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Exhaust Emission Characteristics of Diesel Engine Operating on Biodiesel and its Blends at Elevated Temperature of Air

K.Sureshkumar*, K.Muralidharan

PSNA College of Engineering & Technology, Dindigul -624 622, Tamilnadu, India

Abstracts

In this study, performance and exhaust emission characteristics of Pongamia Pinnata oil blends (B10,B20,B30 and B50) with mineral diesel were investigated in preheated intake air conditions in a single cylinder 4-Stroke direct injection CI engine at 75 % maximum load and its rated engine speed 1500 rpm. Two types of heat exchanger designed to preheat the suction air and the heating is accomplished by both engine cooling water and exhaust gases. Two types of heat exchanger includes concentric tube counter flow heat exchanger (to recover heat from engine exhaust gases) and shell and tube heat exchanger (to recover heat from engine jacket cooling water) is mounted along intake manifold to preheat the suction air. Test is carried out at atmospheric air temperature (30ºC), preheated air temperature of 45ºC,60ºC and75ºC.Exhaust emission characteristics such as Carbon Dioxide(CO_2),Carbon monoxide(CO),Unburned Hydrocarbon (HC) and Nitrogen Oxide(NO). Experimental investigation revealed that except Nitrogen Oxide (NO) emission and other exhaust emission parameters such as CO_2,CO and HC are decreased with mineral diesel and among other biodiesel blends a drastic reduction in exhaust emission is observed for Biodiesel blend ratio B20 for all preheated air temperature .However the Nitrogen Oxide (NO) emission increases with increase in biodiesel mixtures for all preheated air temperature.

Keywords: Biodiesel, Pongamia Pinnata, Diesel Engine, Exhaust emission Characteristics, Preheating of Intake Air Temperature and Biodiesel blend ratio..

Introduction

Increasing awareness in the energy and in the emissions of greenhouse gases has prompted both the energy consumers and vehicle manufacturers to consider alternative fuels and highly efficient energy conversion devices. In addition, concerns about compression ignition diesel engine systems are rising due to the need to reduce carbon dioxide (CO2) and fuel consumption. Diesel engines have better thermal efficiency and higher engine torque than gasoline engines. However, their large emissions of nitrogen oxides (NOx) and particulate matter (PM) is a serious obstacle for the wide use of diesel engines in automobiles. Therefore, many engine researchers and manufacturers have worked to develop the optimal methods for reducing harmful emissions from diesel engines. In the past two decades, various methods to reduce exhaust emissions have been developed, including the low temperature combustion (LTC) [1-4] the premixed compression ignition [5,6], multiple-injection strategies [11-13], and the use of alternative fuels (dimethyl ether, biodiesel, gas-to-liquid (GTL), hydrogen, and bioethanol [14–15]. Using biofuel in diesel engines is an attractive method for reducing emissions. This article deals with the use of diesel–biodiesel blended fuels in a compression ignition diesel engine.

Diesel engine operates on the principle of compression ignition. Therefore these engines rely on compression in cylinder to raise the air temperature and pressure such that upon injecting the fuel, the air- fuel mixture auto ignites. The injected fuel spray needs to be finely scattered and evaporate and mix redily. This mixture should mix with rapidly swirling hot air in the combustion chamber.

The energy needs of the world are increasing rapidly. The decrease in fossil fuels, emission pollution caused by them and increasing fuel prices make biomass energy sources more attractive. The increase in energy demand and decrease in oil reserves have focused attention on biofuels [16]. Biodiesel is a fuel that is manufactured from vegetable oils with the help of catalysts, and may be directly used in diesel vehicles with little or no modification. When biodiesel is used, HC, CO, and PM ratios in exhaust emissions are lower, while sometimes very small NOx increases occur . In many studies, it has been reported that biodiesel causes significantly lower PM and CO emissions compared with fossil fuels .

