EXPERIMENTAL INVESTIGATIONS ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING PREHEATED PONGAMIA METHYL ESTER AS FUEL

Dinesha P[1], Mohanan P[2]
[1]Department of Mechanical Engineering, KVGCE., Sullia, Karnataka, India.
[2]Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, India.

ABSTRACT

Biodiesel is a renewable fuel, which can reduce the use of petroleum based fuels and possibly lower the overall greenhouse gas emissions of internal combustion engines. Therefore, to reduce emissions, researchers have focused their interest in the areas of biodiesel as alternative fuel for diesel engine. Investigations have shown that B20 blend has good performance and emission characteristics on CI engines. Further increase of biodiesel fraction in the blends will increase the viscosity and decrease performance. To increase the fraction of biodiesel in blends, it is required to reduce the viscosity by preheating. In the present work, an experimental investigation is carried out on a four stroke single cylinder CI engine to find out the performance and emission characteristics with preheated B40 blend of pongamia biodiesel and B20 biodiesel. The B40 blend 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 present research from raw pongamia oil. Experiments were done using B40 biodiesel blend at different preheating temperature and for different loading. A significant improvement in performance and emission characteristics of preheated B40 blend is obtained. B40 blend preheated to 110˚C showed maximum 8.97% increase in brake thermal efficiency over B20 blend at 75% load. Also the highest reduction in UBHC emission and smoke opacity values were obtained as 78.12% and 73.54% respectively over B20 blend for B40 blend preheated to 110˚C at 75% load. Thus preheating of higher biodiesel blend at higher temperature improves the viscosity and other properties sharply and improves the performance and emission.

KEYWORDS: *Transesterification, Preheating, Biodiesel blends, Heat exchanger, Waste heat from exhaust gas.*

I. INTRODUCTION

Industrial development and economy of any country is mainly depends on its energy resources. Majority of the world's energy needs are supplied through petrochemical sources, coal, natural gases, hydroelectricity and nuclear energy. Diesel and gasoline fuel plays a very important role in meeting the energy requirement of various applications across the world. The high energy demand in the industrialized world and wide spread use of fossil fuels is leading to fast depletion of fossil fuel resources as well as environmental degradation. Due to the depletion of the world's petroleum reserves and the increasing environmental concerns, it necessitates continued search and sustainable development of alternative energy sources that are environmental friendly [1-2]. Biomass sources, particularly vegetable oils, have attracted much attention as an alternative energy source. They are renewable, non-toxic and can be produced locally from agriculture and plant resources. Their utilization is not associated with adverse effects on the environment because they emit less harmful emissions and green house gases [3]. Biodiesel, a form of biomass particularly produced from vegetables oils, has recently been considered as the best candidate for a diesel fuel substitution [4-6]. Biodiesel is a clean renewable fuel, simple to use, biodegradable, nontoxic, and essentially free of sulphur and aromatics [7]. 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 [8]. 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 [9]. Biodiesel is quite similar to petroleum derived diesel in its main characteristics such as cetane number, energy content, viscosity and phase changes. It has a reasonable cetane number and hence possesses less knocking tendency. Biodiesel 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 [10].

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 [11-12].

1.1 Biodiesel from pongamia oil

As biodiesel is mainly produced from vegetables oils, Pongamia oil is a very good source of biodiesel [13]. Oil of Pongamia pinnata 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. The oil contains primarily eight fatty acids viz. palmitic, stearic, oleic, linoleic, lignoceric, eicosenoic, arachidic and behenic. Pongamia oil has high viscosity and poor combustion characteristics which 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.

1.2 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 [14]. The transesterification is a widely applied, convenient and most promising method for reduction of viscosity and density of vegetable oils. Despite transesterification process, which has a decreasing effect on the viscosity of vegetable oil, biodiesel still has 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 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. The higher viscosity of biodiesel compared to diesel limits the use of complete biodiesel and biodiesel blends 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, the 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.

