Chapter 7

Experimental Investigation of Preheated Diesel and Blended Biodiesel on Engine Performance and Emission using Waste Heat of the Coolant with Energy economic Analysis

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The present experimental study investigates the utilization of preheated *Methyl ester orange peel blend* of D-30%OPB biodiesel (30% Orange peel blend with 70% diesel) as a renewable fuel to the diesel engine. The orange peel methyl ester is a sustainable, renewable, toxic less, alternative fuel produced from the transesterification of orange peel oil. Biodiesel and diesel are preheated to a temperature ranging from 30 – 43°C using the heat extracted from the coolant waste from a preheating section (PHS). Coolant energy is dependent upon the engine load. Preheated diesel and biodiesel are tested in a diesel engine at different loading conditions at a fixed speed to evaluate the engine performance (brake thermal efficiency (BTE), brake specific consumptions (BSFC)), exhaust emissions (HC, NO_X, and CO), and fuel energy distribution.

7.1 Experimental facility

The four-cylinder engine and the radiator, coupled with a dynamometer is used for the experimental investigation. The detailed schematic view of the work configuration is shown in Fig. 7.1. Pictorial representation of the experimental setup is shown in Fig. 7.2. The engine specifications are tabulated in Table 7.1. Load on the engine has been applied and varied using an eddy dynamometer generally called brake power. Fuel can be preheated using the energy of waste exhaust gas, hot coolant from the engine through a concurrent heat exchanger or external heating coil. Due to load increment, in terms of brake power, the coolant out from the engine also carries higher energy at relatively higher temperatures corresponding to the higher brake power. Therefore, In the present investigation fuel has been preheated extracting energy from the hot coolant from the engine before the radiator at different brake power. The preheating section was installed before the radiator for energy transfer to the fuel. Both diesel and D-30%OPB biodiesel were used to run the engine separately. Under no-load conditions, the engine was run for 15 minutes to reach a steady condition. When the temperature change of the parameters remains constant then a steady state is achieved. For separate load (brake power), the engine was run for 15 minutes and the data was recorded. The detailed dimension of the Preheating Section (PHS) is listed in Table 7.2. The experimental and schematic diagram of PHS is shown in Fig. 7.3. Test engine contains different thermocouples to measure the entry and exit temperature of coolant from the water jacket, calorimeter, and exhaust temperatures.

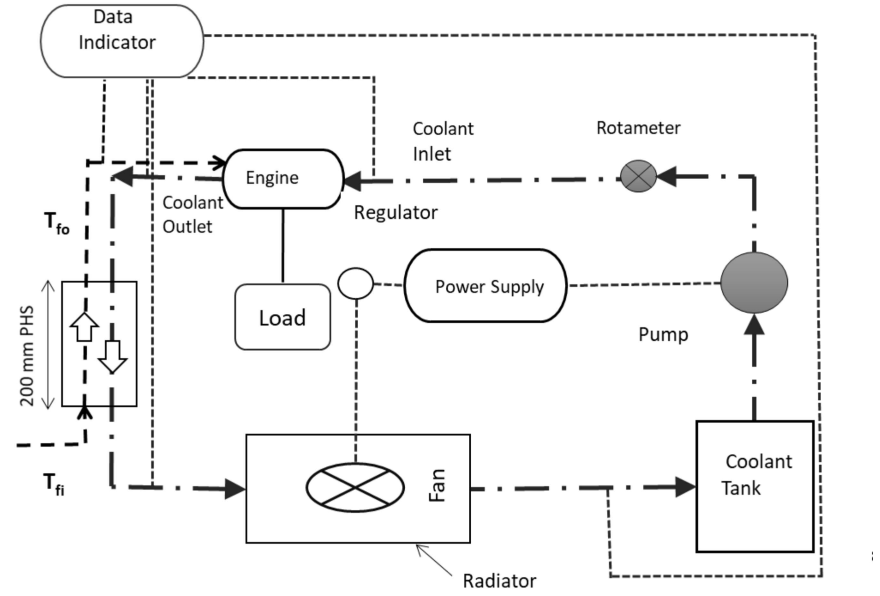


Fig. 7.1. Schematic representation of experimental work.

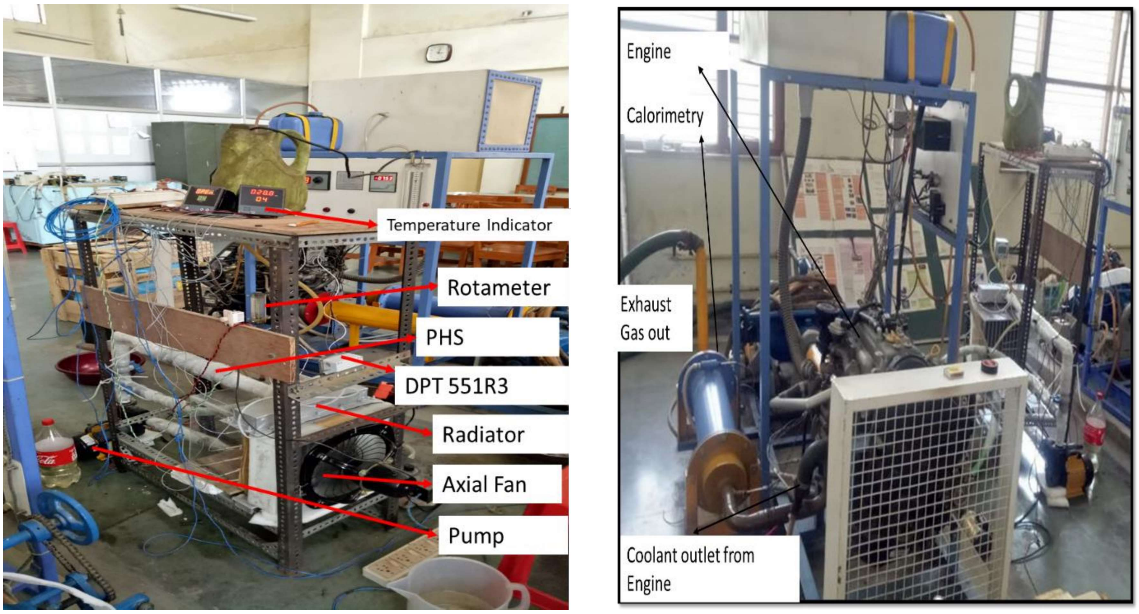


Fig. 7.2. Experimental setup.

Also, emissions are tested from the engine. The exhaust gas from the engine is used to measure the emission of CO_2, CO, HC, and NO_X. Emissions are measured from a gas analyzer of model AVL DI 444. To reduce the experimental error, the engine was operated 3 times under varying loads.

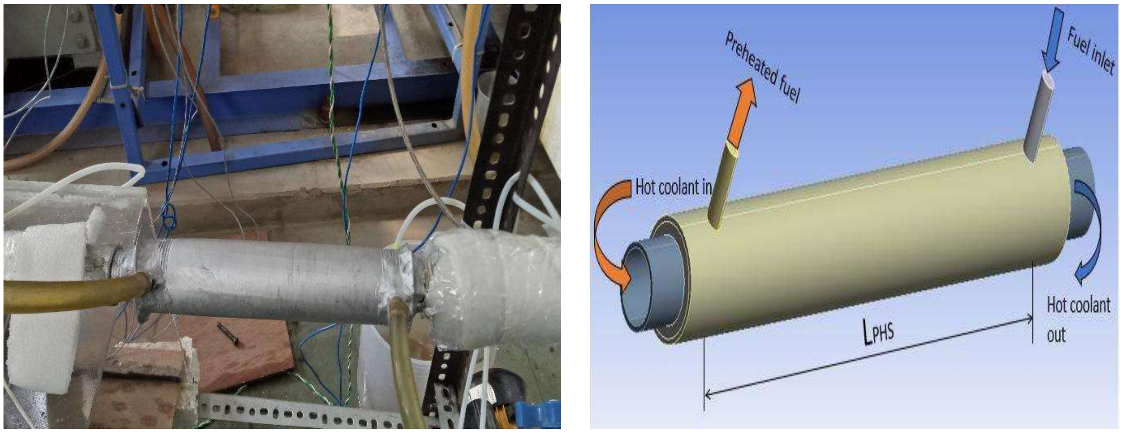
Table. 7.1 Test Engine characteristics.