As the fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best

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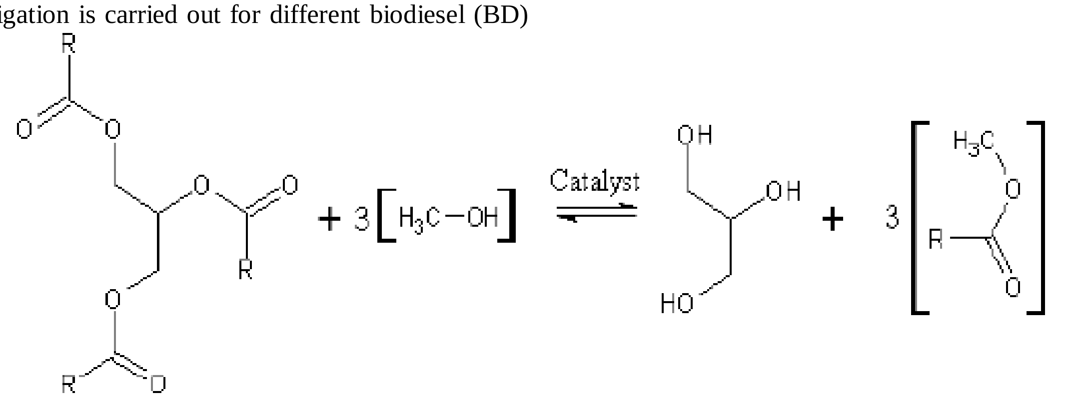
available sources to fulfill the energy demand of the world. The petroleum fuels play a very important role in the development of industrial growth, transportation, agricultural sector and to meet many other basic human needs. However, these fuels are limited and depleting day by day as the consumption is increasing very rapidly. Moreover, their use is alarming the environmental problems to society. Hence, the scientists are looking for alternative fuels. India is importing more than 80% of its fuel demand and spending a huge amount of foreign currency on fuel. Biodiesel is gaining more and more importance as an attractive fuel due to the depleting nature of fossil fuel resources. The purpose of transesterification process is to lower the viscosity of the oil. The main drawback of vegetable oil is their high viscosity and low volatility, which causes poor combustion in diesel engines. The transesterification is the process of removing the glycerides and combining oil esters of vegetable oil with alcohol. This process reduces the viscosity to a value comparable to that of diesel and hence improves combustion. Biodiesel emits fewer pollutants over the whole range of air–fuel ratio when compared to diesel. [18]

In this paper, the required amount of biodiesel is prepared from non-edible source of Pongamia pinnata kernel seed .Methyl ester of Pongamia Pinnata (PPME) is derived by chemical process of Transesterification, its properties are measured and detailed experimental investigation is carried out for different biodiesel (BD) mixtures like B10,B20,B30 and B50 and effects of both preheated intake air temperature and biodiesel blend ratio on performance characteristics are experimentally investigated at 75 % maximum load and at constant rated engine speed. Test is conducted three times and average value taken for calculation purpose. Exhaust emission Parameters such as Carbon Dioxide(CO2),Carbon monoxide(CO),Hydrocarbon Emission(HC),Nitrogen Oxygen(NO) and Exhaust gas Temperature is measured from the Five gas analyzer. Test is conducted three times and average value is considered for results and discussion.

Production of biodiesel

The tranesterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline or lipase as a catalyst to form mono alkyl ester that is biodiesel and glycerol. However the presence of strong acid or base accelerates the conversion. It is reported that alkaline catalyzed transesterification is fastest and require simple set up therefore, in current study the oil of Pongamia Pinnata were transesterified with methyl alcohol in presence of strong alkaline catalyst like sodium hydroxide or potassium hydroxide in a batch type transesterification reactor. The transesterification reaction is given below 22 this process has been widely used to reduce the high viscosity of triglycerides.



Triglyceride Methanol (3) Glycerol Methyl Esters (3)

To prepare biodiesel from pongamia crude oil first sodium hydroxide was added in to the methyl alcohol to form sodiummethoxide; simultaneously oil was heated in a separate vessel of transesterification reactor and subjected to heating and stirring. When temperature of oil reached at 60ºC then sodium methoxide was mixed in to the oil and reaction mixture was stirred for one and half hour. After reaction completion, the reaction mixture was transferred in separating funnel. The mixture of glycerol and methyl ester was allowed to settle for 8 hours. After settling for 8 hours glycerol and methyl esters was separated manually. The methyl ester was the washed with hot water to remove traces of sodium hydroxide impurity. The washed biodiesel then distilled to remove moisture and final good quality biodiesel was subjected for

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chemical analysis. The property of Various biodiesel blends is given in **Table 1.**

Table 1 Properties of Various Biodiesel

Property	Raw Oil	Pongamia Pinnata Methyl Ester (PPME)	B10	B20	B30	B50	DIESEL
Density in kg/m^3	938.2	857.9	838.6	841.4	845.8	848.2	833.7
Kinematic viscosity at 40^{o}C in Cst	35.98	21.45	14.32	16.21	17.31	17.45	2.72
Flash point (^{o}C)	237	172	92	102	112	118	48
Fire Point (^{o}C)	320	210	145	156	158	162	220
Calorific Value (MJ/KG)	37.87	41.66	40.34	40.84	41.45	41.78	43.06
Cetane Index	46	48	51	51	53	54	50

