Scientific Journal Impact Factor (SJIF): 1.711

e-ISSN: 2349-9745
p-ISSN: 2393-8161

International Journal of Modern Trends in Engineering and Research
www.ijmter.com

A Comparative Analysis of Compression Ignition Engine Characteristics Using Preheated High Blend of Pongamia Methyle Ester

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Abstract: This paper investigate the scope of utilizing biodiesel with high bland (B20 & B40) developed from the Methyle alcohol from pongamia oils as an alternative diesel fuel. The major problem of using neat pongamia oil as a fuel in a compression ignition engine arises due to its very high viscosity. Transesterification with alcohols reduces the viscosity of the oil and other properties have been evaluated to be comparable with those of diesel. In the present project work, an experimental investigation is carried out on performance and emission characteristics of preheated higher blends of pongamia biodiesel with diesel. The higher blends of fuel is preheated at 60, 75, 90 and 110˚C temperature using waste exhaust gas heat in a shell and tube heat exchanger. Transesterification process is used to produce biodiesel required for the project from raw pongamia oil. Experiments were done using B20 and B40 biodiesel blends at different preheating temperature and for different loading. A significant improvement in performance and emission characteristics of preheated B40 blend was obtained. B40 blend preheated to 110˚C showed maximum 8.72% and 8.97% increase in brake thermal efficiency over diesel and B20 blend respectively at 75% load. Also the highest reduction in UBHC emission and smoke opacity values are obtained as 79.41% and 80.6% respectively over diesel and 78.12% and 73.54% respectively over B20 blend for B40 blend preheated to 110˚C at 75% load. Thus preheating of higher blends of diesel and biodiesel at higher temperature improves the viscosity and other properties sharply and improves the performance and emission.

Keywords: Transesterification, Preheating, Biodiesel blend, waste heat from exhaust gas.

I. INTRODUCTION

A. Bio diesel: A renewable fuel

Industrial development and economy of any country is mainly depends on its necessitates continued search and sustainable development of alternative energy sources that are environmental friendly. Biomass sources, particularly vegetable oils, have attracted much energy resources. Due to the depletion of the world's petroleum reserves and the increasing environmental concerns, it attention as an alternative energy source. Biodiesel, a form of biomass particularly produced from vegetables oils, has recently been considered as the best candidate for a diesel fuel substitution

Biodiesel is a clean renewable fuel, simple to use, biodegradable, nontoxic, and essentially free of sulphur and aromatics. It can be used in any compression ignition engine without the need for modification. Also usage of biodiesel will allow a balance to be sought between agriculture, economic development and the environment. Rudolph Diesel, the inventor of the Diesel engine, used peanut oil as the fuel for its demonstration in diesel engine. However, it is only in recent years that systematic efforts have been made to utilize vegetable oil as fuels in the engines.

Biodiesel, which can also be known as fatty acid methyl ester (FAME), is produced from transesterification of vegetable oils or animal fats. Biodiesel is quite similar to petroleum-derived diesel in its main characteristics such as cetane number, energy content, and viscosity and phase changes. It has a reasonable cetane number and hence possesses less knocking tendency. Biodiesel

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contains no petroleum products, but it is compatible with conventional diesel and can be blended in any proportion with fossil-based diesel to create a stable biodiesel blend. Therefore, biodiesel has become one of the most common biofuel in the world.

Chemically, biodiesel is a mixture of methyl esters with long-chain fatty acids and is typically made from nontoxic, biological resources such as vegetable oils, animal fats, or even used cooking oils. Vegetable oils include edible and non-edible oils. Many standardized procedures are available for the production of bio-diesel fuel oil. There are four primary ways to produce biodiesel, direct use and blending of raw oils, micro emulsions, thermal cracking, and transesterification of vegetables oils and animal fat oil. The most commonly used method for converting oils to biodiesel is through the transesterification.

