EXPERIMENTAL STUDY ON THE EFFECT OF FUEL AND INLET AIR PREHEATING ON THE PERFORMANCE OF A BIODIESEL POWERED CI ENGINE

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ABSTRACT*:* In an IC engine, major part of the heat energy produced is lost as waste heat. Exhaust heat recovery to improve the performance of IC engines and use of alternative fuel as substitute for conventional fossil fuel have become the topic of interest to many researchers. The aforesaid topics were addressed independently and separately by several researchers. In the present work, preheating of fuel and inlet air, simultaneously, on the performance of CI engine powered by coconut testa biodiesel is studied. Preheating of fuel and inlet air is done by utilizing waste heat that is being dissipated from the engine. A finned tube cross flow heat exchanger fixed to the engine exhaust pipe is usedto extract waste heat from exhaust gas for preheating of fuel and inlet air.The results of the study reveal that for fixed injection timing thermal efficiency of the engine increases with increase in temperature of the fuel and oxidizer admitted to the engine until a limiting value is reached, thereafter, the thermal efficiency decreases due to undesirable conditions. The emission of CO and unburnt HC was found to decrease with increase in inlet temperature of fuel and oxidizer. At the opposite, slight increase in emission of $CO_2$and NOx was observed with increase in inlet temperature of fuel and oxidizer.

KEYWORDS*:* **Alternative fuel, Coconut testa biodiesel, Cross flow heat exchanger, Exhaust heat recovery, Preheating**

Introduction

Internal combustion (IC) engines are one of the most important prime movers driving many of the automobiles today. Also they are the primary source for power generation around the world. Experiencing the current trend, we are well known to the fact of energy crises and internal combustion engine are the major consumer of fossil fuel. Heat energy is generated in the engine by the combustion of fuel. But only around 30% to 40% of the total generated heat is converted into useful work and the rest is expelled to the environment as waste heat. Therefore, it is of great concern to utilize this waste heat into useful work by employing some techniques for development of waste heat recovery systems. Preheating the fuel and oxidizer by exhaust gas is one of the attractive means of energy recovery from lost energy. A heat exchanger can be used to extract the waste heat of exhaust gas to preheat the fuel and inlet air. Other means include exhaust gas recirculation, turbo charging, supercharging, thermoelectric generators etc.

Also the rapid depletion of conventional fuel and fluctuation of petroleum price in the global market have promoted research for alternative fuels for CI engines. Among various possible options, fuels derived from triglycerides (vegetable oils/animal fats) present promising ‘‘greener’’ substitutes for fossil fuels. Vegetable oils, due to their agricultural origin, are able to reduce net CO2 emissions to the atmosphere. Biodiesel have similar property of petro diesel fuel so it can be used directly in to a diesel engine without any engine modification. Non toxicity, biodegradability and low emissions are advantages of biodiesel. Coconut testa is a waste product of coconut from a coconut processing industry, after preparing coconut milk, virgin oil etc. Due to the wide availability, non-edible nature and high degree of saturation of the oil, biodiesel produced from testa has enormous potential in meeting the future fuel demands

Many researchers studied about various techniques to recover the waste heat from IC engines. M. Hatami et al. studied about various methods to recover the exhaust waste heat from diesel engines. He studied about various heat exchanger designs for exhaust waste recovery in his review paper. He also conducted a numerical study of finned type heat exchangers for ICEs exhaust waste heat recovery. Saiful Bari et al. studied about waste heat recovery from a diesel engine using shell and tube heat exchanger. Vijay V S et al. also studied various heat exchanger designs for exhaust waste recovery.