Experimental setup and procedure

The engine used in this experiment was a single cylinder water-cooled, 4-stroke, DI diesel engine and it was coupled with electric dynamometer. The specifications of the Test Engine are shown in **Table 2**. The dynamic fuel injection timing was set at 24^o BTDC (before top dead center). The engine exhaust emissions like Unburned hydrocarbon (HC) , Nitrogen Oxide (NOx), Carbon Monoxide(CO), and carbon dioxide (CO_2) were measured with AVL Five gas analyzer .AVL Five gas analyzer specification shown in **Table 3.** Fuel consumption was measured by a burette attached to the engine and a stop watch was used to measure fuel consumption time for every 10 cm^3 fuel. A mechanical fuel pump was used in the injection system. Nozzle with a hole diameter of 0.35 mm was used in the injection system. To preheat intake air, two heat exchangers are designed and is provided along with intake manifold as shown in figure 1.The atmospheric air is first heated by the Engine jacket cooling water in a shell and tube heat exchanger and then secondly heated by Engine's exhaust gases in a concentric tube counter flow heat exchanger. Thermocouples are provided at various location in the experimental setup to measures the temperature of preheated air, engine jacket cooling water (both inlet and outlet) and exhaust gas temperature (both inlet and outlet) of the heat exchanger. Separate Flow control valves are also provided to regulate flow of both jacket cooling water and exhaust gases and to maintain the required preheated air temperature. The experiment is conducted for each of Preheated intake air temperature i.e 30^{o}C,45^{o}C,60^{o}C and 75^{o}C for different blending of biodiesel B10,B20,B30,B50 and pure diesel when the engine loaded at 75% of the maximum load and running at its rated speed .The experimental data reading was taken three times and the mean of the three was taken.The experimental set up shown in **Figure 1**. Preheated Intake Air Temperature is noted and corresponding performance parameters like Mechanical Efficiency(η_{mech}),Combustion Efficiency, Brake Thermal Efficiency (η_{bth}), Brake Specific Fuel Consumption (BSFC) and Volumetric efficiency are calculated. The Exhaust emissions like Carbon-dioxide (CO_2), Carbon Monoxide (CO), HC emission, Nitrogen Oxide (NOx) and percentage of excess oxygen were measured and it is noted. The experiments conducted three times and average values are taken for results and discussion.

Table 2 Test Engine Specification

Engine Make	Kirloskar Engine
Engine Types	Single Cylinder Four stroke Diesel engine
Rated HP/KW	5 / 3.7
Engine rated Speed	1500 rpm
Bore Diameter	80 mm
Stroke	110 mm
Brake specific fuel consumption	245 gm/KW-hour
Compression Ratio	16.5:1
Types of fuel pump	High Pressure Mechanical type

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Table 3 AVL Five Gas Analyzer Specification:

Type	Digas 444
Power Supply	11 to 22 VDC/100-300 VAC @50 Hz
Power Consumption	25W maximum
Operating Temperature	5 to 45 ºC
Storage temperature	0- 50 ºC
Relative Humidity	≤95 % Non-Condensing
Inclination	0 to 90o
Normal Gas flow	1801/h
Maximum Over Pressures	450 KPa
Oxygen Sensor Type	Electro chemical
Oxygen sensor Model	O_2 SENS1