B. Biodiesel from pongamia oil

A biodiesel is mainly produced from vegetables oils. Pongamia oil is a very good source of biodiesel. Oil of Pongamiapinnata is a non-edible oil of Indian origin. Karanja and Honge are the other Indian names of Pongamia oil. It is found mainly in the native Western Ghats in India, northern Australia, Fiji and in some regions of Eastern Asia. This medium sized (max height 18 m) tree is found almost throughout India up to an altitude of 1200 m. It grows fast and matures after 4 to 7 years yielding fruits which are flat, elliptic and approx. 7.5 cm long. Each fruit contains 1 to 2 kidney shaped brownish red kernels. The oil content of the kernel is 30 to 40%. A single tree is said to yield 9 to 90 kg seed per tree, indicating a yield potential of 900 to 9000 kg seed/ha (assuming 100 trees/ha), 25% of which might be rendered as oil. The oil contains primarily eight fatty acids viz. palmitic, stearic, oleic, linoleic, lignoceric, eicosenoic, arachidic and behenic. Of these, the four which are commonly found in most oils, including Pongamia, are the saturated acids, palmitic (Hexadecanoic acid), stearic (Octadecanoic acid) the unsaturated acids, oleic (Octadec-9- enoic acid) and linoleic. This dark brown oil has a repulsive odor and shows fungicidal properties. It is popular in southern part of Bharat due to its low cost and ready availability. However, as for other oils there are limitations in the use of this non-edible oil as fuel. Its high viscosity and poor combustion characteristics can cause poor atomization, fuel injector blockage, excessive engine deposit and engine oil contamination. In India the prohibitive cost of edible oils prevents their use in biodiesel preparation, but non-edible oils are affordable for biodiesel production.

C. Preheating of biodiesel-diesel blends

Although vegetable oils have some similar physical fuel properties with diesel fuel in terms of energy density, cetane number, heat of vaporization and stoichiometric air/fuel ratio, the use of neat vegetable oils or its blends as fuel in diesel engines leads to some problems such as poor fuel atomization and low volatility mainly originated from their high viscosity, high molecular weight and density. It is reported that these problems may cause important engine failures such as piston ring sticking, injector coking, formation of carbon deposits and rapid deterioration of lubricating oil after the use of vegetable oils for a long period of time. There are different methods used for improving fuel properties and decreasing viscosity and density of oils such as dilution of vegetable oils with solvents, pyrolysis, micro emulsification with alcohols and transesterification. Although most of these methods do not eliminate the problems completely. On the other hand, the transesterification is a widely applied, convenient and most promising method for reduction of viscosity and density of vegetable oils. The fuels produced by transesterification of the oils are called biodiesel. Despite transesterification process, which has a decreasing effect on the viscosity of vegetable oil, it is known that biodiesel still has some higher viscosity and density when compared with diesel fuel. The viscosity of fuels has important effects on fuel droplet formation, atomization, vaporization and fuel–air mixing process, thus influencing the exhaust emissions and performance parameters of the engine. It has been also revealed that the use of biodiesel leads to a slight reduction

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in the engine break power and torque, and a slight increase in the fuel consumption and brake specific fuel consumption compared to diesel fuel. These changes can be attributed to the lower heating value of biodiesel.

So far many authors reported use of B20 blend (20% biodiesel and 80% diesel) in I.C. engine as an optimum blend and replacement for diesel fuel. The higher viscosity of biodiesel than diesel limits the use of complete biodiesel and higher blends of diesel and biodiesel in the I.C. engine. The higher viscosity has effect on combustion and proper mixing of fuel with air in the combustion chamber. It inhibits the proper atomization, fuel vaporization and combustion. Due to high viscosity fuel droplet size will be bigger and the fuel droplet will not get burned. When these droplets mix with the hot gases in the later part of the power stroke oxidation reaction occurs but may not have enough time to undergo complete combustion. Some authors have reported ignition delay when 100% biodiesel is used.

