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Effective Utilization of Waste Heat from Engine Exhaust Gas for Preheating the Fuel to Enhance the Performance of Diesel Engine

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Abstract. Fuels that replace the fossil diesel are the need of hour and at the same time should result in lower engine out emissions. Locally available honge biodiesel (BHO) was selected for their feasibility check as CI engine fuel and found a best option to replace the diesel by 100%. In the first phase, the study evaluates best fuel injection timing (IT) and injector opening pressure (IOP) for the biodiesel fuel (BDF) to yield best brake thermal efficiency (BTE) and revealed that BDF yielded best BTE at IT of 19^o before top dead centre (bTDC) and IOP of 240 bar. In the second phase, the effect of preheating the BDF by utilizing the waste heat energy of exhaust gas on the performance of CI engine was studied with best BTE conditions. The study revealed that heating the BDF to 80^{o}C, use of toriodal re-entrant combustion chamber (TRCC) yielded the performance of CI engine similar to conventional operation with standard diesel.

Keywords: Honge biodiesel (BHO); Toriodal re-entrant combustion chamber (TRCC); Preheating; Performance.

1. Introduction

The greenhouse gas (GG) emissions and fuel to power IC engines are the two major worldwide environmental and energy challenges. The large numbers of road vehicles is manufactured worldwide and road vehicles yield GG emissions and consume fuel. A wide range of plants (more than 300 species) yielding oil seeds can be grown in the waste forest land to get both edible and nonedible oils from which biodiesel fuel (BDF) could be produced which are biodegradable, environmental friendly, renewable [1,2]. The edible oil for CI engine application is not encouraged due to their huge demand by society for consumption [3-6]. The vegetable oils have higher kinematic viscosity due to the presence of unsaturated free fatty acid (FFA) and the higher molar mass. Serious engine fouling could be seen in the CI engine powered with them due to the incomplete fuel burning and thereby carbon deposition on the injector tip and valve seat was observed. The incomplete fuel combustion inside the combustion chamber (CC) dilutes and thickens the lubricating oil **[7]**. Hence the direct use of these vegetable oils for CI engine units is not recommended. An effort is made in this experimental study to test the feasibility of BHO and BCO (Both are non-edible) for stationary CI engine application and also to enhance the performance of the engine by preheating them.

2.Literature review

The CI engine running at lower load and speed (high idling condition) showed the increased SFC and NO_x emission with JOME compared to diesel but lower amount of CO and HC emissions in the engine out gas [8].The CI engine test powered with Annona methyl ester blends at different fuel IT showed 6.4% higher brake thermal efficiency (BTE) at 33º bTDC and 11.9% lower specific fuel consumption compared to original IT 27º bTDC. The NOx emission in the exhaust was bit higher while the smoke emission was lower by 13.5% at 33º bTDC than the original fuel IT [9]. Experimental test on multi cylinder CI engine fuelled with Moringa Oleifera BDF B10 and B20 with speeds ranging from 1000–4000 rpm at 100% load revealed that the brake power (BP) was lower and brake specific fuel consumption (BSFC) was higher for both B10 and B20 BDF in comparison with mineral diesel due to the increased frictional losses and increased time for heat transfer to the cylinder wall at all engine speeds [10]. The CI engine tests powered with karanja BDF and its blends to investigate its performance, emission and heat release rate (HRR) showed similar BTE for all the blends at higher loads. On the other hand increased BDF proportion in the blends showed lower BTE at lower loads. At higher engine speeds and loads, the engine out CO emissions were lower. But the CO emissions found higher for higher values of BDF proportion in the blends at lower engine load. The HRR found increased with increase in BMEP [11]. The experimental work with waste cooking oil B(50) from restaurants showed 19.2% increased BTE, 52% reduction in hydrocarbon (HC) emission, 37.5% reduction in CO emissions and 36.84% increase in engine out NO_x emissions [12]. The combined impact of IOP and combustion chamber (CC) shape on the performance of Pongamia oil methyl ester (POME) powered CI engine was studied and the study revealed that the toriodal re-entrant combustion chamber (TRCC) resulted in higher level BTE with improved BSFC at higher IOP. The trend seen could be due to higher IOP and better air motion prevailed that led to improved combustion [13]. The effect of CC shapes & injection strategies on the performance of Uppage oil methyl ester (UOME) powered diesel engine was studied and results showed that toriodal CC (TCC) was best to yield better engine performance at fuel IT of 19º bTDC using injector of 6 hole and 0.18 mm diameter [14]. The tests were performed on CI engine run with waste plastic oil at four fuel IT selected (23º, 20º, 17º and 14º bTDC). The retarded fuel IT of 14º bTDC resulted in lower NOx, CO and HC emissions with higher BTE, carbon dioxide (CO_2) and smoke levels at all the test conditions in comparison to fuel IT of 23º bTDC [15]. The experimental study revealed that BDF of Jatropha, Karanja and Polanga seed oil were quite suitable for CI engine. The neat Polanga BDF (PB100) provided maximum peak cylinder pressure (PP) (6.61 bars higher than that of mineral diesel). The ignition delay (ID) were consistently shorter for JB100 (varying between 5.9º and 4.2º crank angle (CA)), KB100 (varying between 6.3º and 4.5ºCA) and PB100 (varying between 5.7º and 4.2º CA) lower than mineral diesel [16]. The tests with the Sal methyl ester (SME) and its blends in a single-cylinder four-stroke CI engine improved performance like BTE and SFC, lowered emissions like CO, HC and smoke. The cumulative heat release of SME10 was slightly higher than baseline value. The combustion duration (CD) calculated at mass fraction burned (MFB) (0.05 to 0.95) was early at the initial stage and reduced ID up to 2.8 CA when SME volume fraction in the blend further added. The SME-diesel blends up to 40% by volume could be used in CI engine without modification [17]**.** Biodiesel powered engine showed lower BTE, much higher BSFC and higher heat losses except the exhaust heat loss than mineral diesel fuel [18]. The BDF powered IC engine could tax the food chain of the human society which lead to food shortages and also provide beneficial greenhouse effect. Engine consumes more BDF in comparison to the diesel fuel because of its lower heat energy content and cost has raised by using BDF as an alternative for mineral diesel [19]. The lower heat energy content of BDF could reduce the engine power with increased BSFC [20]. Neat Jatropha oil (JO) and blend of diesel and JO in 50:50 volume ratio was heated to investigate the performance of CI engine but performance not explained precisely [21]. JO was heated using the heat energy of the exhaust gas and its effect on the performance of CI engine was studied. The study revealed that viscosity could be brought to the level close to the viscosity of diesel. The performance in terms of BTE improved and also emissions