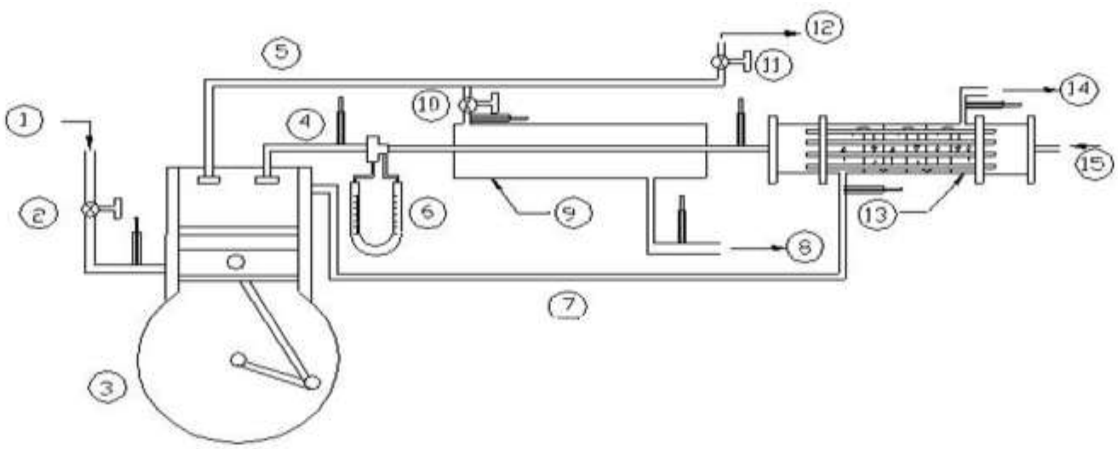

Figure 1.Experimental Set Up For Effects of Intake Suction Air Preheating and Biodiesel Blend Ratio

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1.Cooling water Inlet(T_1°C)	**6.U tube Manometer**	**12.Exhaust gas To AVL Five gas Analyser**
2.Flow Control valve	**7Engine Cooling water Outlet**	**13.Shell and Tube Heat Exchanger-1**
3.Diesel Engine loaded with Eddy current Dynamometer	**8.Exhaust gas outlet from HE 2**	**14.Cooling water outlet from HE1**
4.Thermometer Intake Manifold	**9.Concetric Tube Counter Flow Heat Exchanger-2**	**15.Intake air**
5.Exhaust Gas	**10 &11.Flow Control Valve**	

Results And discussion

Exhaust Emission Characteristics

CO_2 Emissions Vs Preheated Intake Air Temperature.