It has been reported that CO emission increases in higher biodiesel blends with diesel. Because of the oxygen in the esters complete combustion takes place in lower blends of biodiesel and diesel, CO emission is less. But due to high viscosity and small increase in the specific gravity may suppress the complete combustion process. Because of higher viscosity of the higher ratio blends the fuel droplet will not get burned. When these droplets mix with the hot gases in the later part of the power stroke oxidation reaction occurs but may not have enough time to undergo complete combustion and produce higher CO emission. In case of higher blends the brake thermal efficiency decreases with the increasing percentage of the biodiesel. This is due to poor mixture formation as a result of low volatility, higher viscosity and density which leads poor atomization and reduced cone angle. For higher diesel biodiesel blend and neat vegetables oils the premixed combustion is reduced and diffusion combustion is increased. This is mainly due to longer ignition delay resulting in late burning. Due to this more amount of energy is released in the later part of combustion process which reduce efficiency.

Higher viscosity of higher blends of diesel and biodiesel can reduce by applying suitable techniques like preheating. Preheating of the oil and blending of oil with diesel tried to improve performance. Because of the heating process, the viscosity and density of biodiesel decrease and improves volatility thus leading to a favorable effect on fuel atomization and combustion characteristics. It can improve the oxidation of biodiesel in the cylinder and CO emissions arisen from incomplete combustion can decrease.

II. METHODOLOGY, EXPERIMENTAL SET UP AND PROCEDURE

The existing four stroke single cylinder diesel engine of kirloskar make was retrofitted with some of additional equipment and was interfaced with a personal computer. The essential component chosen and instrumentation system were carefully selected. Scheme of experimentation was planned to full fill the objective framed under the present work.

A. Details of experimental engine setup

The engine tests are conducted on a computerized single cylinder four-stroke, naturally aspirated, open chamber (Direct Injection) and water-cooled diesel engine test rig. The specification of diesel engine used for experiments is given in Annexure I. It was directly coupled to an eddy current dynamometer. The engine and the dynamometer are interfaced to a control panel, which is connected to a computer. Test rig is provided with necessary equipment and instruments for combustion pressure and crank angle measurements with accuracy. These signals are interfaced to computer through an analog and digital converter (ADC) card PCI-1050 which was mounted on the motherboard of the computer. Provision was also made for interfacing airflow, fuel flow,

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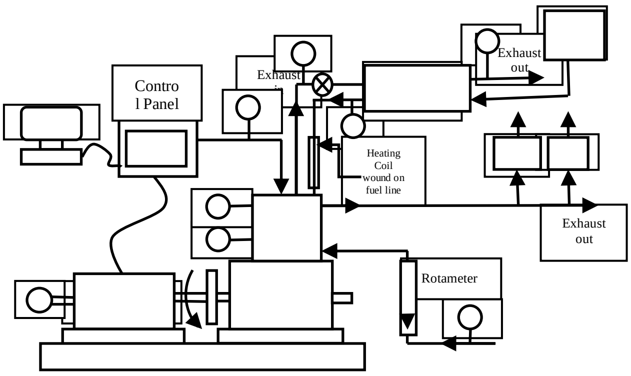
temperatures and load measurement with computer. The setup has standalone type independent panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air flow and fuel flow measurements, process indicator and engine indicator. For measurement of water flow rate for engine cooling, rotameter is provided.

One outlet from exhaust pipe is taken and feed to coiled shaped copper tube heat exchanger. The flow of exhaust gas is controlled by butterfly valve connected between heat exchanger and exhaust pipe. The temperature required to preheat the fuel is controlled by varying flow rate of exhaust gas. To minimize the temperature loss while flowing through fuel line, heating coil is mounted on the fuel pipe. Heating coil maintained the required temperature of fuel before entering to nozzle injector. Temperature of heating coil is controlled by using dimmer stat. Temperature of fuel at the exit of heat exchanger is measured by thermocouple mounted on copper tube. Inlet temperature of exhaust gas in heat exchanger is measured by temperature sensor which is connected to control panel. Thermometer is also mounted in exhaust line of heat exchanger to measure the exit temperature of exhaust gas.

The computer software Engine Soft Version 2.4 supplied by the test rig supplier "Apex Innovations Pvt. Ltd" will be used for recording the test parameters such as fuel flow rate, temperatures, air-flow rate, load etc. and for calculating the engine performance characteristics such as brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, brake specific fuel consumption, volumetric efficiency etc. The calorific value and the density of the particular fuel should be fed to the software for calculating the above said performance parameters.