observed were close to diesel operation [22, 23]. Preheating the cotton seed oil BDF increased the NOx emission but have favorable effects on the BTE and CO emissions [24]. Preheated rubber seed oil (RSO) fuelled CI engine operation showed increase in BTE from 26.56% to 27.89% when RSO heated to 155ºC. NOx emission increased with increase in fuel temperature [25].
After going through the exhaustive literature, it was found that scarce literature is available on the use of waste heat contained in the exhaust gas to preheat the BDF besides employing the TRCC shape and nozzle geometry to improve the diesel engine performance. Therefore an attempt is made to experimentally investigate the feasibility of locally available BDF for stationary CI engine by heating it and using different combustion strategies to improve the performance in terms of higher BTE and lower exhaust emissions.

3.Experimental details

3.1. Fuels used

In the present experimental work, BHO BDF derived from the locally available honge oil was used. The physical and chemical properties of BHO were measured at Bangalore Test House Laboratory, Bengaluru, Karnataka, India. The properties of the fuels used in the current investigation are given in Table 1.

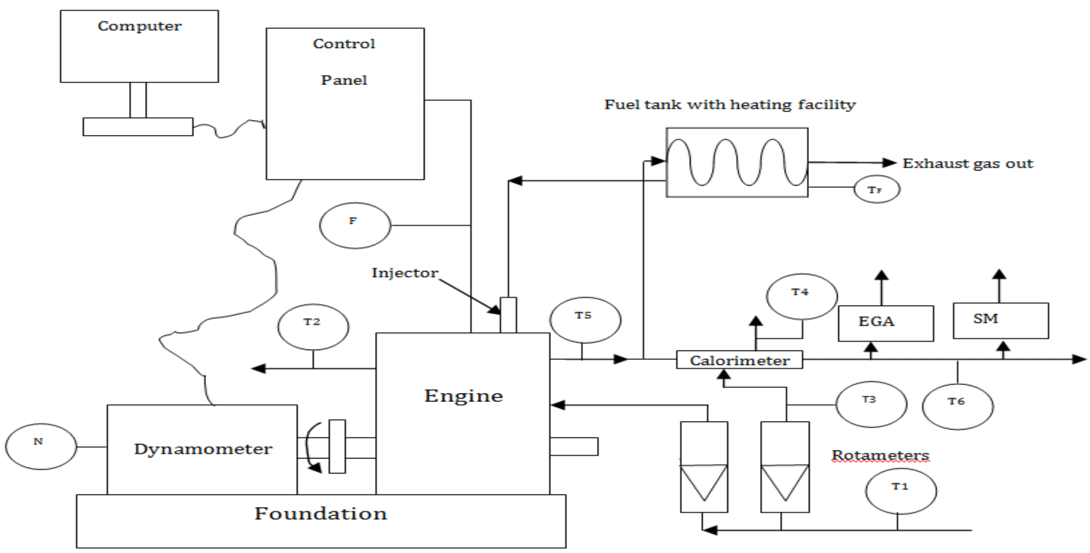
Table 1: Properties of Diesel and BHO

Sl. No.	Properties	Diesel	BHO	Standard limits		ASTM standard
				Min.	Max.	
1	Viscosity (cSt at 40°C)	4.59	5.6	1.9	6	ASTM D445
2	Flash point (°C)	65	163	100	-	ASTM D93
3	Calorific Value (kJ/kg)	45000	36010	-	-	ASTM D5865
4	Density (kg/m3 at 15 °C)	830	890	860	900	ASTM D4052
5	Cloud Point (°C)	-10	-2	-	-	ASTM D2500
6	Pour Point (°C)	-2	1	-	-	ASTM D97
7	Cetane Number	50	42	47	-	ASTM D613
8	Cold Filter Plugging Point (°C)	4	5	-	-	ASTM D6371
9	Moisture (%)	0.02	0.02	-	0.05	ASTM D2709
10	Carbon Residue (%)	0.1	0.12	-	0.05	ASTM D4530