Make	Kirloskar
Engine Model	4-stroke, 4-Cylinder, water coolant diesel engine
Bore	85mm
Stroke	92mm
Compression Ratio	18:1
Engine CC	2088 CC
Injection pressure	180 bar
Lubricating oil	SAE 40

Rated speed	1500RPM

Table. 7.2 PHS dimension for fuel preheating.

PHS dimensions	
Inner Tube internal diameter (D_i)	25mm
Tube thickness (t)	3mm
Outer tube internal diameter (D_{oi})	38mm
Preheated length section (L_{PHS})	200mm

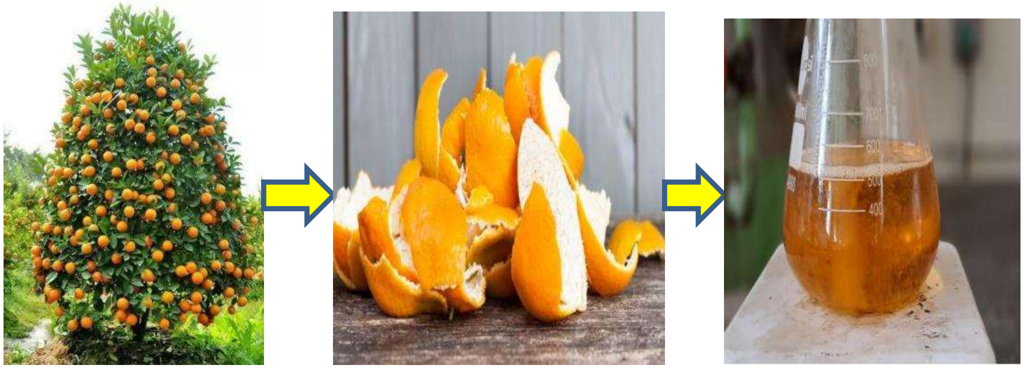


(a) (b)

Fig. 7.3. Preheating section, (a) Experimental view; (b) schematic view.

7.1.1 Preparation of biodiesel from orange peel oil

The orange tree almost takes three to five years to grow and produce oranges in the season of November to May in the central and western regions of India. Based on National horticulture board report, 50 to 64 lakh tonnes of orange is produced in India per year. Furthermore, estimation of 100-200g of orange peel can be extracted per kg of orange fruit. 700mL of orange peel oil (Orange peel oil) can be extracted from 1.2kg of orange peel. Components of orange tree, peel, and oil are shown in Fig. 7.4. The path process of production of methyl ester formation from the crude oil level-wise is illustrated in Fig. 7.5. Orange peel oil was purchased from local vendors of Varanasi, India. A 525mL of an orange peel oil sample is heated to 65°C in a flat bottom flask. A mixture is prepared, by dissolving 160 ± 5mL of methanol in the ratio of 30% (v/v) of OPO, mixed with 1% of KOH i.e, 2.4g of KOH as the catalyst is transferred to the heated OPO.



Orange Tree **Orange Peel** **Orange Peel Oil**

Fig. 7.4. Components of Orange Tree, Peel, and Oil.

Dissolved mixture is stirred continuously at a constant speed of 900RPM for 90-100min at the same temperature. Once the reaction time is over, the mixture is kept in a separate funnel by adding warm water for the washing process and allowing it to settle. Due to the density difference mixture is settled in the three-layer top layer is methyl ester, the bottom layer is of glycerol and the intermediate layer is water as shown in Fig. 7.6. The washing technique eliminates the remaining catalyst, methanol, and glycerol from the mixture. Top layer OPO, methyl ester is separated, collected, and measured to be 48mL. The yield of methyl ester from the OPO is evaluated to be 92.3%.

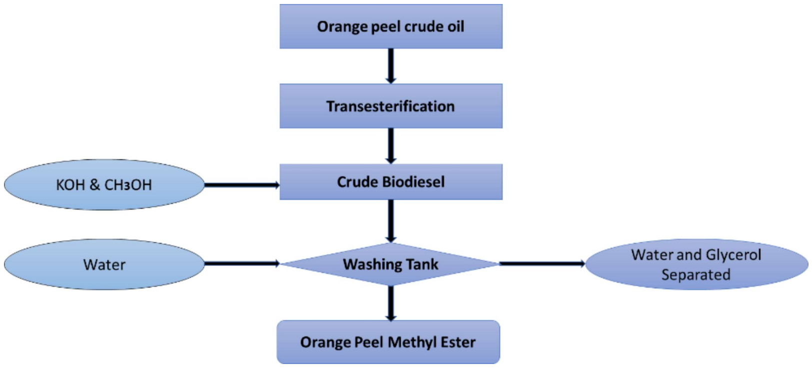


Fig. 7.5. Path process of orange peel oil Methyl Ester production.

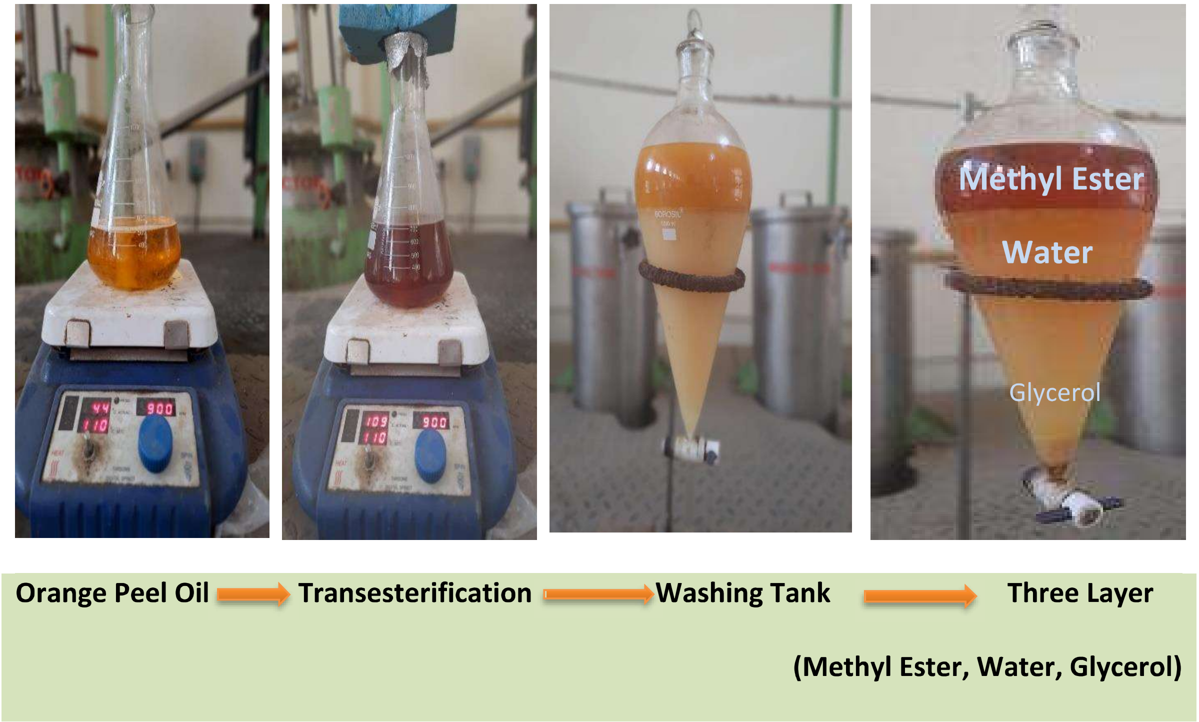


Fig. 7.6. Process of Orange peel Methyl ester production

The chemical reaction equation for the formation of methyl ester and glycerol from the triglycerides and methanol using a catalyst is shown in Fig.7.7. Here OPO is the triglycerides and KOH is used as a catalyst for a faster production rate of products.