Airflow measurement was done by the conventional method u-tube manometer as well as by air intake DP unit present in the control panel. Engine speed was sensed and indicated by an inductive pickup sensor in conjunction with a digital RPM indicator, which was a part of eddy current dynamometer controlling unit. A strain gauge type load cell mounted beneath the dynamometer arm measures the load and signals are interfaced with ADC card to give load in kg. Temperature sensors of RADIX Pvt. Ltd. make are positioned at deferent locations to measure temperatures. Inlet exhaust gas temperature of heat exchanger is measured as T5 and outlet temperature is measured with thermometer fitted in the exhaust pipeline. An AVL Di-gas 444 five gas Exhaust gas analyzer was used to measure the NOx (ppm), CO (%), CO_2 (%) and HC (ppm) emissions in the exhaust.

B. Procedure followed for the performance and emission test

To conduct the engine performance and emission test, the biodiesel obtained by trans-esterification process was blended with petroleum diesel to get a volume proportion of B40 (60% diesel + 40% biodiesel). The experiment were conducted at the design injection timing of 27.5deg.btdc, constant speed of 1500 rpm, design injection pressure 180bar and 17.5 Compression ratio. To record the data online, software was logged every time and data was stored in the computer hard disk, which can be retrieved when it is required. Baseline data is created by running the engine with diesel and B20 blend for performance and emission test. The experiments were conducted at 25%, 50%, 75%, of full load, and full load conditions with B40 blend at 60 ^{0}C, 75 ^{0}C, 90 ^{0}C and 110 ^{0}C preheating temperature. Data such as fuel flow, inlet and outlet exhaust gas temperature to heat exchanger, exhaust smoke opacity, NOx, CO, CO2, and HC emissions were recorded at the above mentioned load conditions and preheating temperature. Steady state performance and emission readings were taken during each trial run and the average of the experimental results used for further calculations.

From the above data an extensive study was made in comparing the performance and emissions of diesel engine for different loads, for different fuel samples at 27.5deg.btdc injection timing for different preheating temperatures.

III. RESULT & DISCUSSION

Analysis of performance and emission of B40 (40% Biodiesel + 60% Diesel) blend preheated at 60˚C, 75˚C, 90˚C, and 110˚C temperature and B20 blend

A. Brake thermal efficiency (BTE)

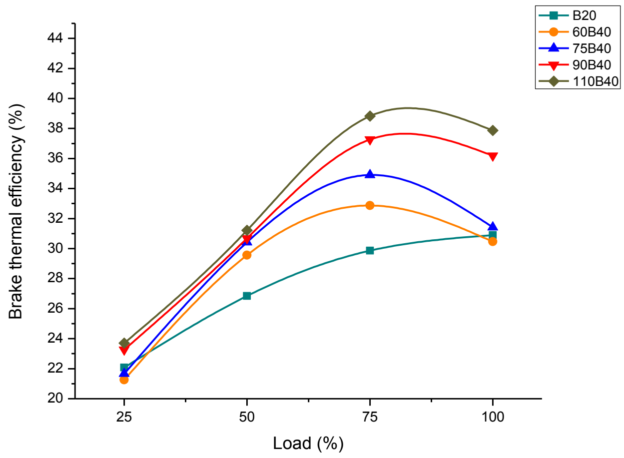


Figure 1. Variation of BTE for B40 blend at different preheating temperature and B20

From figure 1 it was observed that B40 blend has higher brake thermal efficiency at 110˚C preheating temperature compared to other temperatures and B20 blend. It was showing increasing trend in BTE with increasing preheat temperature. The significant improvement in BTE was observed only after 50% loading. The increase in BTE is more when preheating temperature is increased from 75˚C to 90˚C as compared to increase in BTE when temperature is increased from 90˚C to 110˚C. It showed maximum BTE at 110˚C at 75% loading. The increasing BTE can be attributed to the good combustion characteristics of fuel because of their decreased viscosity and improved volatility by means of preheating process. As the preheating temperature is increased from 60˚C to 110˚C viscosity of blend decreased sharply and volatility of molecule increased. It has favorable effect on atomization and vaporization of fuel. The maximum thermal efficiency was found to be 38.83% at 110˚C at 75% loading following 37.87% at full load condition. 8.97% and 6.97% increase in brake thermal efficiency was obtained over B20 blend at 75% and full load condition.