Researchers were also interested in studying the effect of preheating the fuel and inlet air. Some of these also used the exhaust gas for preheating purpose. MohitRaghuwanshi et al. studied the performance of CI engine by preheating inlet air and diesel by waste heat utilization. Preheated vegetable oils as an alternative fuel were also been investigated by many researchers. Deepak Agarwal et al. studied the performance and emission characteristics of jatropha oil (preheated and blends) in a direct injection CI engine. Similar studies were carried out by HanbeyHazar et al. and Narayan Lal Jain et al. using raw rapeseed oil and thumba oil respectively. Effect of intake air preheat and fuel blend ratio on a diesel engine operating on biodiesel methanol blend were studied by Nadir Yilmaz et al. PriyabrataPradhan et al. studied the combustion and performance of a CI engine with preheated jatrophacurcus oil. These studies revealed that the preheating of fuel to a safe limit will improve its performance like increased break thermal efficiency and reduced fuel consumption. Preheating also resulted in reduced emissions of CO and HC. NOx emission results found to be varying with fuel. The elevated temperature was supposed to be increasing the NOx emission but in some case the reduced ignition delay with the use of preheated fuel reduced the NOx emission.

Literature review unveils that preheating of fuel and air to a safe limit influences the engine performance favourably. Earlier studies conducted to analyse the effect of preheating of fuel and air on engine performance were done independently and study on engine performance affected by simultaneous preheating of fuel and air was not addressed.

Present study is to experimentally investigate the effect of preheating of both fuel and air simultaneously on the engine performance of a CI engine powered with coconut testa biodiesel.

I. MATERIALS AND METHODS

A. Biodiesel Production and Property Testing

Biodiesel was produced from coconut testa oil by alkali catalyzed transesterification process with 20% methanol and 0.8% potassium hydroxide (KOH). Different fuel properties of this coconut testa biodiesel were evaluated and are given in Table 1. Properties of the biodiesel met the standard specifications.

Table 1 Properties of diesel and coconut testa biodiesel

Property	Diesel	Coconut testa biodiesel
Viscosity (cP)	2.35	3.4
Density (g/cm3)	820	832
Calorific value (kJ/kg)	44800	36424
Flash point (°C)	50	114
Fire point (°C)	-	126
Acid value (mgKOH/g)	0.10	0.249
Saponification value (mgKOH/g)	-	220.38
Iodine Value (mgL/g)	-	20.75

B. Experimental Setup

Tests were conducted on Kirloskar made direct injection diesel engine. Table 2 shows the specifications of the engine.

A finned tube cross flow heat exchanger was fabricated to extract the waste heat from exhaust gas to preheat the fuel and inlet air. The heat exchanger is a three fluid heat exchanger. The heat exchanger is shown in Figure 1.

Table 2 Engine Specifications

SPECIFICATION	DESCRIPTION
Manufacturer	Kirloskar
Number of cylinders	1
Number of stroke	4
Rated power	5 HP
Rated speed	1500 rpm
Bore×Stroke	80 ×110
Cooling type	Water cooled
Loading type	Rope brake drum loading
Brake drum diameter	330 mm

The hot exhaust gas is used to heat the fuel as well as inlet air. K type thermocouple wire is used for measure the inlet and exit temperatures of the three fluids with the help of a Data Acquisition System (DAS). It is connected to the exhaust line of the Kirloskar diesel engine.

Figure 1 Heat Exchanger

An AVL digas analyzer was used to measure the emission from the engine. The schematic of the experimental setup is shown in Figure 2.

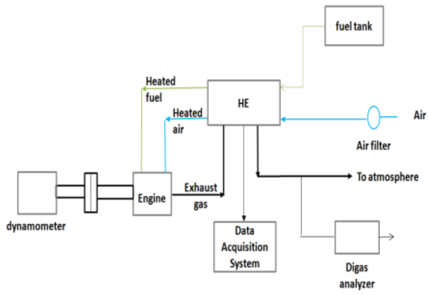

Figure 2 Schematic of Experimental Setup

II. RESULTS AND DISCUSSION

A. ENGINE PERFORMANCE

1) Brake Thermal Efficiency (BTE)

In the case without preheating, the brake thermal efficiency of the engine when fuelled with biodiesel was more than the efficiency when fuelled with diesel at all loading conditions. This is because of the more oxygenated coconut testa biodiesel undergo proper combustion to release most of the chemical energy available for fuel into heat energy. Maximum increase in BTE for biodiesel observed was 7.69% of that of diesel at 0.77 bar BMEP. Same trend was observed while the experiment was carried out with preheated fuel and air utilizing the exhaust from engine for diesel and biodiesel.