Many investigations have shown that the performance and emission characteristics of B20 biodeiesel blend is similar to that of diesel fuel. If the biodiesel proportion is further increased, the density and viscosity of the blends increases. Higher viscosity of these blends can be reduced by adopting suitable techniques like preheating. Because of the heating process, the viscosity and density of biodiesel decreases and improves volatility thus leading to a favorable effect on fuel atomization and combustion characteristics. It will improve the oxidation of biodiesel in the cylinder and CO emissions arisen from incomplete combustion will decrease [14-18].

1.3 Preheating of biodiesel blends: Related research work

Murat Karabektas et. al. [19] carried out experiments at full load conditions in a single cylinder, four-stroke, direct injection diesel engine. Before supplied to the engine, Cotton seed methyl ester (COME) was preheated to four different temperatures, namely 30, 60, 90 and 120˚C. The test data were used for evaluating the brake power and brake thermal efficiency (BTE) together with CO and NOx emissions. The results revealed that preheating COME up to 90˚C leads to favorable effects on the BTE and CO emissions but causes higher NOx emissions. Moreover, the brake power increases slightly with the preheating temperature up to 90˚C. The authors suggest that COME preheated up to 90˚C can be used as a substitute for diesel fuel without any significant modification in expense of increased NOx emissions. M. Pugazhvadivu and K. Jeyachandran [20] determined the performance and exhaust emission characteristics of a single cylinder diesel engine using diesel, waste frying oil (without preheating) and waste frying oil preheated to two different inlet temperatures (75 and 135˚C). The engine performance was improved and the CO and smoke emissions were reduced using preheated waste frying oil. It was concluded from the results of the experimental investigation that the waste frying oil preheated to 135˚C could be used as a diesel fuel substitute for short-term engine operation. In the present work B40 blend is selected as fuel and preheated to reduce the viscosity.

II. EXPERIMENTAL SETUP

2.1. Computerized Engine Test rig

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 as shown in Fig.1. The specification of diesel engine used for experiments is given in Table.1. It is 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 to digital converter (ADC) card PCI-1050 which is mounted on the motherboard of the computer.

Table.1 Test Engine Specification

Engine	Four-stroke, single cylinder, constant speed, water cooled CI Engine
Make	Kirloskar
Model & BHP	TV1 & 5.2kW@ 1500 RPM
Compression Ratio	17.5:1
Dynamometer Type	Eddy Current, with loading unit
Load Measurement	Strain Gauge Load cell
Interfacing	ADC card- PCI 1050