B. Brake specific energy consumption (BSEC)

From figure 2 it was observed that all temperature showed decreasing in values of BSEC with increasing load. 90˚C and 110˚C temperature showed sharp decrease in values of BSEC compared to other temperatures and B20 blend. The significant reduction in BSEC values were obtained only after 50% loading. Higher preheating temperature results in better spray and improved atomization during injection thereby improvising the combustion may be attributed for this. It can be seen that BSEC for 90˚C at 75% and full load are 9.66 MJ/KW-hr and 9.27 MJ/KW-hr respectively while for 110˚C at 75% and full load are 9.95 MJ/KW-hr and 9.51 MJ/KW-hr respectively. For 110˚C preheated B40 blend 2.79 and 2.14

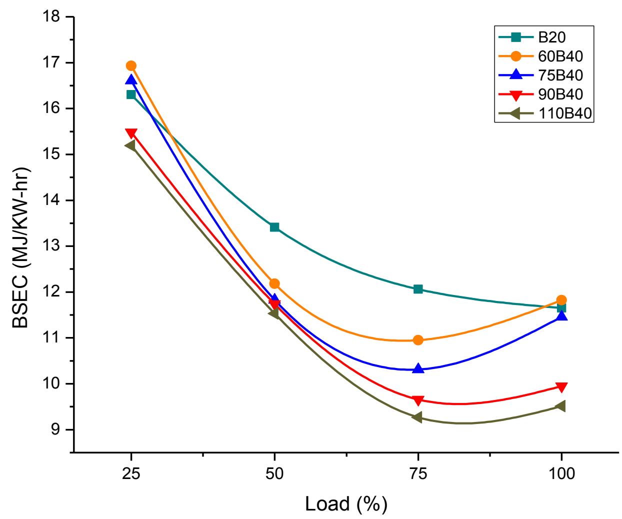


Figure 2. Variation of BSEC for B40 blend at different preheating temperature and B20

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MJ/KW-hr decrease in BSEC values were obtained over B20 blend for 75% and full load. BSEC values are observed to be higher for low load condition. At low load condition exhaust temperature is found to be lower, hence it could not preheat inlet fuel effectively as compared to be at higher load. Because of this it did not have favorable effect on combustion and leads to increasing BSEC at low load. While much decreased in BSEC values are observed at higher loads and at all temperature.

C. Unburned hydrocarbon (UBHC)

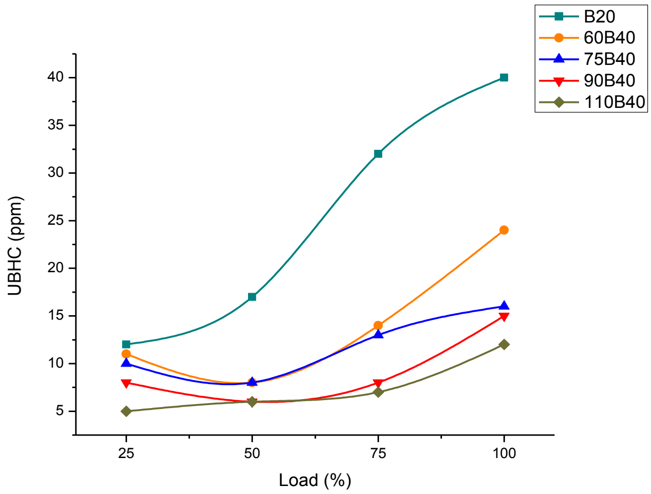

Figure 3. Variation of UBHC of B40 blend for different preheating temperature and B20