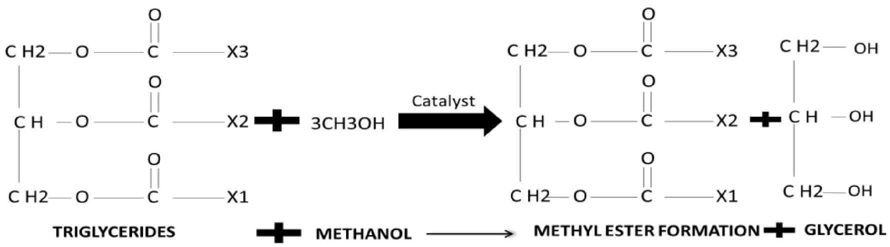


Fig. 7.7. Transesterification reaction equation.

7.1.2 Fuel physiochemical Properties

The sample of the fuels was used to measure the physicochemical properties in the lab by following ASTM standards. Brookfield viscometer, Open cup Cleveland (for flash and fire point), and Bomb calorimeter device are used to measure viscosity, flash point, and calorific value of the prepared sample, respectively is shown in Fig. 7.8. Using mass and volume conventional technique density of the fuel sample was measured as shown in Fig. 7.8(a). The measured properties of diesel and D-30%OPB biodiesel are tabulated in Table 7.3. The viscosity of D-30%OPB biodiesel (30% Methyl ester and 70% diesel) is higher than the diesel. When the fuel is preheated, reduction in viscosity to enable better fuel atomization, spray, and combustion characteristics. With the load variation in the CI engine, the maximum preheating of fuel temperature was obtained to be 43℃ at 5.6kW brake power load conditions.

Table. 7.3 Physiochemical properties of fuels.

Properties	**Units**	**Measuring standard**	**Diesel**	**D-30%OPB biodiesel**
Density	kg/m^3	ASTMD1298	850	870
viscosity	cP	ASTMD445	3.35	3.85
LCV	MJ/kg	ASTMD240	42.60	39.40
FlashPoint	℃	ASTMD93	67	77

Fire point	°C	ASTMD93	72	81

(a) (b) (c)

Fig. 7.8. Measurement apparatus (a) Density (b) Bomb calorimeter (c) Open-cup Cleveland apparatus.

7.1.3 Data Evaluation

To investigate the preheating of fuel effects on the engine, coolant outlet energy used purposely in fuel heating and imposed to the engine as a waste energy utilization, data reduction includes,

Fuel consumed for different applied loads is calculated as

$$\dot{m}_{fuel} = \frac{Vol.of\ fuel * \rho_{fuel}}{t} \qquad (7.1)$$

(BP) is calculated as

$$BP = \frac{Ld * ES * 0.746}{2200} \qquad (7.2)$$

where Load applied load(kg), ρ_{fuel} is the fuel density, t is the time (s), and ES is engine speed kept constant (1500RPM).

Brake specific fuel consumption (BSFC) is calculated as

$$BSFC = \frac{\dot{m}_{fuel}}{BP} \tag{7.3}$$

Brake thermal efficiency is given by

$BTE = \frac{BP}{LCV * \dot{m}_{fuel}}$ where LCV Is lower calorific value. (7.4)

The energy liberated by fuel is given by

$$Q_{fuel} = \dot{m}_{fuel} * LCV_{fuel} \tag{7.5}$$

The energy carried by coolant from the engine is calculated by

$$Q_{coolant} = \dot{m}_{coolant} * c_{p,coolant} * (T_{cin} - T_{co}) \tag{7.6}$$

The energy carried by exhaust gas from the engine is given by

$$Q_{exh} = \dot{m}_{exh} * c_{p,exh} * (T_{exh,outlet} - T_{amb}) \tag{7.7}$$

Where, $\dot{m}_{exh} = \dot{m}_{a} + \dot{m}_{fuel}$

Brake power and unaccounted heat energy from the engine are calculated as

$$Q_{BP+UH} = Q_{fuel} - (Q_{coolant} + Q_{exh}) \tag{7.8}$$

For cost analysis of the heat exchanger, the Total cost is given by

$$\text{Total cost}_{HX} = \text{Fixed cost} + \text{HX operating cost} \tag{7.9}$$

Where, $(\text{Fixed cost})_{HX} = (\text{Manufacturing cost} + \text{Cleaning cost} + \text{Fitting cost})_{HX}$

Annual fuel consumption (AFC) in (l/yr) is evaluated as

$$AFC = \frac{\dot{m}_{fuel}\, t_{run}}{\rho_f} \tag{7.10}$$

Annual fuel saving (AFS) in (l/yr) is determined as

$$AFS = AFC_{normal} - AFC_{wph} \tag{7.11}$$

Similarly, fuel saving for the month is given by, $Fuel\ saving = \frac{AFS}{12}$ in (l/month) and for analysis, the cost of diesel is Rs 100/l and for blended biodiesel, Rs 90/l cost is considered for the analysis.

Cost recovery (in hours) is determined as

$$\text{Cost recovery} = \frac{8*(\text{Total cost})_{HX}}{\text{cost of fuel saving}_{day}} \text{ (in hours)} \tag{7.12}$$

For energy utilisation, Energy utilised for preheating of fuel is given by

$$E_{utilised} = \dot{m}_{fuel}\ c_{p,fuel}\ (\Delta T_{fuel})_{PHS} \tag{7.13}$$

7.1.4 Instrument error investigation

The Experimental investigation requires uncertainty estimation, instrumental error, and the determination of variables used to complete the test to support the repeatability. However, uncertainty may appear from different factors, experimental observation, calibration, inappropriate evaluations, and atmospheric conditions. Different parameters' uncertainty is determined using standard error, deviation, and mean for the repeated set of observations. Uncertainty of the several variables is listed in Table 7.4, evaluated at lower load (BP 5.6kW). The Overall experimental uncertainty (OEU) is evaluated as follows.

$$OEU = \sqrt{\left\{\left(U^2_{Engine\ load}\right)+\left(U^2_{fuel\ utilization}\right)+\left(U^2_{Temperature}\right)+\left(U^2_{coolant\ flow}\right)+\left(U^2_{Engine\ speed}\right)+\left(U^2_{time}\right)+\left(U^2_{CO}\right)+\left(U^2_{NO_X}\right)+\left(U^2_{HC}\right)\right\}}$$

$$= \sqrt{\left\{(0.1)^2+(0.9)^2+(0.1)^2+(0.9)^2+(0.1)^2+(0.5)^2+(0.1)^2+(0.6)^2+(0.1)^2\right\}}$$

$$= \pm 1.50\ \%$$

Table. 7.4 Uncertainty of different parameters.

Parameter	Uncertainty (%)	Magnitude
Engine Load (kg)	±0.1	10.6kg
Temperature (°C)	±0.1	43.2°C
Coolant flow rate (lpm)	±0.9	10lpm

Brake specific fuel consumption (kg/kW-h)	±1.4	0.38kg/kW-h
Brake thermal efficiency	±1.7	24.5%
Engine speed (RPM)	±0.1	1500RPM
Time (s)	±0.5	20s
CO	±0.1	______
NO_X	±0.6	______
HC	±0.1	______

7.2 Results and Discussion

In the present experimental investigation both fuel, Diesel, and D-30%OPB biodiesel is preheated (30.2 – 43°C) before entry to the engine using an intermediate heat exchanger. Fuel temperature is dependent upon the coolant entry temperature which is controlled using the engine load variation in terms of brake power. Fuel temperature and coolant entry temperature at different load conditions is presented in Table 7.5. The preheating reduces fuel viscosity and enables better fuel spray and combustion (**Augustine et al., 2012; Mekonen and Sahoo et al., 2018; Anis et al., 2019**). Tests are conducted for diesel, D-30%OPB biodiesel (30% Methyl ester and 70% Diesel) with and without preheating conditions at different loads. The optimum performance was obtained with preheating temperature of 43°C at 5.6kW load condition. D-30%OPB biodiesel contains more oxygen content.