3.2 Experimental procedure

In the first phase, the experimental tests were carried out on a 5.2 KW CI engine powered with BDF at the engine speed of 1500 RPM and at different loads to obtain best engine operating parameters that yield best BTE. The injector used had 3 holes of 0.3 mm orifice size and IOP was 205 bar. The CC shape was not changed i.e., kept hemispherical in first phase. Figure 1 depicts the CI engine test rig used for the present experimental work. The readings were recorded when engine operation was stable. In the second phase, the experiments were conducted at 80% load using BDF at a room temperature of 35 ºC with 6 hole injector of 0.2 mm hole size. Then the BDF temperature was varied from 50 ºC to 90 ºC in step of 10 ºC. The BDF was heated using heat energy contained in exhaust gas. For this a special heat exchanger type mechanical device was developed in-house and the temperature was recorded using a thermocouple. Flow rate of liquid fuels was measured on the volume basis using a burette and stopwatch. Toroidal reentrant combustion chamber (TRCC) was used in the present experimental investigations in the second phase of experimental work. These results were compared with the results obtained at room temperature. Specifications of the CI engine test rig used for the experimental study are shown in Table 2. A piezoelectric transducer (Make: PCB Piezotronics, Model: HSM 111A22, Resolution: 0.145 mV/kPa) fitted in the engine cylinder head provided the in cylinder gas pressure readings. The average of 100 cycles was taken as the gas pressure value. The heat release rate (HRR) was determined with the procedure given in literature [26, 27]. The start of combustion (SOC) process was determined from the differentiated cylinder gas pressure variation time data at which a sudden rise in the slope showing the point of ignition due to the high premixed heat release was seen. The end of combustion process was taken as the point at which 90% of the heat release had occurred (Determined referring the cumulative heat release curve). The ID is the time lag period between the start of injection and the start of ignition. The start of injection was taken based on the static fuel IT.

Exhaust gas composition during the steady-state operation was measured by employing a Hartridge smoke meter and five-gas analyzers (A DELTA 1600 S-non dispersive infrared analyzer). The accuracies of the measured values and the uncertainties in the calculated output parameters are provided in Table 3.



T1, T3 – Inlet cold Water Temperature, T2 – Outlet Engine Jacket Water Temperature

T4 – Outlet Calorimeter Water Temperature, T5 – Exhaust Gas Temperature before Calorimeter

T6 - Exhaust Gas Temperature after Calorimeter, T_F - Temperature of BDF, SM – Smoke Meter

F – Fluid Flow differential pressure Unit, N – Speed Encoder, EGA – Exhaust Gas Analyser,

Fig. 1 CI engine test rig used for the present experimental work

Table 2: CI Engine specifications

Sl. No.	Parameter	Specification
1	Type of engine	Kirloskar make Single cylinder four stroke direct injection diesel engine
2	Rated power	5.2 KW @1500 RPM
3	Cylinder diameter	87.5 mm
4	Stroke length	110 mm
5	Compression ratio	17.5 : 1

6	Software used	Engine soft
Air measurement manometer		
7	Made	MX 201
8	Type	U- Type
9	Range	100 – 0 – 100 mm
Eddy current dynamometer		
10	Model	AG – 10
11	Type	Eddy current
12	Maximum	7.5 (kW at 1500 - 3000 RPM)
13	Flow	Water must flow through Dynamometer during the use
14	Dynamometer arm length	0.180 m

Table 3: The accuracies of the measured values and the uncertainties in the calculated output parameters

Measured variable	**Accuracy (±)**
Load, N Engine speed, rpm Temperature, °C Fuel consumption, g	0.1 4 1 0.1
Measured variable	**Uncertainty (%)**
HC CO NOx Smoke Temperature of BDF	±5 ±2.5 ±2.3 ±1.3 ±5
Calculated parameters	**Uncertainty (%)**
BTE , % HRR, J/°CA	±1.2 ±1.0

4. Results and discussions

This section discusses the experimental results of CI engine with diesel and BDF. The fuel IT and IOP for best BTE with BDF were obtained in the first phase of the experimentation at different loads.

4.1 Effect of Injection Timing on the Performance of CI Engine

Experimental work on the BDF powered CI engine was carried out with compression ratio (CR) of 17.5 at three fuel IT of 19°, 23° and 27° bTDC. The injector employed for the initial experimentation was of 3-holes with orifice size 0.3 mm and hemispherical CC was used. The normal IOP of 205 bar was used to inject all liquid fuels. Engine was always made to run at rated speed of 1500 rpm. Table 4 provides the results of CI mode of engine operation and operating conditions.

Table 4: Results of CI mode of engine operation at room temperature with diesel and BHO

Characteristic	**CI mode of engine operation**	
	Diesel	**BHO**
	(IOP: 205 bar, IT: 23° bTDC Injector: 3 hole, 0.3 mm diameter)	**(IOP: 240 bar, IT: 19° bTDC, Injector: 6 hole, 0.2 mm diameter)**
BTE (%)	31.25	28.0

Smoke (HSU)	46	48
HC (ppm)	36	40
CO (% vol.)	0.13	0.136
NOx (ppm)	1095	1070
PP (bar)	74	72
ID (°CA)	9.9	10
CD (°CA)	38	39
HRR (J/°CA)	74	74

Performance in Terms of Brake Thermal Efficiency

The effect of the fuel IT on the BTE of CI engine powered with BDF with brake power (BP) is depicted in Fig. 2. At 80% load, the engine showed highest BTE of 30% with mineral diesel fuel at an IT of 23° bTDC and IOP of 205 bar. The BDF showed best BTE at fuel IT of 19° bTDC for BHO. However maximum BTE achieved with BDF powered CI engine operation at 19° bTDC was lower by 15.7% compared to mineral diesel operation. The BTE of the BHO fuelled CI engine operations were lower compared to diesel at all the three IT considered for the study. The decrease in BTE of the engine powered with BDF might be attributed to the lower heat energy content in them and higher specific fuel consumption (SFC).