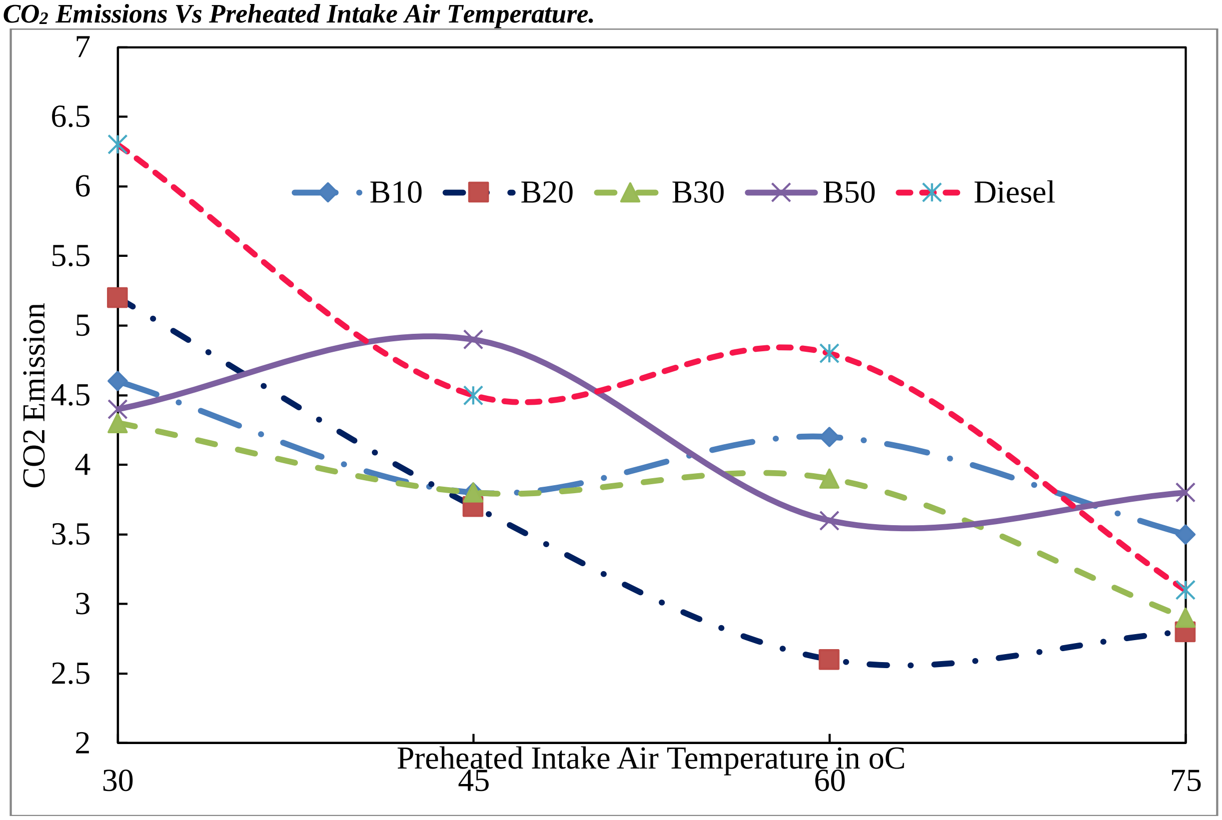

Figure. 2. Carbon Dioxide (CO_2) Emission Vs

Preheated Intake Air Temperature

It is seen in **Figure 2** shows the CO2 emissions of the neat diesel fuel and the biodiesel mixtures. CO and CO_2 is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted in to CO_2.. For biodiesel mixtures CO_2 emission was lower than that of diesel fuel, because biodiesel mixtures contain some extra oxygen in their molecule that resulted in complete

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combustion of the fuel and supplied the necessary oxygen to convert CO into CO_2. Compared to neat diesel fuel, biodiesel mixtures reduced CO_2emissions for all preheated intake air temperature. Among all biodiesel blends B20 gives better results.

CO Emissions Vs Preheated Intake Air Temperature.

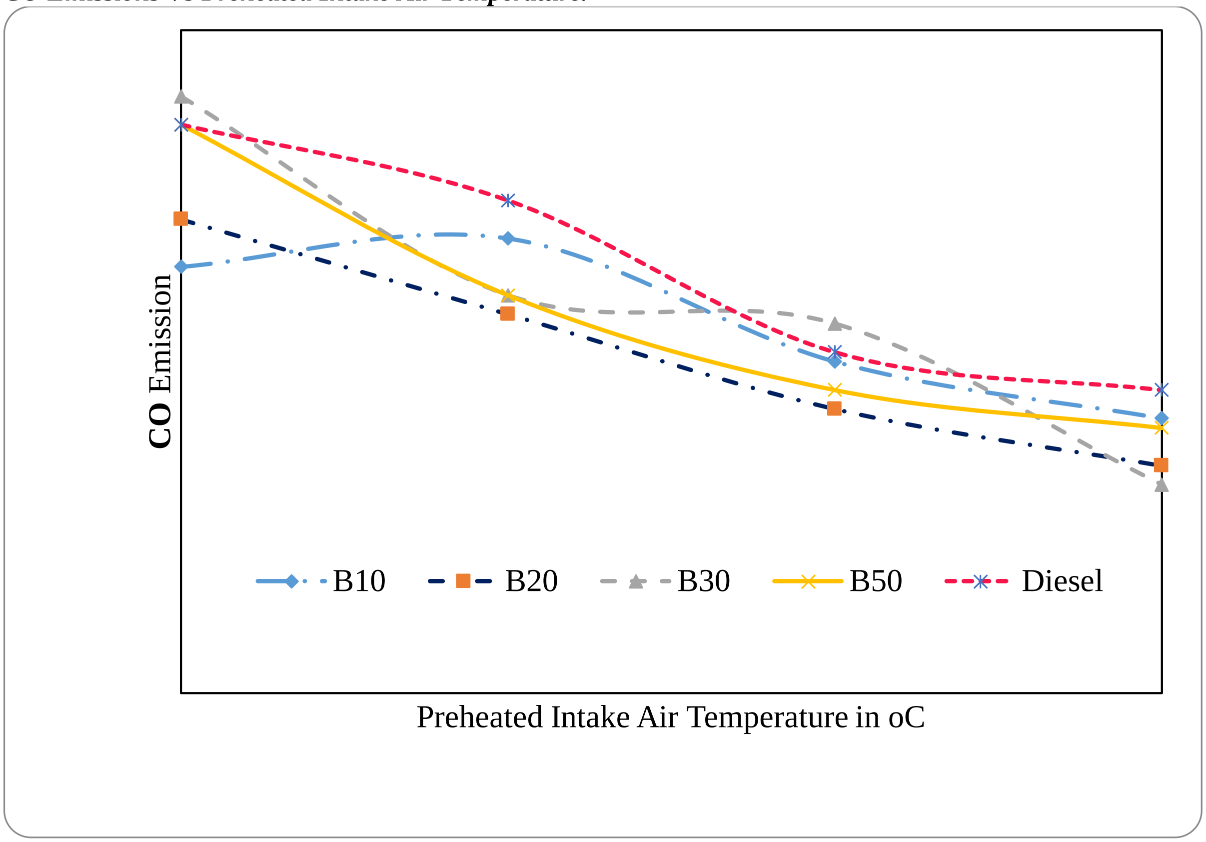

Figure. 3 .Carbon Monoxide (CO) Emission Vs Preheated Intake Air Temperature

CO emissions decreases as the preheated intake air temperature increases as shown in **Figure.3.**If the combustion is incomplete due to shortage of air or due to low gas temperature, CO and CO2 will be formed. It also indicates that blend concentration in biodiesel decreases the CO emission as compared to Mineral diesel. This is due to the reason that,both oxygen content present in Biodiesel mixture and high gas temperature are helps convert CO into CO_2.Except for the case of Biodiesel blend B20,intake air preheat temperature helps other biodiesel blends increases CO emission as compared with B20 biodiesel blend. This is due to the reason that, low oxygen content and low cetane index increases the ignition delay and leads to incomplete combustion which causes CO emission.