Comparing the efficiency of engine while powered with preheated biodiesel and inlet air, the efficiency without preheating was less. This was due to the fact that the preheating of biodiesel led to reduced viscosity of the biodiesel which will improve its atomization. Also the increase in temperature of both biodiesel and air will leads to better combustion inside the cylinder. Maximum increase in BTE for preheated biodiesel observed is 9.6% of that of unheated case at 0.77 bar BMEP.

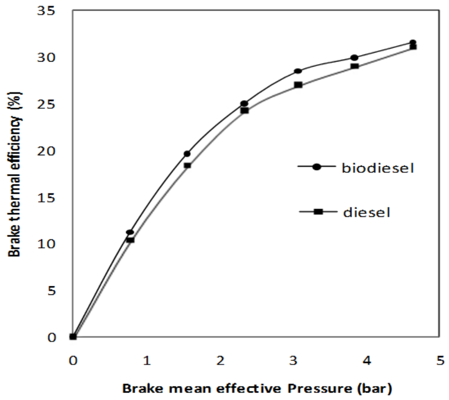

Figure 3.A Variation of BTE with BMEP for unheated diesel and biodiesel

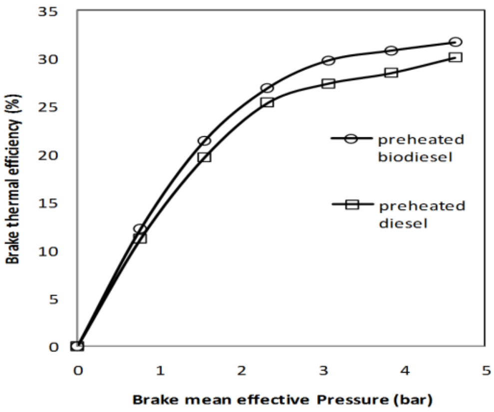

Figure 3.B Variation of BTE with BMEP for preheated diesel and biodiesel

Similar results are shown while comparing preheated diesel with unheated diesel. During initial loading conditions, the BTE is higher for preheated diesel than unheated diesel. As load reaches maximum, the BTE of preheated diesel falls below unheated case. As load increases, the inlet temperature of diesel and air to engine increases. As the auto ignition temperature of diesel is low comparing to the biodiesel, this will result in abnormal combustion inside the cylinder. So the BTE of preheated diesel falls below unheated case at higher loads. Maximum increase in BTE for preheated diesel observed is 8.03% of that of unheated. Maximum value of BTE is 30.11% and 31.11% for preheated and unheated case of diesel respectively

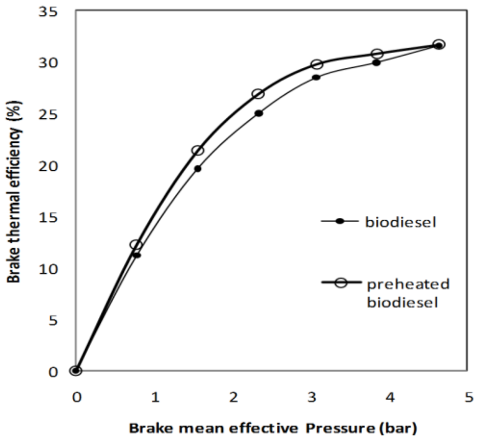

Figure 3.C Variation of BTE with BMEP for preheated biodiesel and unheated biodiesel