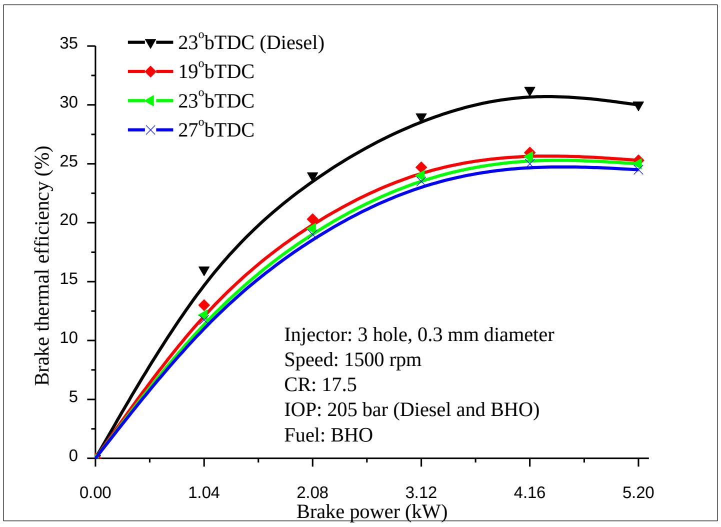


Fig. 2 Effect of the fuel IT and BP on the BTE of CI engine

4.2 Effect of Injector Opening Pressure (IOP) on the Performance of CI Engine

Effect of change in the IOP on the performance of the CI engine powered with BDF was studied. The IOP was varied from 220 to 260 bar. The engine operating parameters such as fuel IT and CR were kept constant at 19° bTDC and 17.5 respectively for BDF.

Brake Thermal Efficiency

The effect of variation in the IOP on the BTE of the CI engine at different loads is presented in Fig. 3. Of all the IOP, the highest BTE was achieved with IOP of 240 bar. This could be due to better fuel atomization and atomized fuel mixing with air, resulting in improved combustion. A higher IOP (260 bar) led to wall wetting and showed lower BTE. The maximum BTE for BHO operation was found to be 26.7% at 80 % load at an IOP of 240 bar.

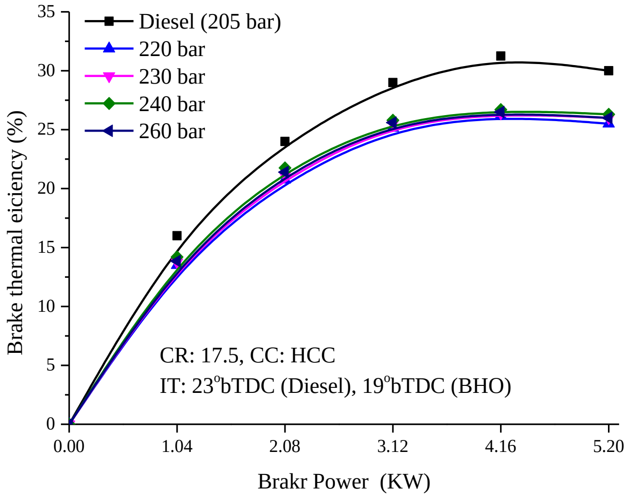


Fig. 3 Effect of the IOP and BP on the BTE of CI engine

4.3 Effect of Preheating the BDF on the Performance of CI Engine

This section explains the performance of BDF powered CI engine using a 6-hole nozzle of 0.2 mm orifice diameter. In order to study the effect of preheating the BDF on the CI engine performance, the temperature was increased from 50-90°C in step of 10°C using an in-house developed fuel heating facility. Results obtained with these temperatures were compared with the result obtained without preheating the BDF. During the engine test the fuel IT, IOP, CR and speed were kept constant. The readings reported are at 80% load only. The fuel IT and IOP were kept at best BTE condition obtained in the sections 4.1 and 4.2.

4.3.1 Brake Thermal Efficiency

Figure 4 shows variation in BTE of the CI engine operated with BDF. A 6 hole nozzle having an orifice of 0.2 mm resulted in maximum BTE at a fuel temperature of 80°C compared to all other temperature selected for the study, this could be mainly attributed to reduced viscosity of the injected fuel. Toroidal reentrant CC used could also enhanced the air fuel mixing. A six holes injector with smaller diameter nozzle holes resulted in better fuel atomization, mixing of air with fuel inside the CC and this further led to better combustion and hence higher levels of BTE. At 90°C temperature a little decrease in BTE was observed. It could be on account of increased penetration of fuel. Maximum BTE achieved was 29.4% and 29.0% respectively for BHO operation. The BTE values are 5-6% higher than the values obtained at room temperature of 35°C.