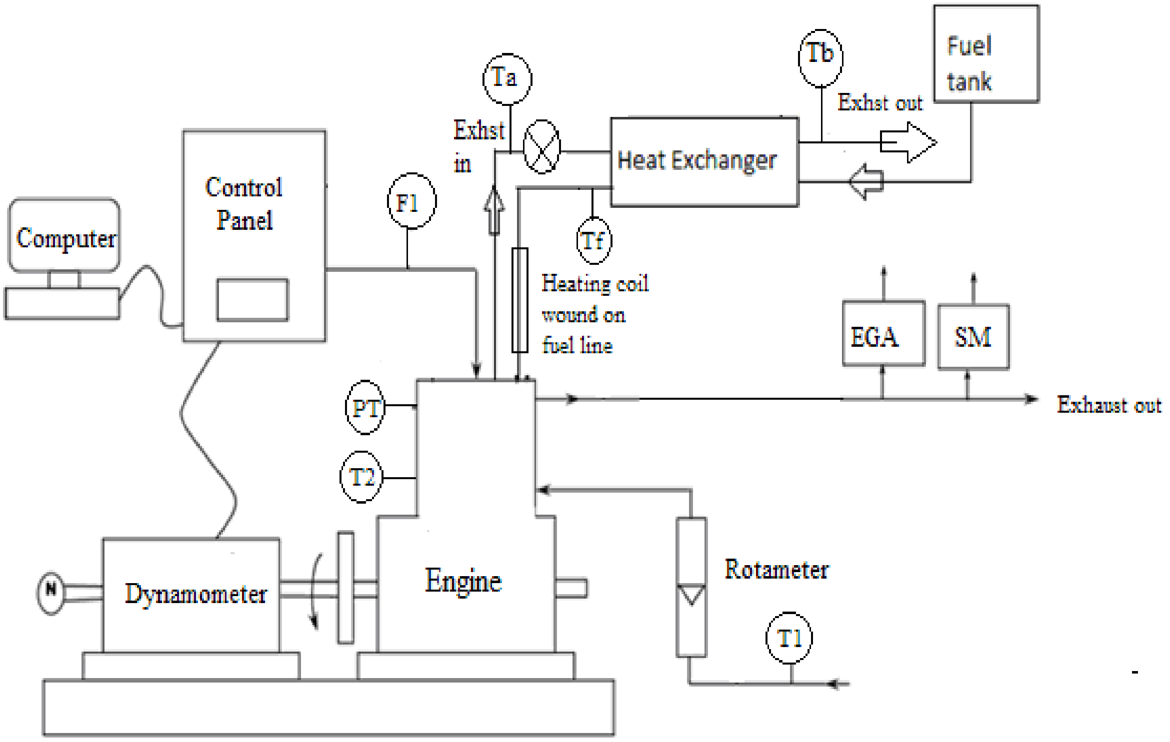

Figure 1. Schematic diagram of the experimental test rig

T1- Inlet engine water temperature PT - Pressure transducer N - RPM Decoder

T2 - Outlet engine jacket water temperature Ta, Tb - In and out temperature of exhaust gas in H.E

Tf - Fuel temperature at outlet of H.E EGA - Exhaust Gas Analyzer (5 gas)

F1- Fuel Flow (Differential Pressure unit) SM – Smoke Meter

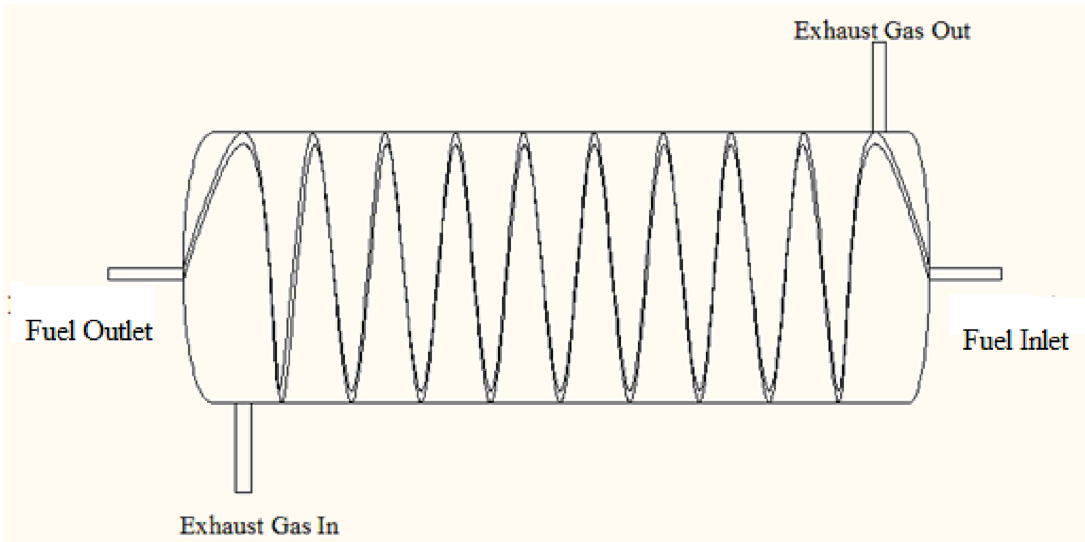

Figure 2 Heat Exchanger

III. RESULTS AND DISCUSSION

A wide range of experiments were carried out at different load conditions to examine the effect of preheating on performance parameters like BSEC, brake thermal efficiency and also an analysis is carried out on the emission parameters like NOx, CO, HC and smoke. The tests have been carried out with B40 blend preheated at 60˚C, 75˚C, 90˚C, and 110˚C temperatures and loading conditions of no load, 25%, 50%, 75% and 100% of full load.