From figure 3 it was observed that B40 has lower emission of unburned hydrocarbon at 110˚C for all loading conditions as compared to other preheating temperature and B20 blend. B20 blend was showing maximum UBHC emission compared to all other preheated B40 blend. It was showing decreasing trend in UBHC emission with increasing preheat temperature. The decreasing UBHC emission is more when preheating temperature is increased from 75˚C to 90˚C as compared to decrease in UBHC emission when temperature is increased from 90˚C to 110˚C. The maximum reduction of UBHC over B20 blend was 78.12% for B40 blend at 110˚C. UBHC are generally results of incomplete combustion of fuel. Preheating of B40 blend before to the injection was resulting in decrease of viscosity of B40 biodiesel blend and better mixing of fuel with air that leads to favorable effect on combustion of fuel and hence UBHC emissions are less at 90˚C and 110˚C temperature. The cetane number of ester based fuel is higher than diesel, it exhibits a shorter delay period and results in better combustion leading to low HC emission. Also the intrinsic oxygen contained by the PPME was responsible for the reduction in HC emission.B40 blend emitted more UBHC at 60˚C than other preheating temperature.

D. Nitrogen oxides (NOx)

The oxides of nitrogen in the exhaust emissions contain nitric oxide (NO), nitrogen dioxide (NO2), nitrous oxide and many other oxides of N2. The formation of NOx is highly dependent on the temperature in the combustion chamber and oxygen concentration for the reaction to take place. From figure 5.4 it was observed that NOx emissions are increased at higher preheating temperature and showing increasing trend as load increases. B40 showed higher NOx emission for 90˚C and 110˚C for 75% to full load conditions while B20 showed lowest NOx emission. The maximum NOx emission was 1390 ppm and 1680 ppm for 110˚C preheated B40 blend for 75% and full load. The increasing NOx emission was significant after 50% loading. The higher NOx emission at higher temperature can be attributed to various reasons, such as improved fuel spray characteristics, better combustion of biodiesel due to its oxygen content and

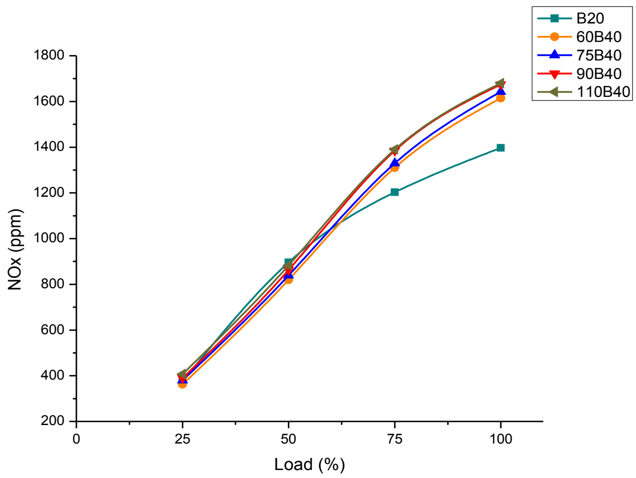

Figure 4. Variation of NOx for B40 blend for different preheating temperature and B20

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higher temperature in the cylinder as a result of preheating. The NOx emissions are lower at 25% and 50 % loading for all preheating temperature.

E. Smoke opacity

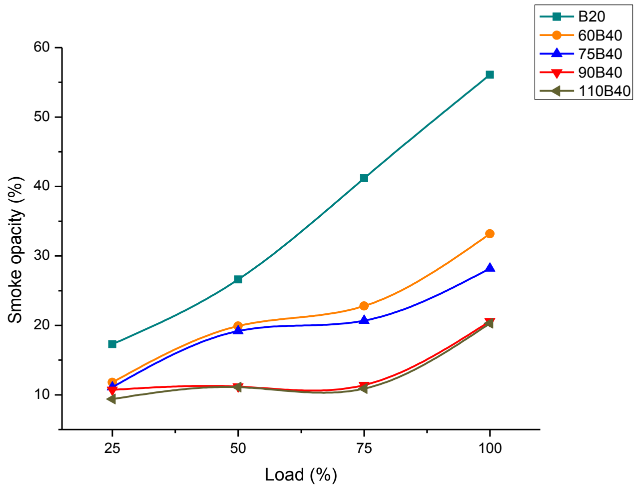

Figure 5. Variation of smoke opacity for B40 blend for different preheating temperature and B20