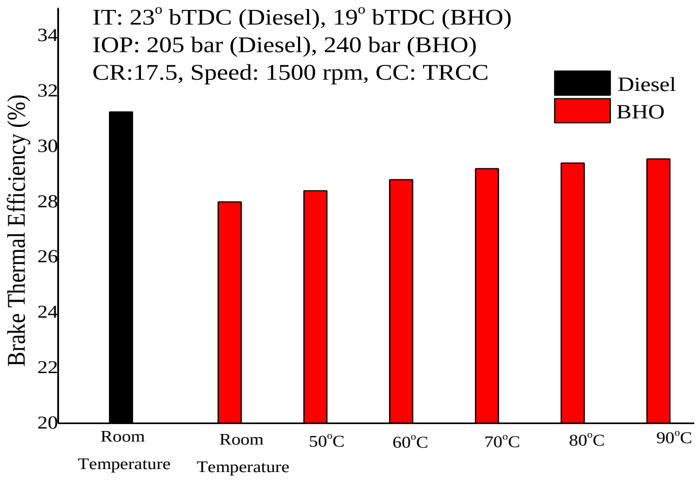


Fig. 4 Effect of different fuel temperature on the BTE of CI engine

4.3.2 Engine Out HC and CO Emissions

Variation in engine out HC and CO emissions of the diesel engine powered with BHO with varying fuel temperature is depicted in Fig.s 5 and 6. A 6 hole injector having an orifice of 0.2 mm at a fuel temperature of 80°C showed HC and CO emissions similar to normal CI mode of engine operation run on diesel. This could be mainly attributed to reduced viscosity and more homogeneous mixture formed at this temperature. Smaller diameter injector resulted in smaller sized fuel atomization, and this further led to better combustion and hence lower HC and CO emissions. The HC emissions values resulted with BDF operation at a fuel temperature of 80°C are 13% lower than the values obtained with the fuel at room temperature. The CO emissions levels with DBF operation at a fuel temperature of 80°C are 4.5% lower than the values obtained with the fuel at room temperature. Slight increase in both HC and CO was observed at 90°C due to wall wetting.

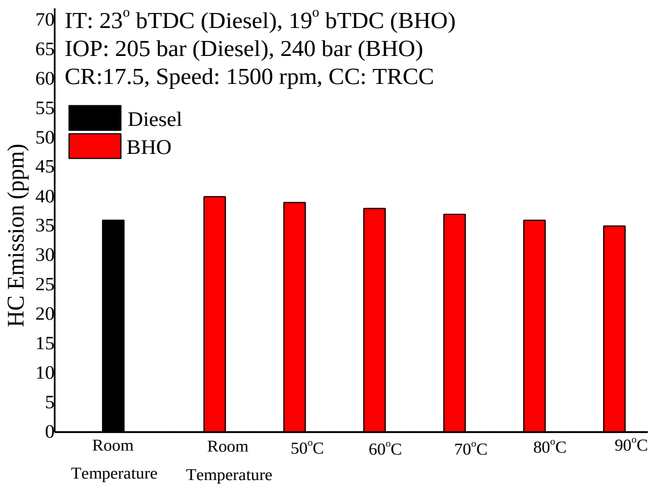


Fig. 5 Effect of different fuel temperature on the HC of CI engine

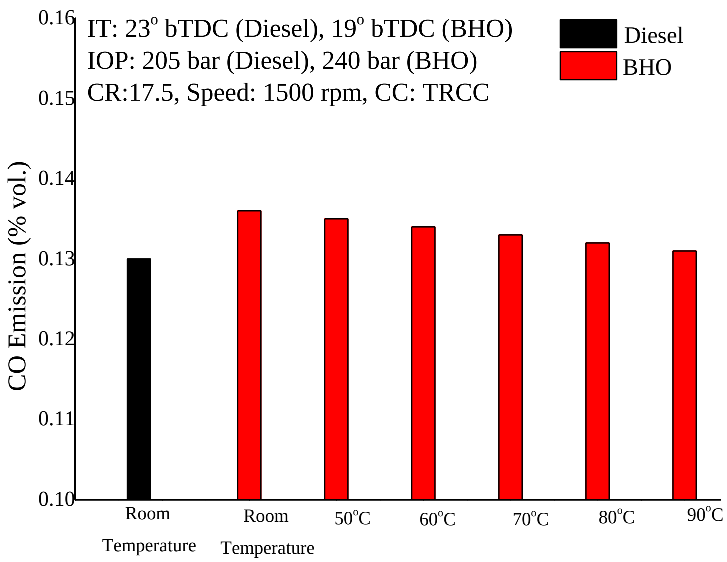


Fig. 6 Effect of different fuel temperature on the CO of CI engine

4.3.4 Engine Out NO_x Emissions

Figure 7 indicates the variation in the engine out NO_x emission of CI engine with variation in fuel temperature of BHO. The NOx emission increased with increase in the fuel temperature. It is well known fact that the viscosity of the fuel decreases with increase in fuel temperature. The reason for the increased NO_x emission could be due to better mixture and combustion prevailing inside the combustion chamber and more heat released during premixed combustion on employment of TRCC and six hole injector of 0.2 mm hole diameter. The NOx levels with DBF operation at a fuel temperature of 90°C are 8.5% higher than the values obtained with the fuel at room temperature. The NOx found higher with DBF than the CI mode of engine operation powered with mineral diesel at a fuel temperature higher than 70°C. Another reason for this might be slightly higher oxygen content of DBF.

4.3.5 Engine Out Smoke Emissions

Variation in smoke emission of the CI engine run with BHO with varying the fuel temperature is shown in Fig. 8. The higher smoke emissions in the exhaust gas of CI engine are the direct result of incomplete burning of injected fuels. The smoke emissions were higher for BDF compared to diesel at room temperature and the emission decreased as the temperature of the BDF increased due to decrease in the viscosity. Also injector of 6 holes with 0.2 mm hole size resulted smaller sized fuel droplets which improved the mixing of air and fuel that enhanced combustion. The injector of 6 holes yields lesser penetration distance of fuel due to lower mass flow rate per hole which reduced wall impingement there by resulted in decreased smoke emissions on account of complete combustion. As the fuel temperature was increased from room temperature to 80°C the smoke emission was reduced by 10%. But at 90°C the smoke emission was found increased slightly which shows incomplete combustion.