3.1. Brake thermal efficiency (BTE)

From Fig. 3 it is observed that B40 blend has higher brake thermal efficiency at 110˚C preheating temperature compared to other temperatures and B20 blend. It is showing increasing trend in BTE with increasing preheat temperature. The significant improvement in BTE is 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 was found that the maximum BTE was achieved 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 increases 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 conditions respectively [19 &20]

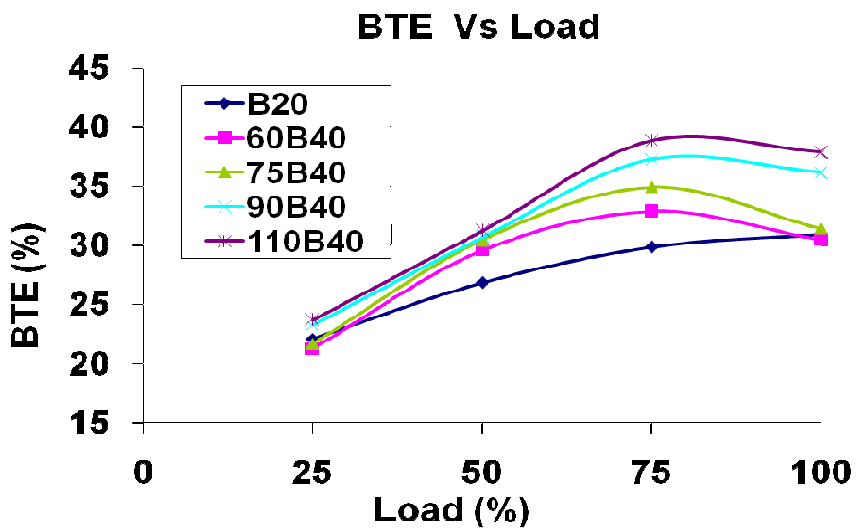

Figure 3 Variation of BTE for B40 blend at different preheating temperature and B20

3.2. Brake specific energy consumption (BSEC)

From Fig. 4 it is 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 are 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 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 is not having 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.

3.3. Unburned hydrocarbon (UBHC)

From Fig. 5 it is 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 is showing maximum UBHC emission compared to all other preheated B40 blend. It is 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.

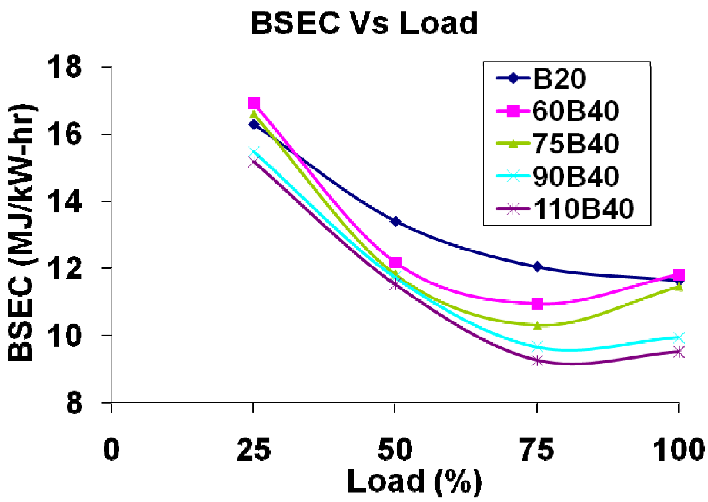

Figure 4 Variation of BSEC for B40 blend at different preheating temperature and B20

The maximum reduction of UBHC over B20 blend is 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 is 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 is responsible for the reduction in HC emission. B40 blend emitted more UBHC at 60˚C than other preheating temperature.

