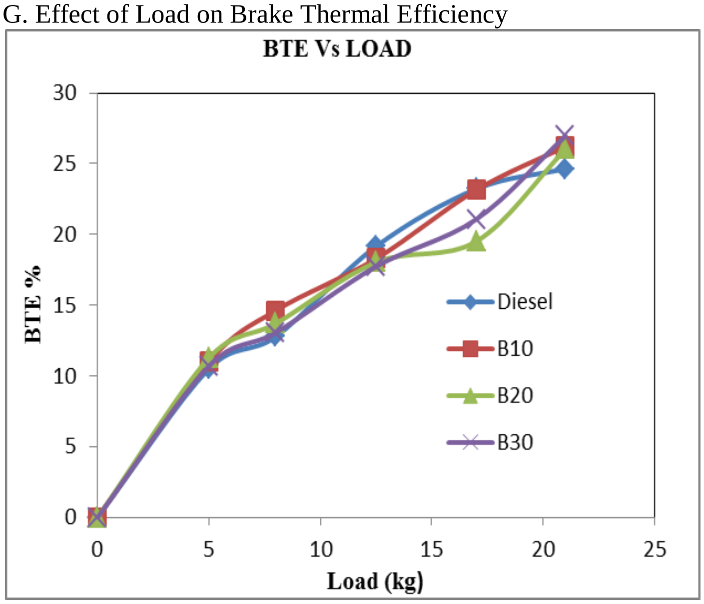

Fig. 8: Variation of Brake Thermal Efficiency with Load

The brake thermal efficiency is defined as the ratio of brake horse power to the heat energy of the fuel supplied during the same interval of time. Figure 8 shows the variation of brake thermal efficiency with different loads for different biodiesel blends and pure diesel. From the plot it is clear that thermal efficiency increases with load. This is due to the reduction in heat loss and increase in power developed with increase in load. The brake thermal efficiency of biodiesel blends is slightly lower than conventional diesel. This reduction in brake thermal efficiency with biodiesel blends was due to higher viscosity, poor spray characteristics and lower calorific value. The higher viscosity leads to decreased atomization, fuel vaporization and combustion.

H. Effect of Load on Indicated Thermal Efficiency

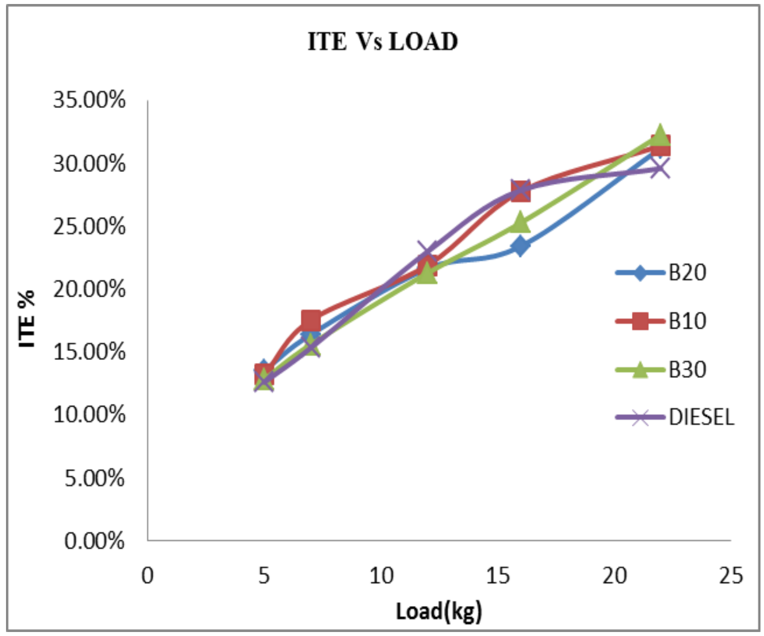

Fig. 9: Variation of Indicated Thermal Efficiency with Load

The efficiency of various biodiesel blends and conventional diesel is shown in figure 4.3. Here efficiency increases with load. However the efficiency of the prepared biodiesel blends is comparable with the efficiency of conventional diesel. Hence the biodiesel blends can be used in engines to obtain good performance.

IV. Conclusions

The reaction parameters time, temperature, methanol to oil ratio and catalyst amount were optimized experimentally. The values obtained were 4 hrs, 60^0C, 4:1 and 0.6% of oil respectively. Engine test results shows that all biodiesel blends were showing values closer to that of diesel values which is evident from the graphs. Thus it can be inferred that biodiesel blends can be efficiently used in engines without any modifications and also with satisfactory performance. All the performance curves obtained from the experiment validate the statement. Efficiency attained was well closer to conventional diesel efficiency and also the amount of fuel consumed was not very high.

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