Table. 7.5 Fuel and coolant temperature for different loading.

Brake power (kW)	Fuel average temperature (°C)	Coolant temperature (°C)	Diesel (°C)	Biodiesel (°C)
1.1	30.2	45.1	30.5	29.9

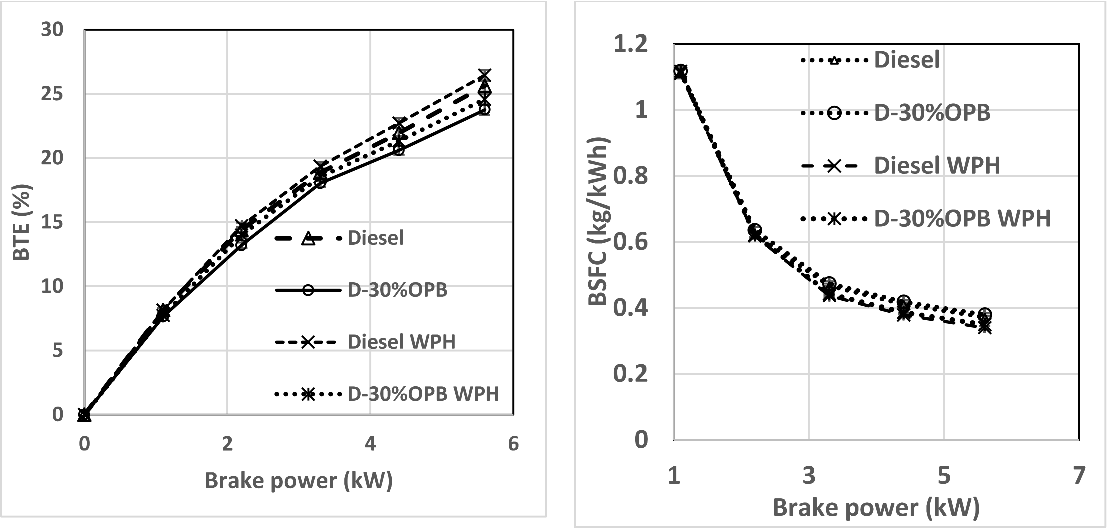
2.2	34.4	49.2	34.6	34.2
3.3	38.5	57.2	39.5	37.5
4.4	41.8	65.4	42.9	40.7
5.6	43	73.8	43.4	42.6

7.2.1 Performance parameter evaluation

Different performance parameters for engine evaluation like Brake thermal efficiency (BTE) and Brake specific fuel consumption (BSFC) are examined for both diesel and biodiesel under normal run and with preheating (WPH) at different load conditions. Performance Parameter BTE signifies the chemical conversion of fuel into power output. However, the other parameter BSFC signifies the fuel consumption for power production. The preferred engine recommends to suit higher BTE and lower BSFC.

7.2.2 Brake thermal efficiency (BTE), Brake specific fuel consumption (BSFC) performance

The brake thermal efficiency dependency on load variation for diesel and biodiesel under normal and preheating conditions are illustrated in Fig. 7.9 (a). The BTE increases with load increment from no load to higher load. BTE for D-30%OPB biodiesel is lower than diesel. The optimum BTE obtained at a 5.6kW load for both diesel and biodiesel with and without preheating. Although with preheating (30.2 – 43°C), the BTE in the case of D-30%OPB biodiesel approaches diesel BTE without any modification to the engine. Heating reduces viscosity and directs smooth flow, better fuel spray characteristics with higher volatility. At 5.6kW load, the value of BTE for diesel, and D-30%OPB biodiesel are 25.6% and 23.7% respectively.



(a) (b)

Fig. 7.9. Performance evaluation for different fuels with preheating; (a) BTE with brake power; (b) BSFC with brake power.

Furthermore, at the same load for preheated fuels, diesel, and biodiesel, the BTE is 26.4% and 24.7% respectively. Higher fuel temperature allows forming of tiny droplets and uniform distribution inside the engine approaches toward homogeneous combustion. For D-30%OPB biodiesel, D-30%OPB WPH, BTE is increased by 2.7%, 3.2%, and 3.3% compared to unheated biodiesel at 3.3, 4.4, and 5.6kW Load respectively. For diesel WPH, BTE is increased by 2.4%, 3.4%, and 3.2% compared to normal diesel run at 3.3, 4.4, and 5.6kW Load respectively.

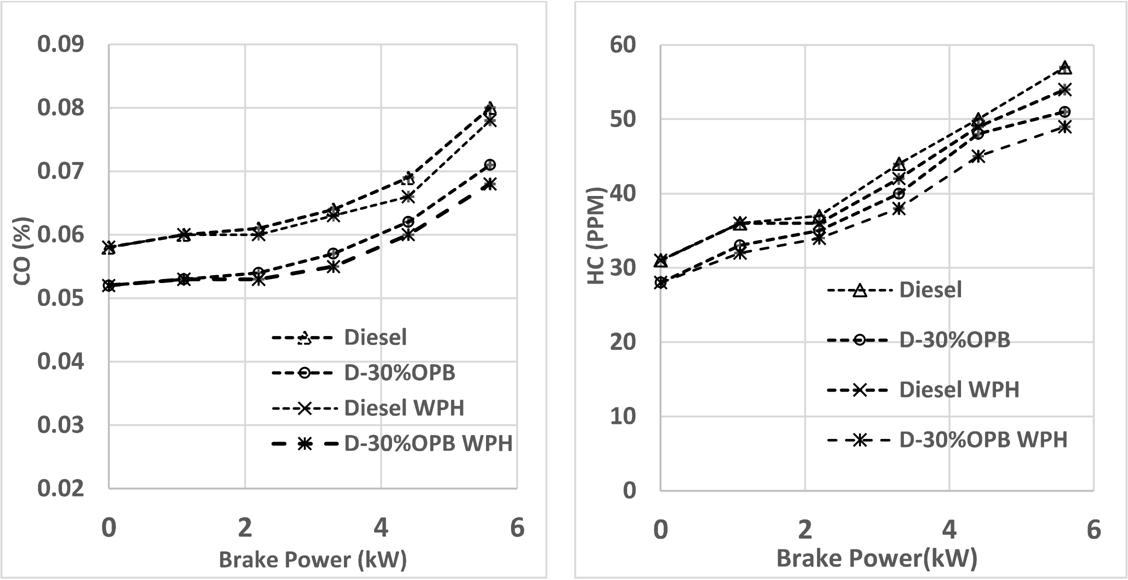
BSFC is a crucial performance parameter to identify the fuel conversion into work done. The BSFC variation with load for diesel and D-30%OPB biodiesel tested under normal conditions and with preheated conditions is shown in Fig 7.9 (b). The fuel consumption at each load was measured using the volume consumption of fuel through the burette at a regular time. Fuel consumption is dependent upon the fuel heating value, engine efficiency, and air-fuel mixing (**Ragu et al., 2010; Augustine et al., 2012; Prabhu et al., 2018; Purusothaman et al., 2009**). The BSFC decreases with the increased load. BSFC for D-30%OPB biodiesel is higher than diesel due to lower fuel heating value. D-30%OPB biodiesel is 1.3%, 1.8%, and 2.2% higher BSFC compared to diesel at 3.3, 4.4, and 5.6kW of load respectively. When the preheated D-30%OPB biodiesel is tested, a reduction in BSFC compared to unheated D-30%OPB biodiesel has obtained a maximum of 7.9% at 5.6kW load conditions due to better combustion.