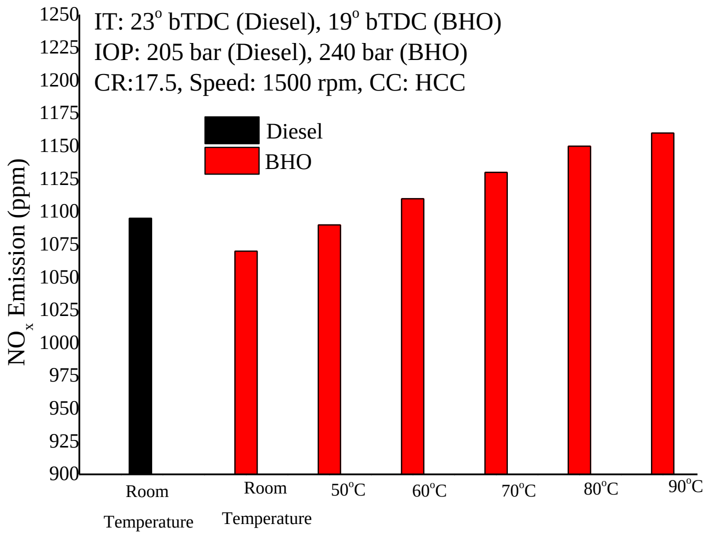


Fig. 7 Effect of different fuel temperature on the NOx of CI engine

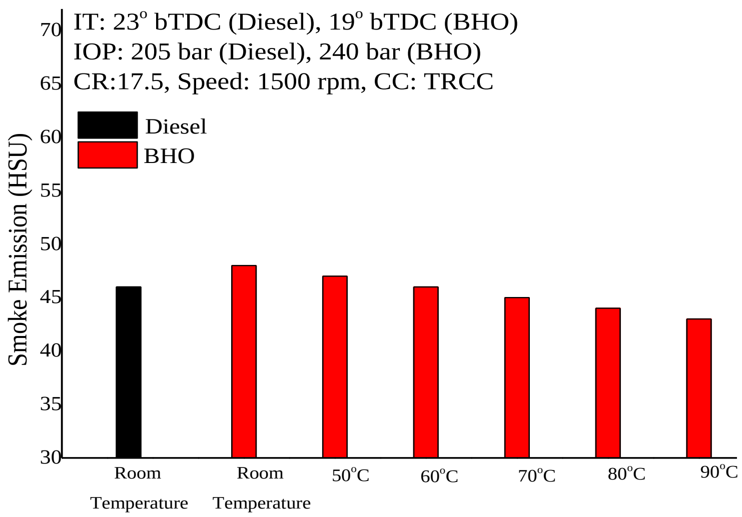


Fig. 8 Effect of different fuel temperature on the smoke of CI engine

4.3.6 Combustion characteristics

The combustion characteristics of CI engine powered with BDF are explained in this section.

Ignition delay (ID)

The variation of ID with different TRCC and BP is shown in Fig. 9. The ID is calculated based on the static IT using pressure crank angle data history for 100 cycles. Decreasing trend of ID was observed with increase in preheating temperature of BDF and also as six injector numbers of holes with smaller sized orifice used contributed in the decreasing trend seen. It could be attributed to decreased viscosity of BDF and better air-fuel mixing and increased combustion temperature. However, the BDF showed ID similar to diesel at a BDF temperature in the range 80°C.

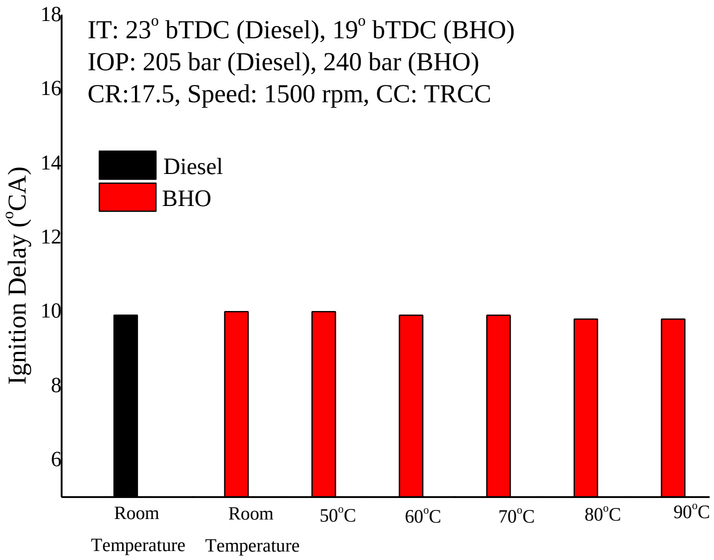


Fig. 9 Effect of different fuel temperature on the ID of CI engine

Combustion duration (CD)

The variation in CD shown in Fig. 10 was calculated based on the duration between the start of combustion (SOC) and 90% cumulative heat release. The total CD is the period of the overall burning process and it is the sum of flame development period and rapid combustion period. Higher CD was observed with BDF compared to diesel operation at room temperature. It might be due to higher viscosity of biodiesels led to improper air–fuel mixing, lower gas temperature and pressure. However CD was reduced with increase in BDF temperature. Also six hole injector with 0.2 mm diameter contributed in reduction in CD for BDF engine operation. The BDF showed similar or even low CD at a temperature of 80°C as compared to diesel powered CI mode at room temperature.