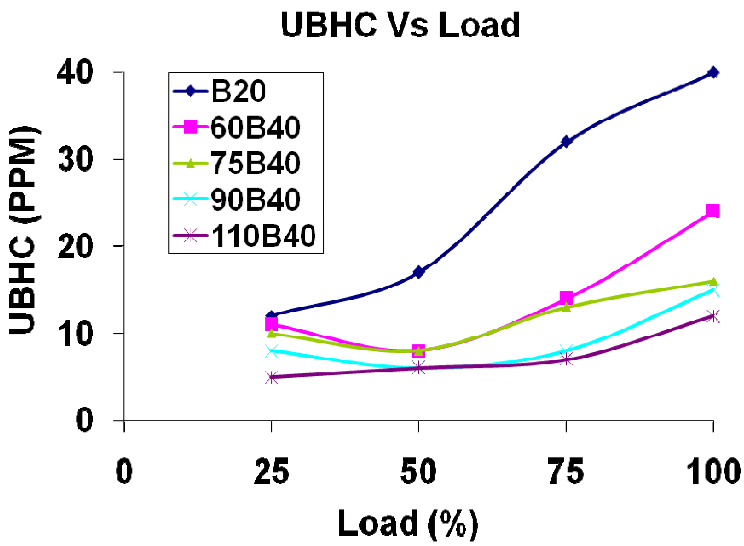

Figure 5 Variation of UBHC of B40 blend for different preheating temperature and B20

3.4. Nitrogen oxides (NOx)

The oxides of nitrogen in the exhaust emissions contain nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide and many other oxides of N_2. The formation of NOx is highly dependent on the temperature in the combustion chamber and oxygen concentration for the reaction to take place. From Fig. 6 it is 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 higher temperature in the cylinder as a result of preheating [19]. Due to low exhaust gas temperature, the NOx emissions are lower at 25% and 50 % loading for all preheating temperature.

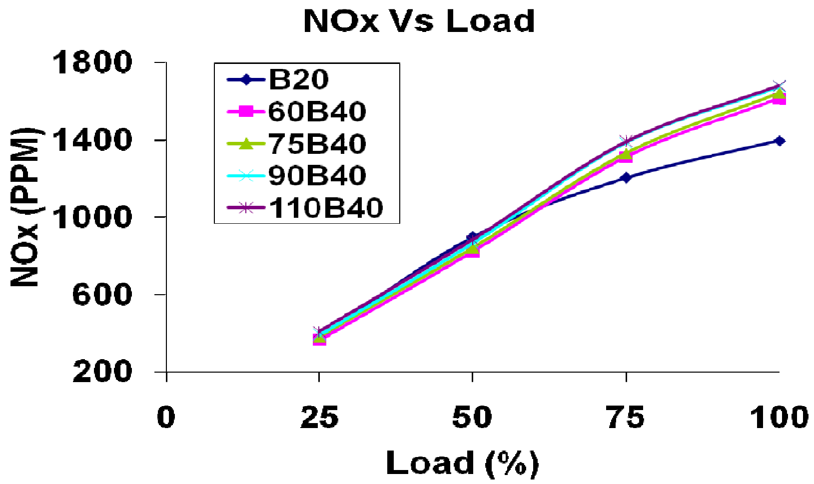

Figure 6 Variation of NOx for B40 blend for different preheating temperature and B20

3.5. Smoke opacity

It is observed from Fig. 7 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 [20]. 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.

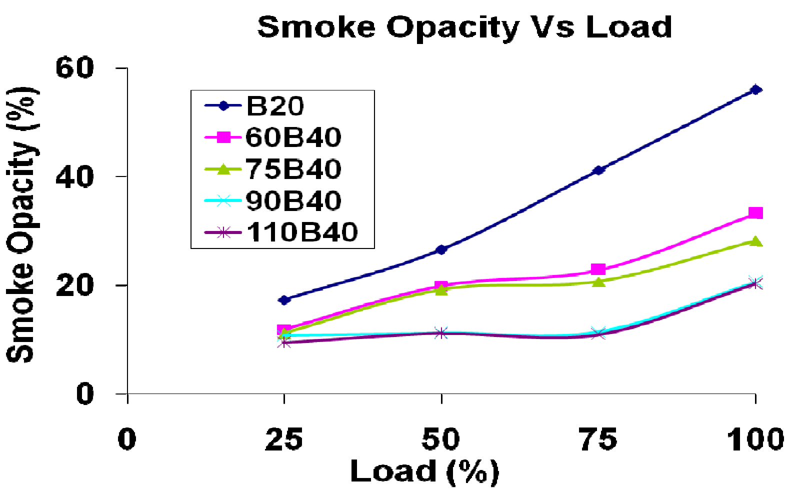

Figure 7 Variation of smoke opacity for B40 blend for different preheating temperature and B20

3.6. Carbon monoxide (CO)

It is observed from the Fig. 8 that CO emission is 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 [19]. 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.