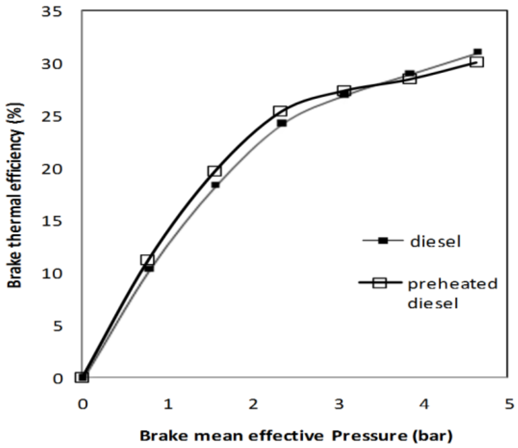

Figure 3.DVariation of BTE with BMEP for preheated diesel and unheated diesel

2) Brake Specific Fuel Consumption (BSFC)

For both diesel and biodiesel when used without preheating, specific fuel consumption decreases with brake mean effective pressure. For the entire range of loads, the specific fuel consumption of biodiesel was more than that of diesel. This is due to the lower calorific value of coconut testa biodiesel. The same trend is seen while comparing biodiesel and diesel are used with preheating.

The fuel injected to the cylinder is on volume basis. The density of diesel is less than the density of the biodiesel. Thus for equal volume of fuel injected less mass of the diesel fuel will be consumed as compared to biodiesel. For the entire range of loads, the specific fuel consumption of biodiesel was more than the specific fuel consumption of diesel.

With the introduction of preheating, the BSFC of biodiesel decreases while comparing with unheated biodiesel at all loading conditions. This is because of the fact that preheating decreases the density of the fuel and so the mass of fuel injected decreases.

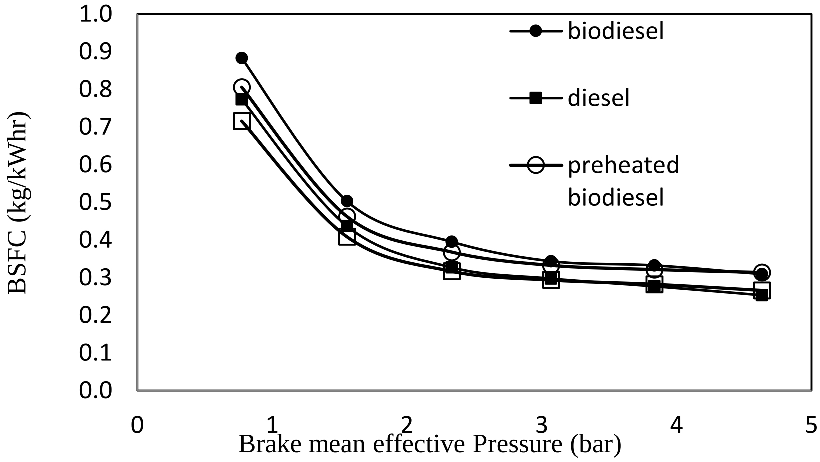

Figure 4Variation of BSFC with BMEP

3) Exhaust Gas Temperature

Due to the more oxygen content in biodiesel the combustion will be more proper in case of biodiesel than diesel. As a result, more energy is released by the combustion of biodiesel and therefore the in chamber temperature will be more for biodiesel and so the exhaust gas temperature will be more for biodiesel than diesel.