Cylinder Gas Peak Pressure

Figure 11 indicates the variation in cylinder gas peak pressure for BDF. The PP depends on the combustion rate and amount of fuel consumed during rapid combustion period. Slower burning nature of BDF during the ID period could be responsible for lower PP compared to mineral diesel at room temperature. The PP observed at a BDF temperature of 80°C was similar to one obtained with diesel operation at room temperature of 35°C. The combined effect of decrease in BDF viscosity and TRCC resulted in higher in-cylinder pressure. Also better burning of fuel due to enhanced air fuel mixing with injector of six holes of 0.2 mm size contributed in elevated PP. It could also be due to the combined effect of lower ID and slightly higher adiabatic flame temperature.

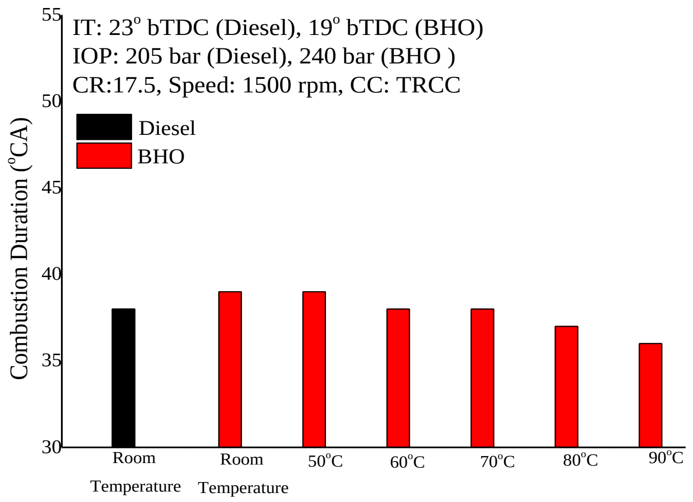


Fig. 10 Effect of different fuel temperature on the CD of CI engine

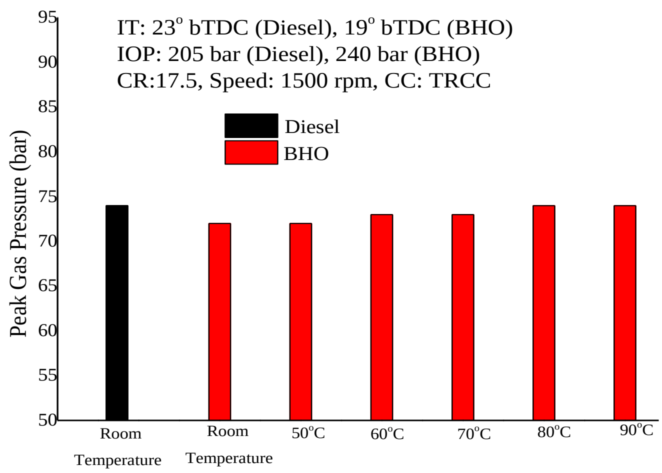


Fig. 11 Effect of different fuel temperature on the PP of CI engine

Heat release rate (HRR)

Figure 12 depicts the variation in HRR of CI engine with BDF temperature. The BDF powered CI engine operation resulted into higher HRR with increase in BDF temperature. Better air fuel mixture due to lower viscosity, enhanced combustion, higher cylinder gas temperature and pressure prevailed might be the reason for the higher HRR. The combined effect of TRCC and injector of six holes with 0.2 mm diameter might also be the reason for the increased HRR. The BDF showed HRR similar to mineral diesel at elevated BDF temperature of 80°C due to improved combustion qualities.

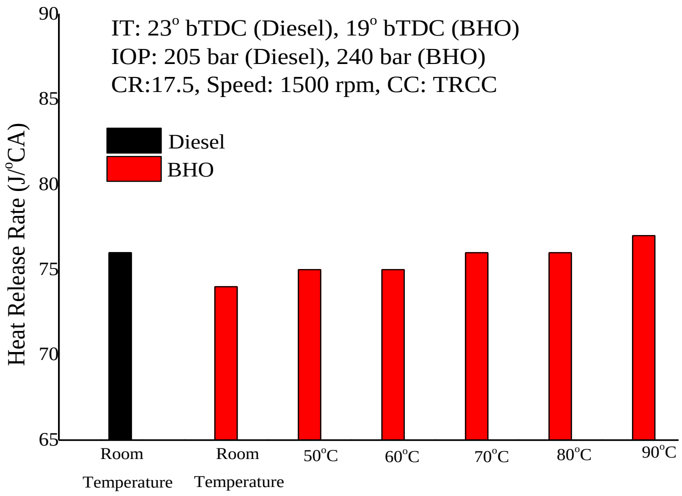


Fig. 12 Effect of different fuel temperature on the HRR of CI engine

Conclusions

The following conclusions are drawn from the exhaustive experimental work results on preheated BDF powered CI engine operated with toriodal reentrant combustion chamber and injector of six holes, 0.2 mm hole size:

- BDF showed 6% higher BTE when BDF temperature was about 80°C compared to BTE obtained with fuel at room temperature.
- BDF resulted in 13%, 4.5% and 11% lower HC, CO and smoke emissions respectively when BDF temperature was about 80°C compared to HC, CO and smoke with fuel at room temperature.
- BDF showed 9% higher NOx when BDF temperature was about 90°C compared to NOx with fuel at room temperature.
- ID and CD decreased with increase in fuel temperature. On the other hand PP and HRR increased with increase in fuel temperature. These values are similar to conventional diesel operation.

Overall the CI engine operation was smooth with preheated BDF with minor hardware modification. An injector of six holes with 0.2 mm orifice diameter and TRCC shape enhanced the performance when engine powered with preheated BDF. The preheated BHO powered engine could yield performance similar to normal diesel powered CI engine when BDF temperature was about 80°C with little penalty on NOx emission. This could utilize the waste heat and good for stationary CI engine units. To say finally the preheated BDF operation could be a way to get CI engine operation similar to diesel operation when TRCC and injector of 6 holes of 0.2 mm diameter each were employed.