Hydrocarbon Emission (HC) Vs Preheated Intake Air Temperature

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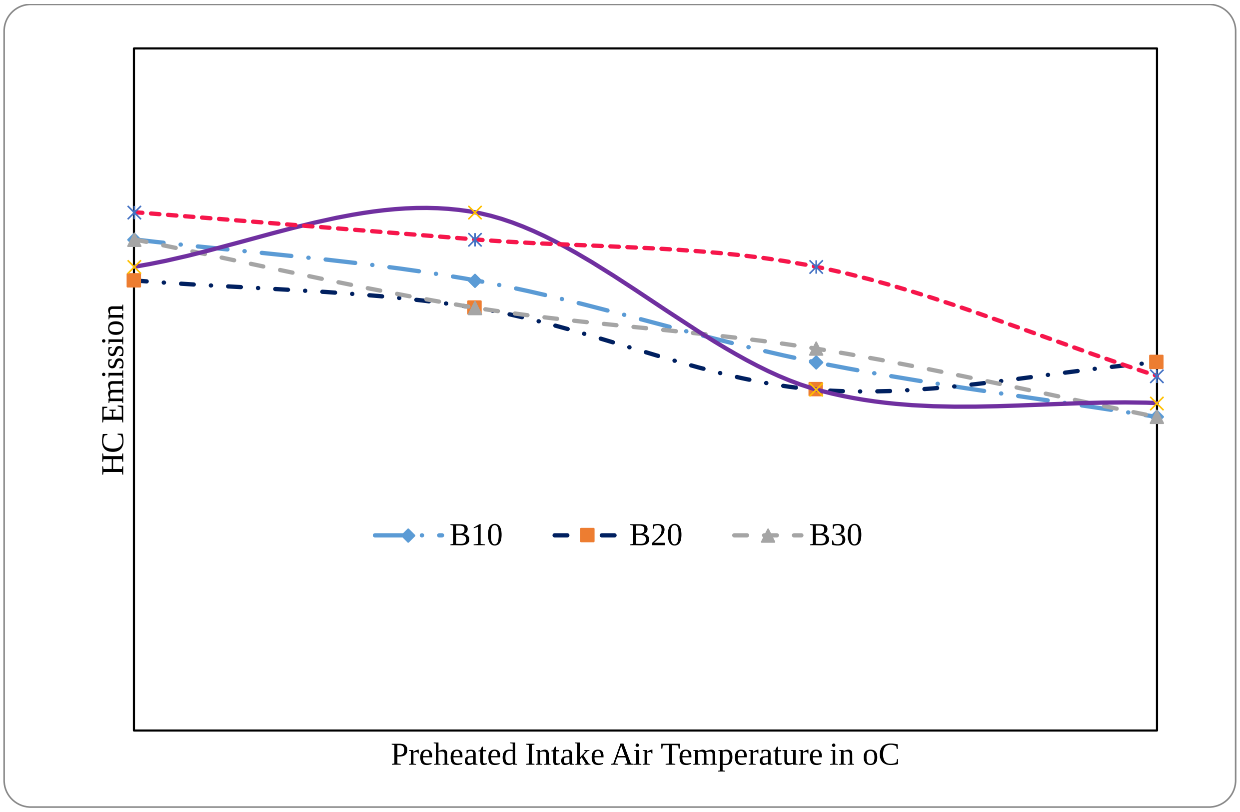

Figure 4. Hydro Carbon (HC) Emission Vs Preheated Intake Air Temperature

Figure.4. Shows the variation of HC emission formed for all biodiesel mixture and mineral diesel with suction air preheated temperature. It also indicates that, biodiesel blend HC emission decreases than mineral diesel as increase in preheated air temperature. The reason is that, gas temperature of air is the dominant factor for formation of HC emission. Preheated suction air temperature improves the hydrocarbon fuel combustion characteristics such as disintegration of liquid fuel in to fine atomized particles, vaporization and perhaps existence of homogeneous phase mixture in the combustion chamber leads to the complete combustion of hydrocarbon fuel which further reduces the formation of HC emission.