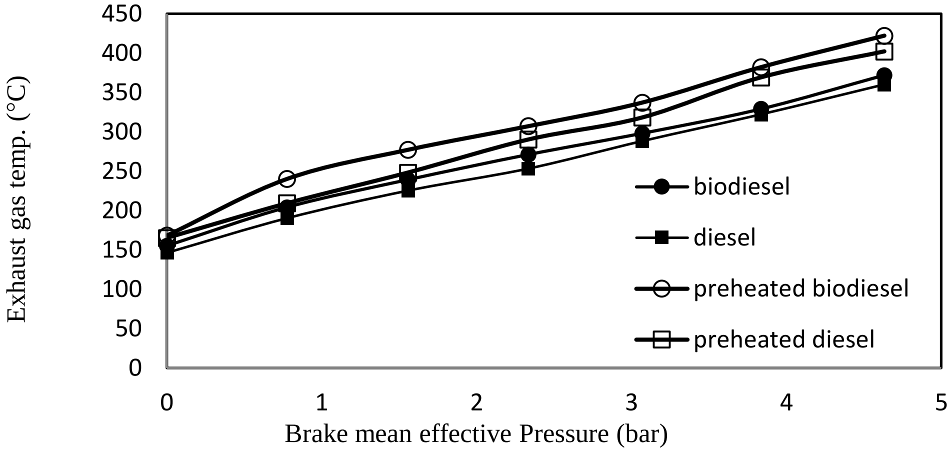

Figure 5 Variation of Exhaust Gas Temperature with BMEP

As the load increases the exhaust gas temperature will increase for both diesel and biodiesel. Same trend is shown while comparing the exhaust gas temperature of the preheated experiment fuelled with both diesel and biodiesel.

With preheating the exhaust gas temperature increases for both diesel and biodiesel. This is because the increase in the inlet energy adds up with the energy liberated due to combustion.

4) ΔT $_{fuel}$ vs. Increase in BTE

Graph were plotted to study the effect of degree of preheat on BTE. ΔT fuel means the increase in inlet fuel temperature due to preheating the fuel. ΔT fuel is plotted against the increase in BTE when preheated as compared to unheated case.

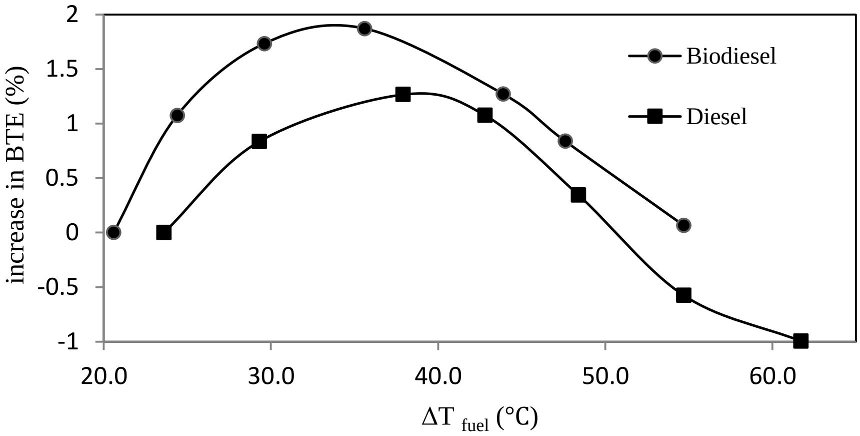

Figure 6Variation of increase in BTE with ΔT $_{fuel}$

With increase in ΔT fuel, for both diesel and biodiesel, the increase in BTE rises and then falls. Maximum increase in BTE is observed at 33°C and 41°C rise of fuel temperature for biodiesel and diesel respectively. For diesel, when the ΔT fuel value increases above 50°C, the BTE of preheated case falls below the unheated case. Lower auto ignition temperature of diesel triggers earlier abnormal combustion than that of biodiesel. This abnormal combustion results in reduced BTE of preheated diesel than unheated diesel.

5) ΔT $_{air}$ vs. Increase in BTE

Increase in BTE varies with ΔT air as similar to that of variation of ΔT fuel.