7.2.3 Evaluation of engine Emissions under preheating

Engine emissions are a crucial parameter to identify the engine run condition. The exhaust emissions CO, HC, and NO_X were measured using a gas analyzer of model AVL DI 444. Emission indicates the combustion and exhaust conditions of the fuel exit to the atmosphere.

7.2.3.1 Effect of preheating on Carbon monoxide (CO), Hydrocarbon (HC), oxides of nitrogen (NO_X), Carbon dioxides (CO_2) emissions emissions

CO emissions account for incomplete fuel combustion within the engine cylinder. The incomplete burning of fuel is mainly due to lean oxygen availability for combustion. Fig. 7.10.(a). illustrates the CO emission for diesel and D-30%OPB biodiesel with preheated and unheated fuel at different load conditions. The CO emissions tend to increase with an increment in load for all fuel tested. D-30%OPB biodiesel shows lower CO emissions compared to diesel due to higher oxygen content availability than diesel and thus a complete combustion increases CO_2 and lowers CO emission. Due to the presence of oxygen, oxidation occurs and conversion of CO to CO_2 emission takes place. At 5.6kW Load conditions, D-30%OPB biodiesel shows 11.2% lower CO emission compared to diesel.



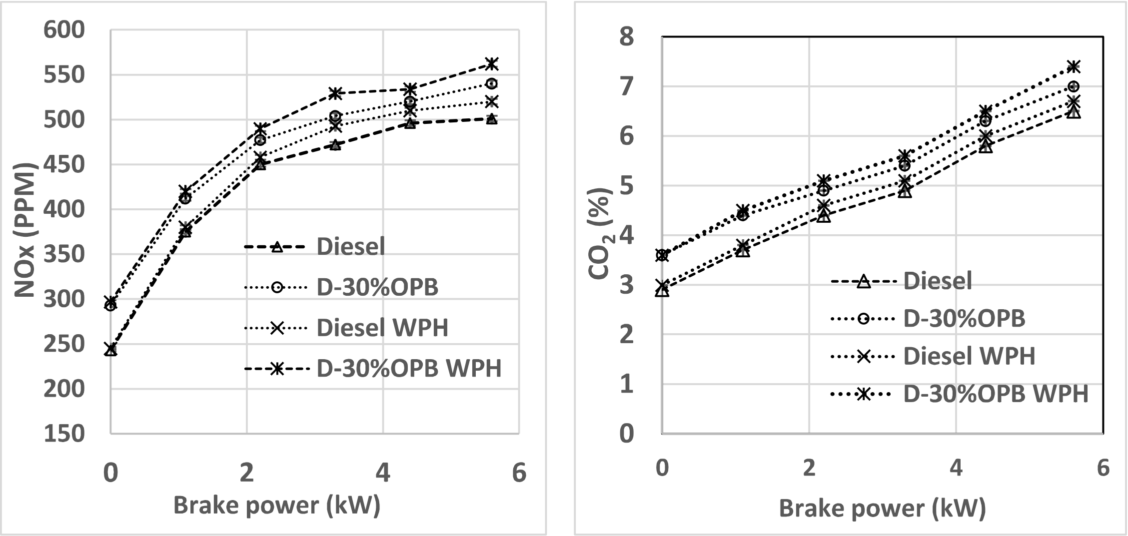
(a) **(b)**

Fig. 7.10. Emissions of different fuel with preheating, (a) CO emissions with brake power (b) HC emissions with brake power.

When the fuel is preheated from the coolant using a preheating section heat exchanger, the CO emission is reduced and operated under both fuels. Fuel preheating reduces viscosity, improved atomization, and better fuel combustion which ensures lower CO emissions. With fuel Preheating, diesel, D-30%OPB biodiesel shows 2.5%, and 4.2% lower CO emissions at 5.6kW load conditions compared to unheated fuel.

HC (Hydrocarbon) emission also signifies partial fuel combustion within the combustion Chamber. HC emission with load under preheated fuels is shown in Fig. 7.10(b). From no load to gradually applied load, the fuel-air ratio becomes lean to rich. HC emissions increases with the load increment for both fuels. However, the highest HC emission obtained to be highest at 5.6kW load condition due to better fuel combustion, the unburnt HC emission is obtained to be higher. Lower HC emission obtained with D-30%OPB biodiesel compared to diesel due to higher oxygen content in form of ester which provokes combustion and converts HC into water, CO, and oxidizes to CO_2. Moreover, when preheated fuel is investigated, a higher temperature of fuel further declines the HC emissions, mainly due to finer atomization and better combustion at elevated fuel temperature. Elevated fuel temperature of D-30%OPB biodiesel and diesel show a maximum reduction of 3.9% and 5.2% lower HC emission at 75% load condition compared to unheated fuel.

During the combustion of fuel, at an elevated temperature, nitrogen and oxygen react to form oxides of nitrogen (NO_X). The exhaust gas from the engine is investigated to measure NO_X emission from a gas analyzer for diesel and D-30%OPB biodiesel WPH and unheated fuel at different load conditions as depicted in Fig. 7.11(a). When the load increased from no load to gradually increased load, the NO_X increases for both diesel and D-30%OPB biodiesel tested. Due to the presence of more oxygen content in D-30%OPB biodiesel, NO_X is more than diesel. With unheated fuel, D-30%OPB biodiesel gains 4.1% NO_X compared to diesel fuel at 5.6kW load conditions. When fuel is preheated and exhaust temperature increased



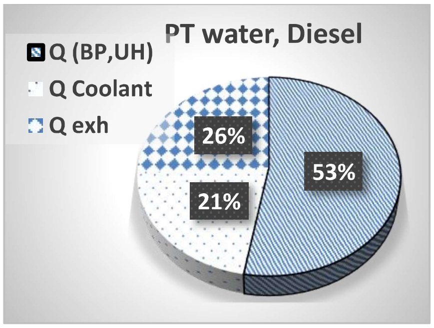
(a) **(b)**

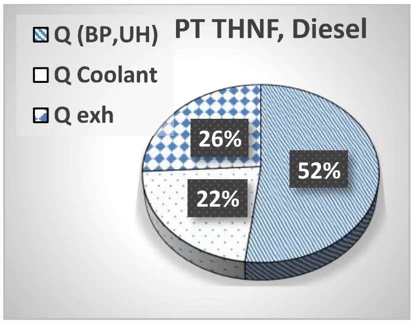
Fig. 7.11. Emissions of different fuel with preheating, (a) NO_X emissions with brake power; (b) CO_2 emissions with brake power.

further due to better combustion of fuel and obtains the highest NO_X at 5.6kW load. Preheated diesel fuel shows 1.7% and 3.7% higher NO_X compared to unheated diesel at 2.2kW load and 5.6kW load respectively. Compared to unheated D-30%OPB biodiesel, heated D-30%OPB biodiesel shows 2.7% and 4.1% higher NO_X at 2.2kW load and 5.6kW load respectively.

CO_2 emission indicates better combustion of the fuel. Fig. 7.11(b). illustrates the CO_2 emissions at different load conditions for diesel and D-30%OPB biodiesel with and without preheating effects. When the load increases the CO_2 emissions increase for all fuel tested. CO_2 emissions obtain a maximum at 5.6kW brake load. Due to the presence of higher oxygen in presence of ester in biodiesel, it shows higher CO_2 emissions compared to diesel at all loads. At 5.6kW brake power applied load, D-30%OPB biodiesel shows 5.7% higher CO_2 emissions than diesel. When preheated fuels are tested under different brake power loads, CO_2 emissions increase. Elevated temperature reduces fuel viscosity, increased fuel atomization, and approaches toward homogeneous combustion. Higher fuel temperature results in better combustion and converts HC into water and CO_2. Thus, HC decreases and CO_2 emission increases with preheating. Under fuel preheating at 5.6kW brake power load condition, D-30%OPB biodiesel shows 5.7% and diesel shows 3.2% higher CO_2 emissions compared to fuel without heat.