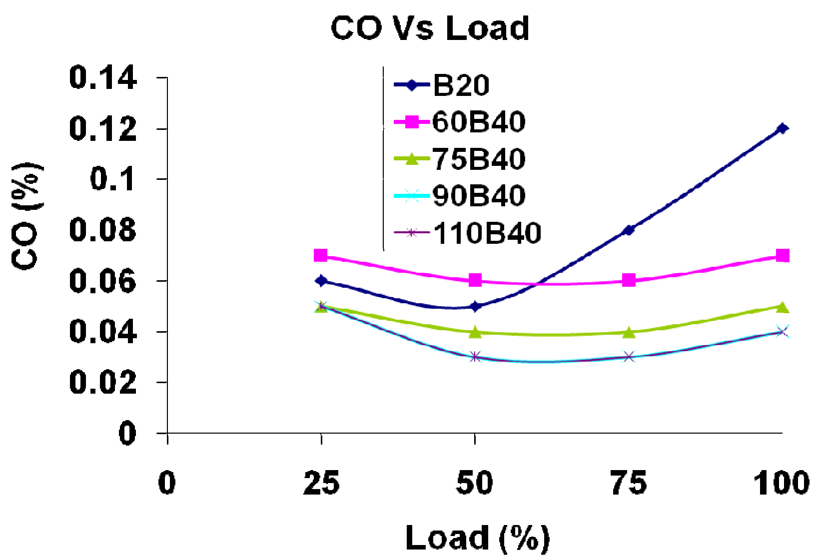

Figure 8 Variation of CO for B40 blend for different preheating temperature and B20

IV. CONCLUSIONS

From the above results findings conclude that the preheating temperature increases the performance and emission characteristics also improved over B20.

- The significant improvement in performance and emission values is obtained after 50% load. The maximum brake thermal efficiency for B40 is 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 is 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 are obtained over B20 blend for 75% and full load.
- The maximum reduction of UBHC over B20 blend is 78.12% for B40 blend at 110˚C.
- The maximum NOx emission is 1390 ppm and 1680 ppm for 110˚C preheated B40 blend for 75% and full load.
- 73.14% reduction in smoke opacity is 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.

REFERENCES

[1] Magin Lapuerta & Octavio Armas. (2008) "Effect of biodiesel fuels on diesel engine emissions", Progress in Energy and Combustion Science, 34, pp198-223.
[2] Surendra R. Kalbande & Subhash D. Vikhe., (2008) "Jatropha and karanj bio-fuel: an alternate fuel for diesel engine", ARPN Journal of Engineering and Applied Sciences, 3(1).