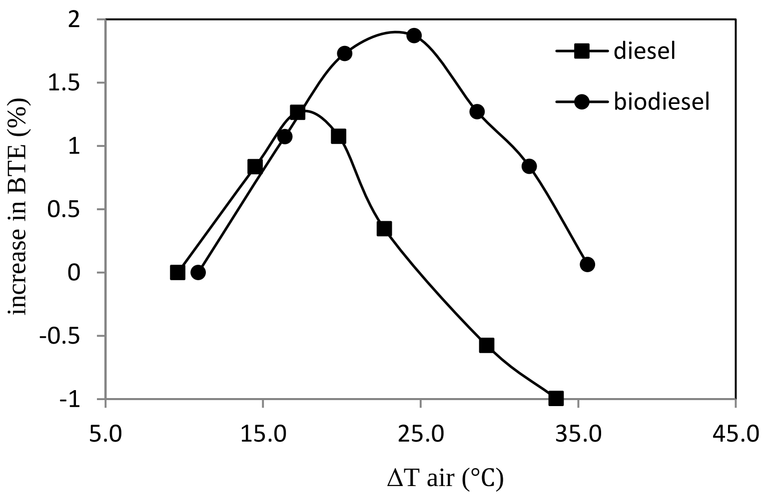

Figure 7Variation of increase in BTE with ΔT$_{\mathbf{air}}$

With increase in ΔT$_{air}$, for both diesel and biodiesel, the increase in BTE rises and then falls. Maximum increase in BTE is observed at 25°C and 17°C rise of inlet air temperature for biodiesel and diesel respectively.

B. EMISSIONS

1) CO Emission

The Figure 8 shows the variation of carbon monoxide emission with brake mean effective pressure (BMEP). CO is emitted as the product of incomplete combustion due to lack of oxygen. Here CO emission decreases with increase in load for all the cases. Increase in load pushes the equivalence ratio combustion closer to stoichiometry, promoting better combustion which forms CO_2rather than the incomplete combustion product of CO.

For unheated air and fuel, CO emission of the diesel is higher than biodiesels. Even though the high viscosity of biodiesel can cause poor atomization of fuel, the presence of extra oxygen in biodiesel aids to improved combustion. Biodiesel is an oxygenated compound, so it promotes better combustion and reduces CO emissions. Similar trend is observed while comparing CO emission of preheated experiments fuelled with biodiesel and diesel.

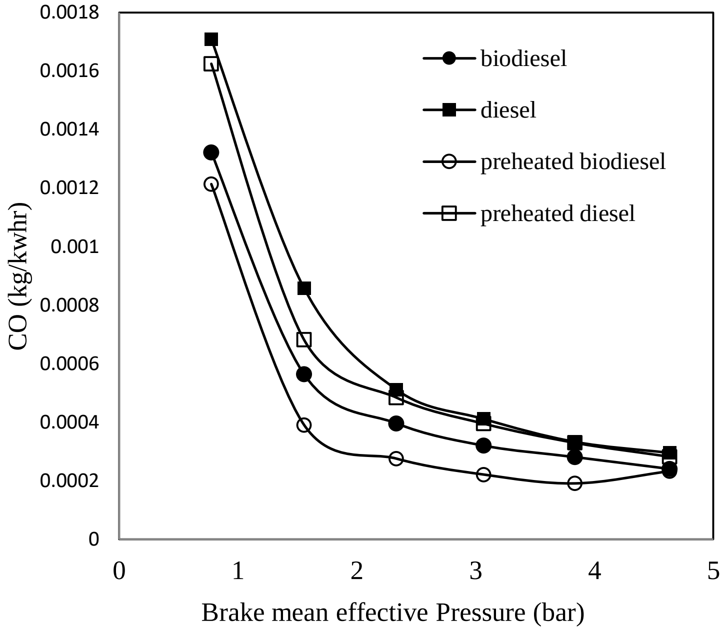

Figure 8 Variation of CO emission with BMEP

Heating of fuel and air aids in improved combustion inside the cylinder due to better atomization of fuel.So with preheating, the CO emission of biodiesel comparing with unheated biodiesel decreases.