7.2.3.2 Energy Distribution with different tube inserts, coolant and fuel at 5.6kW load conditions.





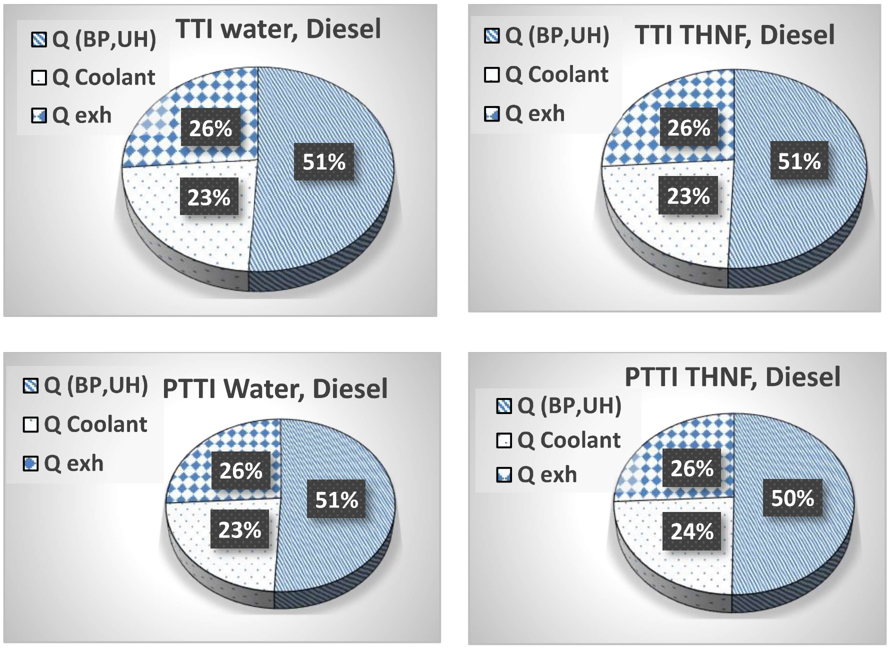


Fig. 7.12. Energy distribution chart for Diesel.

Figure 7.12, shows the energy distribution pie chart for diesel as fuel for different tube inserts with water and 0.12% (v/v) THNF as a coolant at 5.6kW load conditions and constant coolant flow rate. The result shows that with the combination of tube inserts and coolant, energy shared is 21 to 24% of the total energy and the rest energy is shared by exhaust gas, brake power, and unaccounted heat energy. THNF shows higher energy-carrying capacity due to higher thermal conductivity than water. Moreover, due to the presence of tube inserts, the lower temperature of coolant also increases the tendency of higher energy-carrying capacity. However, with preheating of diesel, the effect of energy distribution for various tube inserts with different working fluids is presented in the Fig. 7.13. Exhaust gas energy

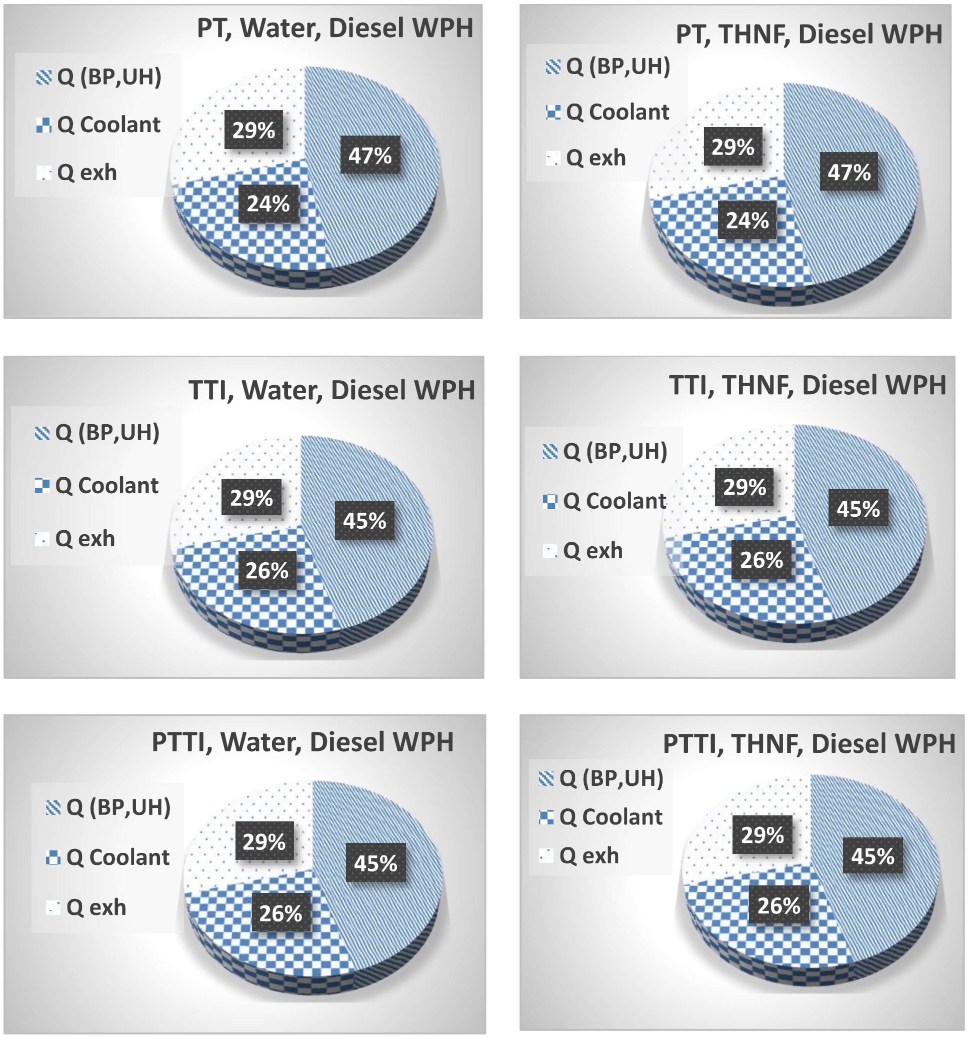


Fig. 7.13. Energy distribution chart for Diesel WPH.

increases due to better fuel combustion in preheated conditions. Also, the energy carried by the coolant is higher than normal diesel. Due to the presence of tube inserts and coolant, the coolant energy carried in the range of 24 to 26%. Furthermore, out of 100% fuel combustion, unaccounted energy, and brake power energy obtains in the range of 45 – 47%, 29% energy is carried by exhaust energy, and the rest is carried by coolant energy. However, the actual data of the energy distribution for normal diesel and PHT diesel at 5.6kW applied load conditions for different tube inserts and coolant is listed in Table 7.6 and Table 7.8 respectively.