[3] Ramadhas A.S., S. Jayaraj & C. Muraleedharan., (2004) "Use of vegetable oils as I.C. engine Fuels - A review", Renewable Energy, 29, pp727–742.
[4] P.K. Devan & N.V. Mahalakshmi., (2009) "A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil–eucalyptus oil blends", Applied Energy, 86, pp675–680.
[5] Roberto G. Pereira, Cesar D. Oliveira, Jorge L. Oliveira, Paulo Cesar P. Oliveira, Carlos E. Fellows & Oscar E. Piamba., (2007) "Exhaust emissions and electric energy generation in a stationary engine using blends of diesel and soybean biodiesel", Renewable Energy, 32, pp 2453–2460.
[6] M.C.G. Albuquerque, Y.L. Machado, A.E.B. Torres, D.C.S. Azevedo, C.L. Cavalcante, Jr., L.R. Firmiano & E.J.S. Parente, Jr., (2009) "Technical Note-Properties of biodiesel oils formulated using different biomass sources and their blends", Renewable Energy, 34 , pp 857–859.
[7] Narayan C.M., (2002) "Vegetable oil as engine fuels-prospect and retrospect", Proceedings on Recent Trends in Automotive Fuels, Nagpur, India.
[8] Gerhard Knothe, Robert O. Dunn & Marvin O. Bagby., "Biodiesel: the use of Vegetable Oils and their Derivatives as alternative Diesel fuels", Oil Chemical Research, National Center for Agricultural Utilization Research, Agricultural Research Service, U.S. Department of Agriculture, Peoria, IL 61604
[9] Avinash Kumar Agarwal., (2006) "Bio-fuels (alcohols and biodiesel) Applications as fuels for Internal Combustion Engine", Energy and Combustion science, pp1-39.
[10] B. Baiju, M.K. Naik & L.M. Das., (2009) "A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil", Renewable Energy, 34, pp1616–1621.
[11] A. Murugesan , C. Umarani , T.R. Chinnusamy, M. Krishnan, R. Subramanian & N. Neduzchezhain., (2009) "Production and analysis of bio-diesel from non-edible oils-A review", Renewable and Sustainable Energy Reviews, 13, pp 825–834
[12] J.M. Marchetti, V.U. Miguel & A.F. Errazu., (2007) "Possible methods for biodiesel production", Renewable and Sustainable Energy Reviews, 11, pp1300–1311.
[13] Malaya Naika, L.C. Meher, S.N. Naik and L.M. Das., (2008) Production of biodiesel from high free fatty acid Karanja (Pongamia pinnata) oil, Biomass and Bioenergy , 32, pp. 354-357.
[14] Deepak Agarwal & Avinash Kumar Agarwal., (2007) "Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine", Applied Thermal Engg, 27, pp2314–2323.
[15] Hanbey Hazar & Hüseyin Aydin., (2010) "Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RRO)–diesel blends", Applied Energy , 87, pp 786-790.
[16] M. Senthil Kumar, A. Kerihuel, J. Bellettre & M. Tazerout., (2005) "Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine", Renewable Energy, 30, pp1443–1456.
[17] Murat Karabektas, Gokhan Ergen & Murat Hosoz., (2008) "The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine", Applied Thermal Engineering , 28, , pp 2136-2143.
[18] Pugazhvadivua & K. Jeyachandran., (2005) "Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel", Renewable Energy, 30, pp 2189–2202.
[19] Murat Karabektas , Gokhan Ergen & Murat Hosoz (2008) "The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine", Applied Thermal Engineering, 28, pp2136–2143
[20] M. Pugazhvadivu & K. Jeyachandran (2005) "Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel", Renewable Energy, 30 , pp2189–2202

AUTHORS

Dinesha P. obtained his Bachelor's degree in Mechanical Engineering from UVCE., Bangalore, India M.Tech degree in Energy Systems & Engineering from VTU., Belgaum, India. At present he is pursuing Ph.D. in Internal combustion Engines and alternative fuels at National Institute of Technology Karnataka, Surathkal. Also he is serving as Asst. Professor in the Department of Mechanical engineering, KVG College of Engineering, Sullia, India. His research interests include IC engines and combustion, alternative fuels and pollution control and renewable energy sources etc. He is the member of many professional societies.

P. Mohanan obtained BSc.(Engg.) in Mechanical Engineering from Kerala University, MSc.(Engg.) in Heat Power Engineering from Kerala University and Ph.D in I.C. Engines from IIT Delhi. Currently he is working as Professor of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, India. He was the Head of the Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, India during

23-12-2003 - 22-01-2007. He has published more than 76 research papers in national and international journals and conferences. He is currently the executive member of Combustion Institute – Indian section besides being a member of many other professional societies. He has guided many M.Tech. and Ph.D.s. His research interests include Internal Combustion engines, alternative fuels, Heat Transfer Environmental Pollution and control, Automobile pollution and renewable energy sources etc.