2) Unburnt Hydrocarbon (UHC) Emission

The figure 9 shows the variation of hydrocarbon emission with brake mean effective pressure.

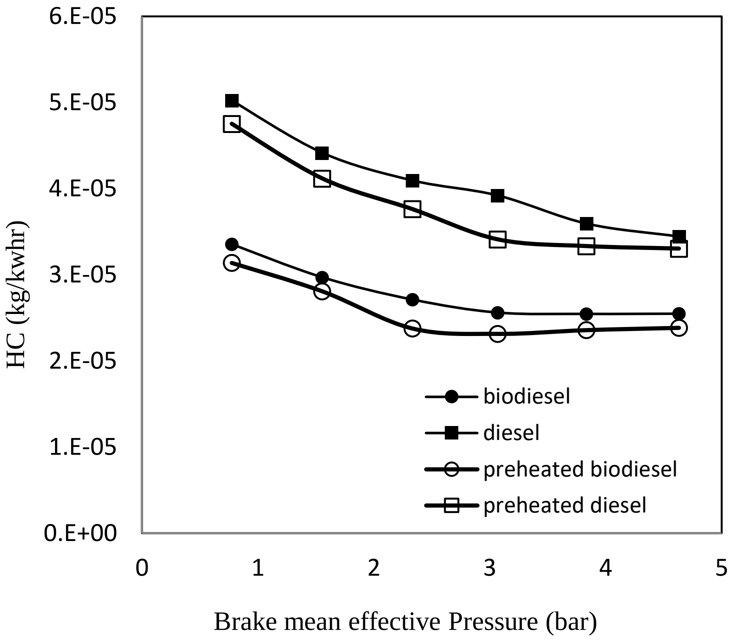

Figure9 Variation of UHC emission with BMEP

It can be seen that for all loads emission of diesel is higher than that of biodiesel for both with preheating and without preheating. The coconut testa biodiesel has oxygen atoms in it. This leads to better combustion within the cylinder as compared to diesel. Therefore, the HC emissions get reduced for coconut testa biodiesel.

With the introduction of preheating, the HC emission of biodiesel again decreases due to improved atomization made possible due to reduced viscosity of the biodiesel. The same is true for diesel fuel with and without preheating.

3) NOx Emission

The Figure 10 shows the variation of NOx emissions of the CI engine with brake mean effective pressure. NOx emissions increase with engine load as a result of the increased combustion temperatures at higher engine loads, because NOx formation is sensitive to temperature. For both preheated and unheated cases, higher NOx formation is occurred when using biodiesels for all range of loads comparing with diesel. More oxygenated nature of biodiesel was the reason for higher NOx emission. The more oxygen content will result in better combustion and so increased in cylinder temperature.

Preheating of fuel will also aids in improved combustion and so an additional increase in incylinder temperature in the case of preheated biodiesel while comparing with unheated biodiesel. And thereby an additional increase in NOx emission in the case of preheated biodiesel.