References

[1] Planning Commission of India, Report of the Expert Committee on Integrated Energy polcy, 2006.

[2] Shashi K. Jain, Sunil Kumar, AlokChaube (2011), Jatropha biodiesel: Key to attainment of sustainable rural bio-energy regime in India, Archives of Applied Science Research, 3 (1): 425-435.

[3] Banapurmath N.R., Tewari P.G., Hosmath R.S.,(2008) Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters, Renewable Energy, 33, , pp 1982–1988.

[4] Soo-Young No (2011), In-edible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review, Renewable and Sustainable Energy Reviews 15 131–149.

[5] International conference on bio-fuels 2012 vision to reality. Energy Fuel Users J January–March 2006:6–8.

[6] P.V. Rao (2011). Experimental Investigations on the Influence of Properties of Jatropha Biodiesel on Performance, Combustion, and Emission Characteristics of a DI-CI Engine, World Academy of Science, Engineering and Technology 75 2011, 855-868.

[7] Mishra, R.D., Murthy, M.S., "Straight vegetable oils usage in a compression ignition engine-A review", Renewable and Sustainable Energy Reviews, 14: 3005-3013, 2010, doi:10.1016/j.rser.2010.06.010.

[8] Rahman SMA, Masjuki HH, Kalam MA, Abedin MJ, Sanjid A, Imtenan S. Effect of idling on fuel consumption and emissions of a diesel engine fueled by Jatropha biodiesel blends. J Cleaner Prod 2014;69:208–15.

[9] R. Senthil, R. Silambarasan & G. Pranesh. The influence of injection timing on the performance and emission characteristics of an Annona methyl ester operated diesel engine. 2016. DOI: 10.1080/17597269.2016.1149768.

[10] Mofijur M, Masjuki HH, KalamMA,Atabani AE, Arbab MI, Cheng SF. Properties and use of Moringaoleifera biodiesel and diesel fuel blends in a multi-cylinder diesel engine. Energy Conversion and Management 2014;82:169–76.

[11] Dhar A, Agarwal AK. Performance, emissions and combustion characteristics of Karanja biodiesel in a transportation engine. Fuel 2014;119:70–80.

[12] El-Kassaby M, Nemit-allah MA. Studying the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel. Alex Eng J 2013; 52(1): 1–11.

[13] Jaichandar S, Annamalai K. Combined impact of injection pressure and combustion chamber geometry on the performance of a biodiesel fueled diesel engine. Energy 2013; 55: 330–9.

[14] D.N. Basavarajappa, N. R. Banapurmath, S.V. Khandal, G. Manavendra. Effect of Combustion Chamber Shapes & Injection Strategies onthe Performance of Uppage Biodiesel Operated Diesel Engines. Universal Journal of Renewable Energy 2 (2014), 67-98.

[15] Mani, M. and Nagarajan, G. (2009). Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on waste plastic oil. Energy, 34, 1617–1623.

[16] Sahoo, P.K., Das, L.M., Babu M.K.J. and Naik S.N., (2007), Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. Fuel, 86, 448-454.

[17] Harveer Singh Pali and Naveen Kumara. Combustion, performance and emissions of Shorearobusta methyl ester blends in a diesel engine. BIOFUELS, 2016. http://dx.doi.org/10.1080/ 17597269. 2016.1153363.

[18] M.J. Abedin, H.H.Masjuki, M.A.Kalam, A.Sanjid, S.M. Ashrafur Rahman, B.M. Masum. Energy balance of internal combustion engines using alternative fuels. Renewable and Sustainable Energy Reviews 26 (2013) 20–33.

[19] E. Sadeghinezhad, S.N.Kazi, A.Badarudin ,C.S.Oon , M.N.M. Zubir , Mohammad Mehrali. A comprehensive review of bio-diesel as alternative fuel for compression ignition engines. Renewable and Sustainable Energy Reviews 282 (2013), 410–424.

IOP Conf. Series: Materials Science and Engineering **376** (2018) 012090 doi:10.1088/1757-899X/376/1/012090

[20] Park SH, Cha J, Lee CS. Impact of biodiesel in bioethanol blended diesel on the engine performance and emissions characteristics in compression ignition engine. Applied Energy 2012;99:334–43.
[21] Forson FK, Oduro EK, Hammond-Donkoh E. Performance of jatropha oil blends in a diesel engine. Renewable Energy 2004;29:1135–45.
[22] Agarwal D, Agarwal AK. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl Thermal Eng 2007;27:2314–23.
[23] Chauhan BS, Kumar N, Jun YD, Lee KB. Performance and emission study of preheated Jatropha oil on medium capacity diesel engine. Energy 2010;35(6): 2484–92.
[24] Karabektas M, Ergen G, Hosoz M. The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine. Appl Thermal Eng 2008;28:2136–43.
[25] Geo VE, Nagarajan G, Nagalingam B. Experimental investigations to improve the performance of rubber seed oil by exhaust gas preheating. SAE paper 2008-28-0049; 2008.
[26] T.K. Hayes, L.D. Savage, S.C. Sorenson, Cylinder Pressure Data Acquisition and Heat Release Analysis on a Personal Computer, SAE Paper, 1986, p. 860029.
[27] G.F. Hohenberg, Advanced Approaches for Heat Transfer Calculations, SAE Paper, 1979, p. 790825.