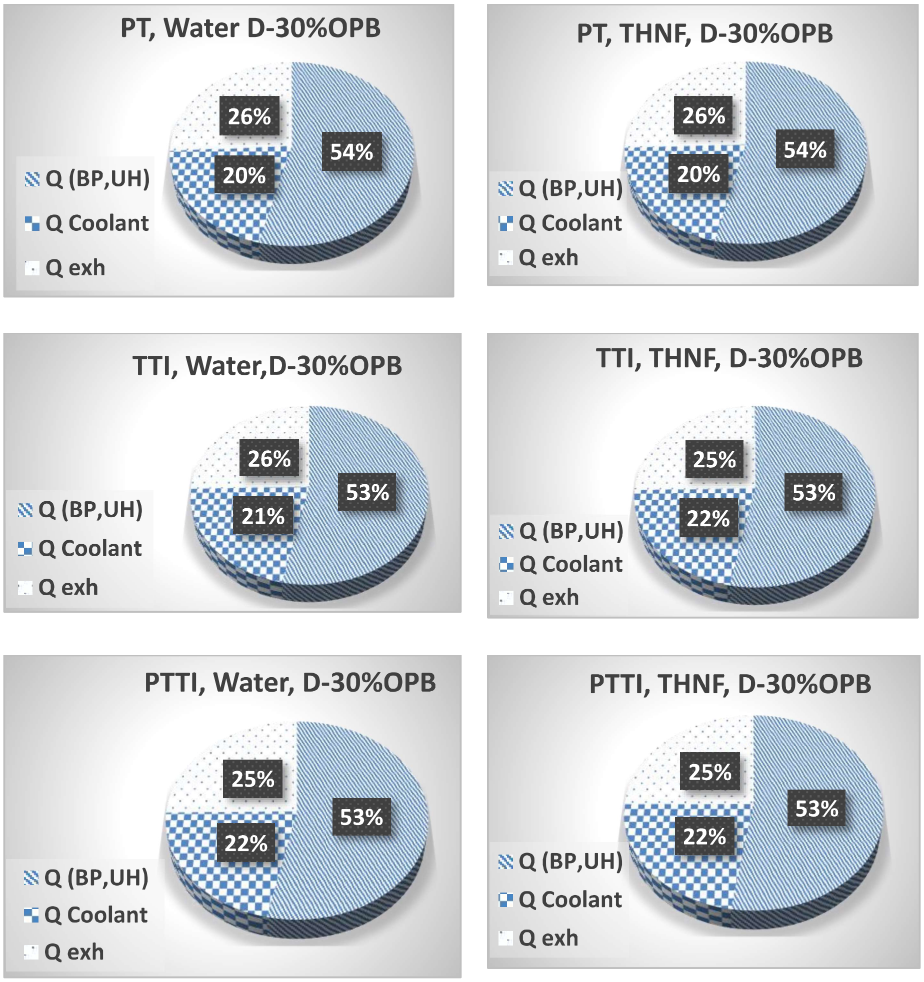


Fig. 7.14. Energy distribution chart for blended biodiesel (D-30%OPB).

To understand the effect of blended biodiesel as a fuel on the energy distribution for different coolant and tube inserts at fixed load conditions, and flow rate is shown in the Fig. 7.14. Due to the presence of tube inserts the energy carried by the coolant ranges from 20-22% and remains higher in the case of perforated inserts. However, the utilization of THNF shows insignificant enhancement in energy. The blended biodiesel requires higher fuel consumption for the same generation of brake power, therefore, energy liberation is also higher. The details of the energy distribution at 5.6kW load conditions of blended biodiesel for different tube inserts cases and 0.12% THNF are listed in Table 7.7. Also, when the preheated blended biodiesel as fuel is operated in the engine the energy distribution pie chart is shown in Fig. 7.15.

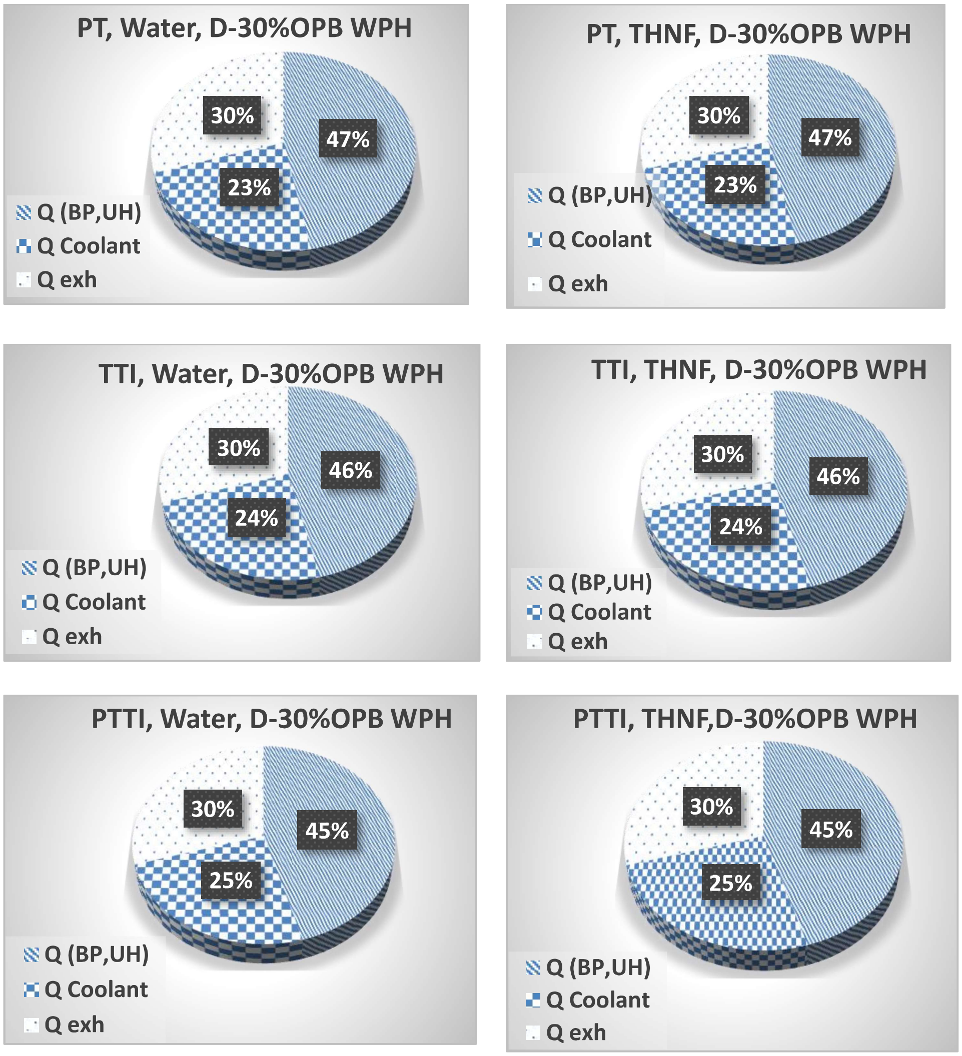


Fig. 7.15. Energy distribution chart for blended biodiesel (D-30%OPB) WPH

The unaccounted and brake power remains in the range of 45-47%, while the exhaust energy increase to 30%, and coolant energy reaches to highest 25%. As the preheated blended biodiesel results in better fuel combustion due to better fuel atomization and lower ignition delay. Therefore, a higher percentage of energy is carried away by exhaust gases and the coolant from the engine during preheated blended biodiesel than the normal blended biodiesel. However, the hybrid nanofluid as a coolant shows little enhancement in the energy-carrying capacity. Furthermore, the energy distribution details of preheated blended biodiesel at 5.6kW load on the engine under different combination is listed in the Table 7.9.

Table. 7.6 At 5.6kW load on engine with Diesel, energy distribution.

Combination, diesel (5.6kW load)	**Q $_{BP+UH}$ (W)**	**Q $_{coolant}$ (W)**	**Q $_{exh}$ (W)**	**Q $_{fuel}$(W)**
Water PT	13045.2	5231.2	6432.6	24708
0.12% (v/v) THNF, PT	12843.3	5472.2	6395.5	24708
Water TTI	12639.2	5637.6	6504.2	24708
0.12% (v/v) THNF, TTI	12582.4	5752.5	6490.1	24708
Water PTTI	12502.6	5802.5	6390.9	24708
0.12% (v/v) THNF, PTTI	12415.8	5905.1	6290.1	24708

Table. 7.7 At 5.6kW load on engine with blended biodiesel energy distribution.

Combination, Biodiesel (5.6kW)	**Q $_{BP+UH}$ (W)**	**Q $_{coolant}$ (W)**	**Q $_{exh}$ (W)**	**Q $_{fuel}$(W)**
Water PT	15175.5	5644.2	7300.3	27974
0.12% (v/v) THNF, PT	14834.7	5758.5	7179.8	27974
Water TTI	15035.7	5981.4	7135.9	27974
0.12% (v/v) THNF, TTI	14927.6	6050.7	7098.7	27974
Water PTTI	15015.2	6103.5	7078.3	27974
0.12%(v/v) THNF, PTTI	14703.2	6253.9	6990.9	27974

Table. 7.8 At 5.6kW load on engine with preheated diesel energy distribution.