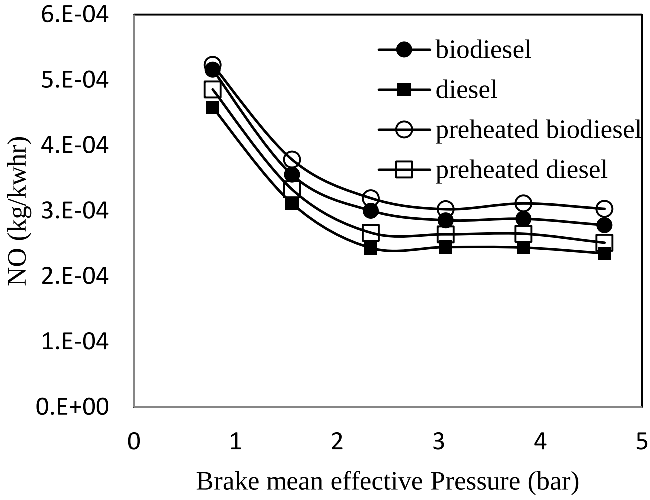

Figure 10 Variation of NOx emission with BMEP

4) CO_2 Emission

For all cases, the CO_2 emission is increases with increase in load, because increase in load promotes better combustion as stoichiometry air fuel ratio is obtained at higher loads. Also increase in cylinder temperature aids in better combustion with loading. CO_2 is a product of complete combustion. When we use biodieselbetter combustion occurs due to the presence of excess oxygen in the biodiesels. So CO_2emission when fuelled with diesel and biodiesel having slight difference. CO_2emissions when fuelled with biodiesel slightly higher that of diesel for both unheated and preheated cases

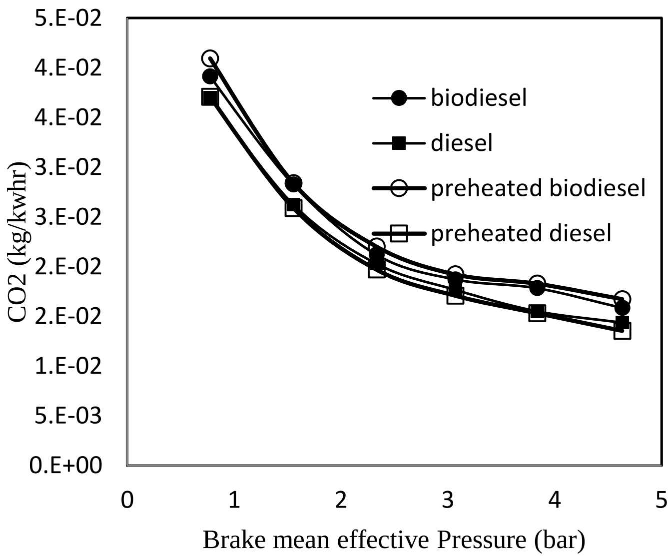

Figure 11 Variation of CO_2emission with BMEP

III. CONCLUSIONS

The present study is concerned with exhaust heat recovery for preheating fuel and air and the effect of preheating on engine performance and emission. Both unheated diesel and biodiesel, and, heated diesel and biodiesel were tested. The results show that the preheating of the biodiesel has notable effect on engine performance and emission characteristics.

The results of the work are summarised below.

1. The biodiesel produced from coconut testa oil is in compliance withASTM standards and can be recommended as an alternative fuel in CI engine without any engine modifications.
2. The presence of oxygen in coconut testa biodiesel favours combustion process,thereby, BTE of biodiesel is observed to be higher than the case when diesel was used. The preheating of biodiesel causes to decrease viscosity which in turn improves the atomization of fuel causing BTE to increase with preheating for biodiesel.
3. During initial loading conditions, an increase can be seen in the BTE of preheated diesel than unheated diesel. But as load reaches maximum, BTE of preheated diesel falls below unheated case.
4. For both diesel and biodiesel, as the inlet temperature of fuel and air increases, BTE initially rises and then falls. This is due to the fact thathigher intake temperature will trigger abnormal combustion which in turn causes reduction in BTE
5. Low calorific value and high density of coconut testa biodiesel results in lower BSFC of biodiesel compared to diesel at all loading conditions.
6. Emission of CO and HC for biodiesel is lower than that of diesel at all loads. This is because of the presence of the extra oxygen in the biodiesel which improves the combustion. Preheating the biodiesel again aids in better combustion and reduce CO and HC emission than unheated biodiesel.

7. CO_2 emission is higher for biodiesel fuel than diesel. This shows better combustion of biodiesel due to the presence of extra oxygen in it. The preheating of biodiesel increases the CO_2 emission because the preheating aids combustion process.
8. Oxygen content in the biodiesel fuel promotes better combustion and combustion chamber temperature increases. This leads to increase in NOx emission compared to diesel at rated load. Also, preheating the biodiesel results in increased NOx emission.

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