NO Emission Vs Preheated Intake Air Temperature.

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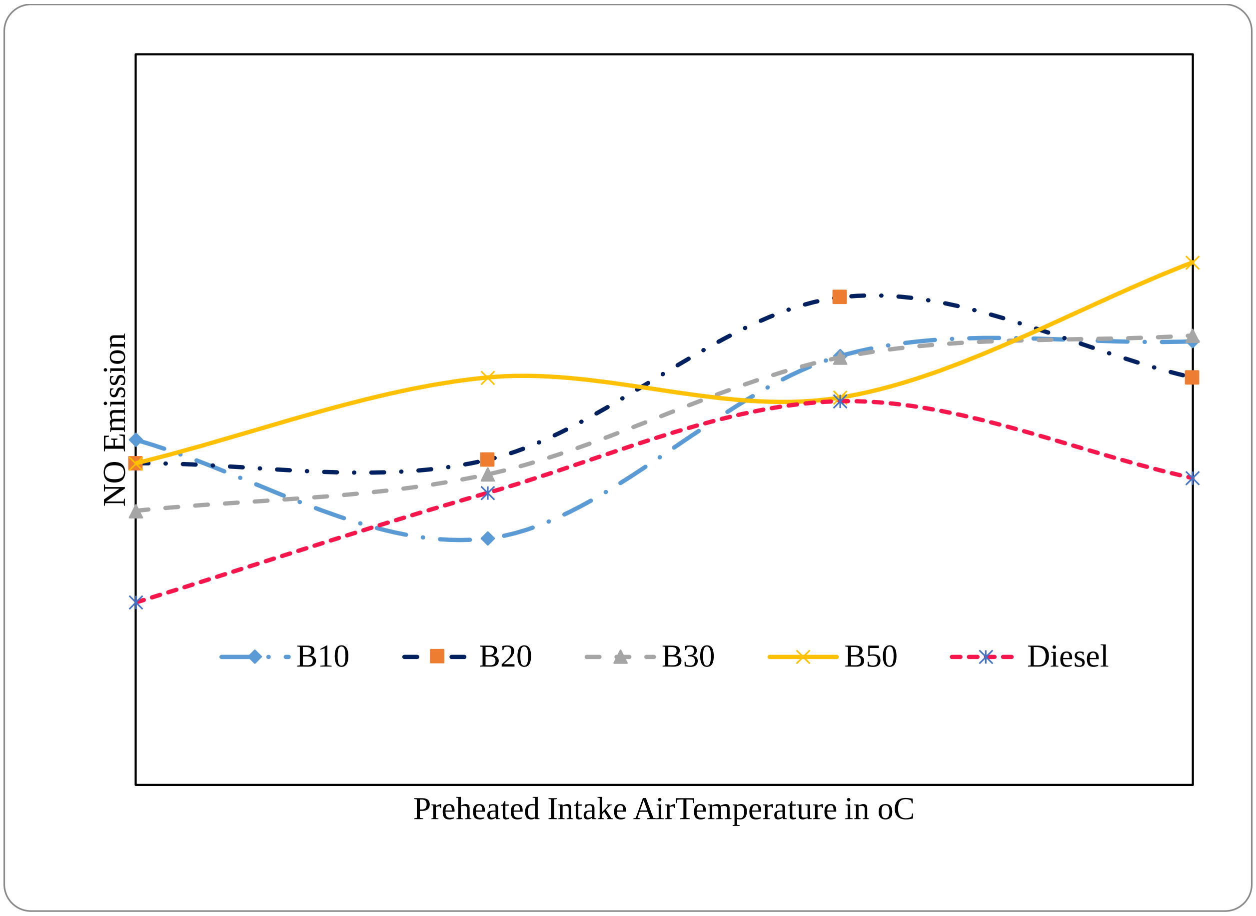

Figure 5 Nitrogen Oxide (NO) Emission Vs Preheated Intake Air Temperature.

As the intake air preheat temperature increases, biodiesel blend mixtures result in higher NO emission than mineral diesel as shown in **Figure.5**.Except ambient temperature high NO emission occurs at intake air preheated temperature. The reason perhaps is that heating effect of suction air is the dominant factor on NO emission. Also, this heating effect of suction air have either direct or indirect influence on latent heat of evaporation and thus leads to higher heating value of fuels which increase the combustion temperature which leads to increase of NO emission.