Combination, Diesel (5.6kW)	**Q $_{BP+UH}$ (W)**	**Q $_{coolant}$ (W)**	**Q $_{exh}$ (W)**	**Q $_{fuel}$(W)**
Water PT	10626.2	5368.8	6583	22578
0.12%(v/v) THNF, PT	10560.6	5506.5	6480.9	22578
Water TTI	10292.4	5782.1	6503.5	22578
0.12% (v/v) THNF, TTI	10207.9	5840.6	6469.5	22578
Water PTTI	10195.8	5890.6	6532.6	22578
0.12% (v/v) THNF, PTTI	10151.3	6095.5	6496.2	22578

Table. 7.9 At 5.6kW load on engine with preheated blended biodiesel energy distribution.

Combination, Biodiesel (5.6kW)	**Q $_{BP+UH}$ (W)**	**Q $_{coolant}$ (W)**	**Q $_{exh}$ (W)**	**Q $_{fuel}$(W)**
Water PT	12027.2	5919.4	7663.4	25610
0.12% (v/v) THNF, PT	11970.2	6040.7	7623.1	25610
Water TTI	11860.7	6125.9	7603.4	25610
0.12% (v/v) THNF, TTI	11773.3	6253.9	7598.8	25610
Water PTTI	11674.9	6332.4	7582.7	25610
0.12% (v/v) THNF, PTTI	11600.1	6467.1	7542.8	25610

7.2.4 Cost estimation and energy utilization

Heat exchanger cost estimation includes the fixed cost and the heat exchanger operating cost. Different tube inserts and the 0.12% (v/v) THNF, water coolant have been used for preheating the diesel and the blended biodiesel. The pump is required to operate the coolant into the HX, hence, its running cost is used. The cost required to pump the fuel and the cost of nanoparticles are not considered. The different cost for tube inserts, coolants, and the total cost of the heat exchanger is listed in the Table 7.10. Also, the required time to recover the cost of utilized and installed heat exchanger with modified inserts is listed in the Table 7.11. With preheating of diesel, cost recovery is possible when the engine runs 572-599.5 hours, due to the tube inserts the cost is higher, therefore, the associated time for cost recovery is also obtained higher. For the coolant, the 0.12% (v/v) THNF shows a slightly higher cost than normal coolant water. Also, for preheating blended biodiesel, the time for the cost of recovery obtained is lower than WPH diesel due to lower cost than diesel. The time for recovery cost WPH blended biodiesel is possible when the engine runs for 480 to 503 hours as listed in the Table 7.11.

Table. 7.10 Heat exchanger cost evaluation.

Cost Parameter	**PT, water**	**PT, 0.12% (v/v) THNF**	**TTI, water**	**TTI, 0.12% (v/v) THNF**	**PTTI, water**	**PTTI, 0.12% (v/v) THNF**
HX Manufacturing cost (in Rs.)	6000	6000	6800	6800	6900	6900
HX cleaning cost (in Rs.)	350	350	350	350	350	350
HX Fitting cost (Rs.)	250	250	250	250	250	250
Preheating HX section cost (Rs.)	600	600	600	600	600	600
HX operating cost (Rs.)	27	40	45	56	57	70
Total cost (Rs.)	7226	7240	7444	7455	7557	7570

Table. 7.11 Cost analysis for heat recovery.

At 5.6kW load		**Diesel**		**Biodiesel (D-30%OPB)**			
		Normal	**WPH diesel**	**Normal**	**WPH D-30%OPB**		
Fuel mass flow (kg/s)		0.00058	0.00054	0.00071	0.00065		
Fuel consumption (l/yr.)		7074.6	6708.7	8342.1	7865.4		
Annual fuel saving (l/yr.)		365.9		476.7			
Fuel saving (l/month)		30.5		39.8			
Cost of fuel saving in a day (Rs.)		101.6		120.2			
Arrangements of HX		PT, water	PT, 0.12% THNF	TTI, water	TTI, 0.12% THNF	PTTI, water	PTTI, 0.12% THNF
Total cost of HX (Rs)		7226	7240	7444	7455	7557	7570
Cost recovery (hours)	Diesel	572	573.5	589.1	590.5	598.1	599.5
	D-30%OPB	480.7	481.6	495	496.2	502.4	503.7

For the investigation, the coolant energy utilized for preheating the fuel. Coolant energy utilized for different coolants, tube inserts and fuel are listed in the Table 7.12. As the fuel mass flow in case of blended biodiesel is higher than the diesel fuel in the preheating conditions, therefore, average energy used from coolant is 414.3W in case of biodiesel than 348.4W. Total

Table. 7.12 Energy utilization WPH.

Waste energy utilized	**PT, water**	**PT, 0.12%(v/v) THNF**	**TTI, water**	**TTI, 0.12% (v/v) THNF**	**PTTI, water**	**PTTI, 0.12% (v/v) THNF**	**Avg**	**%**
WPH Diesel, Energy (W)	344	345	348	350.6	351	352	348.4	6.1

WPH biodiesel (D-30%OPB), Energy (W)	412	412	414	415	416	417	414.3	6.6

6.1% coolant energy is utilized for preheating of diesel fuel, while, 6.6% of coolant energy is successfully utilised to preheat the blended biodiesel.

7.3 Highlights of the study

In the present investigation diesel and prepared biodiesel, D-30%OPB biodiesel (30% methyl ester and 70%diesel) are used to analyze the preheating effects of orange peel oil blend and diesel on the CI engine performance and emissions. Also, an investigation on energy utilization, energy recovery, and economic analysis has been performed. The preheating is done through the waste energy of radiator jacket coolant using a counterflow heat exchanger. Fuel preheating is dependent on the load applied. The key outcomes are:

- Among different load conditions, 5.6kW load is the most suitable load for efficient engine performance for diesel and D-30%OPB biodiesel.
- The optimum increased BTE is obtained to be 3.2% and 3.4% higher for preheated diesel and D-30%OPB biodiesel at 5.6kW load conditions.
- At 5.6kW load, preheated D-30%OPB biodiesel reduces BSFC by 7.8% than unheated D-30%OPB biodiesel.
- At 5.6kW Load, preheated D-30%OPB biodiesel lowers CO emission by 15.1% than unheated diesel. Under the same load, preheating lowers CO emissions by 2.5% and 4.2% corresponding to unheated diesel and D-30%OPB biodiesel.
- The elevated temperature of D-30%OPB biodiesel and diesel obtained a maximum reduction of 5.2% and 3.9% lower HC emission at 5.6kW load conditions compared to unheated fuel.

- NO_X and CO_2 emissions are obtained to be 4.14% and 3.2% higher with preheated diesel than unheated. D-30%OPB biodiesel preheating increased 4.4% NO_X and 5.2% CO_2 emissions than unheated biodiesel.
- On the combination of engine and coolant, the effect of hybrid nanofluid is little significant compared to passive device inserts.
- With preheating, the maximum fuel temperature is preheated up to 43°C at 5.6kW and the mass flow rate of fuel consumption is reduced by 7.4 and 9.1% for diesel and biodiesel fuels.
- On combined investigation of the engine and radiator, with passive inserts and preheating, Due to preheating, exhaust energy increased to 7.4% and the coolant energy increased to 3.5%.
- In low grade energy utilization, 6.1% and 6.6% of the waste energy of coolant is utilized for preheating diesel and biodiesel fuel respectively.
- Cost recovery in terms of fuel saving is 93.8 hours early in case of biodiesel than the diesel fuel. Due to preheating, in a day, cost of fuel saving for biodiesel is 18.3% higher than diesel fuel.

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