It is observed from figure 5 that smoke opacity values tend to increase for B20 blend compared to other preheated blend for all loading conditions. However for 90˚C and 110˚C, smoke values are marginally lower up to 75 % loading and showed higher trend at full load. 73.14% reduction in smoke opacity emission was obtained for 110˚C preheated B40 blend over B20 blend for 75% load. B20 showed higher smoke opacity emission over the other preheating temperatures. The decreasing smoke opacity values is more when preheating temperature is increased from 75˚C to 90˚C as compared to decrease in smoke opacity when temperature is increased from 90˚C to 110˚C. As mentioned earlier, at high temperatures B40 becomes very less viscous and resulted in better atomization and vaporization and leads to complete combustion of the injected fuel. This resulted in reduced smoke emissions. However smoke emission has increased particularly at higher load due to higher fuel consumption because of less calorific value of biodiesel fuel.

F. Carbon monoxide (CO)

It was observed from the figure 4.6 that CO emission was lower for 90˚C and 110˚C temperature for all load conditions while B20 and B40 blend at 60˚C temperature emitted higher CO for all load conditions. The significant improvement in CO emission was obtained after 50% loading. The decreasing CO emission is more when preheating temperature is increased from 75˚C to 90˚C as compared to decrease in CO emission when temperature is increased from 90˚C to 110˚C. High oxygen content and reduced viscosity of B40 blend due to preheating had good effect on complete combustion of fuel and reduced CO emission. For same loading condition a much reduction in CO emission level is obtained at higher temperature than at lower temperature. As it can be clearly seen from graph 62.5% and 66.67% reduction in CO emission is obtained for 110 ˚C preheated B40 blend over B20 blend for 75% load and full load.

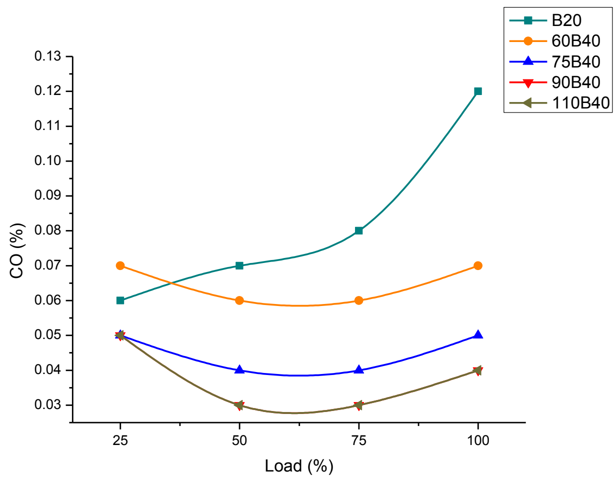

Figure 6. Variation of CO forB40 blend for different preheating temperature and B20

IV. CONCLUSION

The primary objective of the project work carried out here was to optimize the use of higher blends of biodiesel over diesel and B20 blend in the engine by preheating the fuel using exhaust gas heat before injection into the cylinder. From the above results from figures 4.1 to 4.6 it showed that as the

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preheating temperature increases the performance and emission characteristics also improved over B20. The significant improvement in performance and emission values was obtained after 50% load. The maximum brake thermal efficiency for B40 was found to be 38.83% at 110˚C at 75% loading following 37.87% at full load condition. 8.97% and 6.97% increase in brake thermal efficiency was obtained over B20 blend at 75% and full load condition. BSEC for 110˚C at 75% and full load are 9.95 MJ/KW-hr and 9.51 MJ/KW-hr respectively. For 110˚C preheated B40 blend 2.79 and 2.14 MJ/KW-hr decrease in BSEC values were obtained over B20 blend for 75% and full load. The maximum reduction of UBHC over B20 blend was 78.12% for B40 blend at 110˚C. The maximum NOx emission was 1390 ppm and 1680 ppm for 110˚C preheated B40 blend for 75% and full load. 73.14% reduction in smoke opacity emission was obtained for 110˚C preheated B40 blend over B20 blend for 75% load. 62.5% and 66.67% reduction in CO emission is obtained for 110 ˚C preheated B40 blend over B20 blend for 75% load and full load.

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