Exhaust Gas Temperature in ^{o}C Vs Preheated Intake Air Temperature

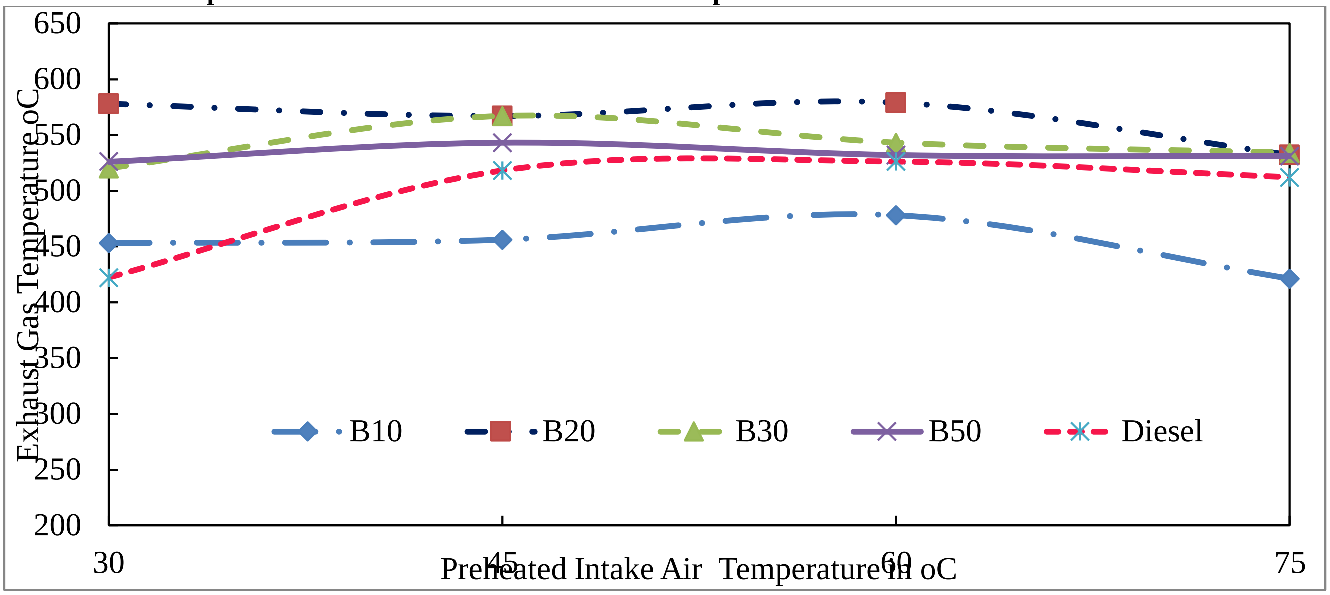

Figure 6 Exhaust Gas Temperature in ^{o}C Vs Preheated Intake Air Temperature.

It is seen in Figure.6. That exhaust gas temperature increases as the preheated intake air temperature increases. Exhaust gas temperature for mineral diesel lower as compared with all biodiesel blends for all suction air temperature. This is due to the reason that, biodiesel blends contains more oxygen content than mineral diesel and preheated air temperature permits efficient
Combustion of biodiesel mixture and higher blend ratio results higher exhaust gas temperature
The biodiesel blend B20 having higher calorific value and cetane index and therefore exhaust gas temperature increased compared to other blend ratio.

Conclusions

Biodiesel prepared by Transesterifcation process from the non-edible seed of Pongamia Pinnata kernel. Biodiesel blends (B10, B20, B30 and B50) were run in single cylinder 4-stroke diesel engine and intake air preheated by Two heat exchangers (Designed to recover heat from both engine cooling water and engine's exhaust gases) Effects of intake air preheat and fuel blend ratio on performance and exhaust emission characteristics of the engine were investigated when engine operating at 75 % of maximum load and its rated speed for the first time in the literature. In general, The exhaust emission characteristics of diesel engine mainly depends on efficient combustion which intern depends on vaporization and atomization of the fuel ,intake air temperature, peak temperature at the end compression and biodiesel and its blend ratio with mineral diesel. It is concluded based on experimental investigation, Except NO and exhaust gas temperature other exhaust emission parameters such as CO2 ,CO and HC decreases for all preheated suction air Temperature and blend ratio and among various blend ratio,the B20 blend ratio gives better results on exhaust emission compared with other blend ratio and mineral diesel therefore diesel engine is to be operated on the optimum blend ratio of B20.

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