Simulation Study on a WPO Fueled Direct Injection Diesel Engine using the Diesel-RK Thermodynamic Engine Simulator

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Abstract

A simulation study was carried out to assess the effects of using plastic oil in a DI diesel engine using the Diesel-RK engine simulating tool. Performance, combustion and emission characteristics of the engine were studied by changing the blending ratio of plastic oil from 0% to 100% under full load conditions. The engine is operated in constant speed mode at a standard compression ratio of 16.5:1, the results obtained for the plastic oil blends are compared to diesel fuel (base line fuel). The results indicate that brake power, brake thermal efficiency and specific fuel consumption improved for all the blends of plastic oil compared to baseline diesel fuel. Furthermore, peak cylinder pressure, peak cylinder temperature and heat release-rate for the plastic oil blends are higher than those of diesel fuel. CO_2, PM and smoke emissions are observed to be less for the plastic oil blends however NO_x emissions were found to be higher than those of reference fuel diesel.

Keywords: DI Diesel engine; waste plastic oil; Diesel-RK simulation.

1. Introduction

For humanity, in view of the global fossil fuel crisis that has occurred within the last ten years, we have to concentrate on developing alternative forms of energy like biomass, hydropower, landfill gas, wind and solar power. Research is ongoing on the development of alternative fuel technologies with a view to replacing fossil fuels. Bio ethanol, biodiesel derived from lipids and waste oil recycling, pyrolysis, gasification, dimethyl ether or biogas are the focus technologies. Furthermore, due to the fact that waste is a matter of concern for each city, an adequate waste management strategy is another key aspect of sustainability. Waste to Energy technology is being explored that can convert potentially harmful waste materials like plastics, biomass and rubber tyres for the purpose of oil production. The pyrolysis process becomes a waste-to-energy technology option to deliver biofuel to replace fossil fuels. In this research, waste plastics and tyres are investigated due to the fact that they can be recycled using existing technology while plastic is sorted and dried. Pyrolysis does not generate any hazardous or polluting emissions as opposed to incineration Due to economic growth and changing patterns of consumption and manufacture, there has been a rapid increase in the production of waste plastics worldwide. Over the past 50 years, global plastics production has continued to rise at a steady pace.

In 2013 approximately 290.9 million tonnes of plastic were manufactured, up by 4 % compared to 2012. But the recovery and recycling of plastic waste continues to be inadequate, which in turn results in millions of tonnes being dumped each year into landfills and oceans. A recently performed study calculated that there are currently 5.25 trillion plastic particles in the world's oceans, which amount to 268,940 tonnes. And because plastic is a unbiodegradable material, it's on the ground and contributes to pollution of the environment.

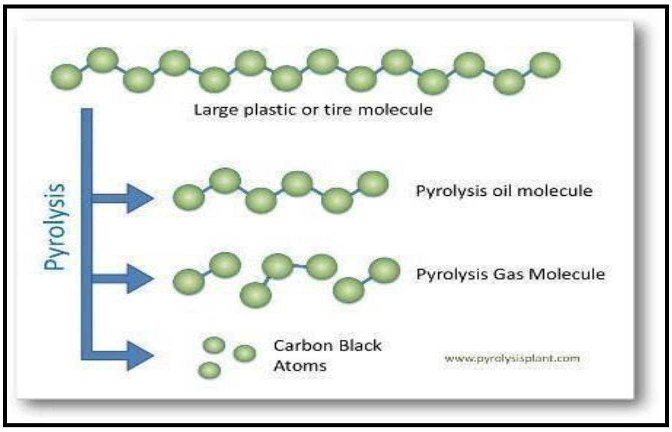
On the other hand, one of the key aspects of sustainable development is also an appropriate waste management strategy since every city has its own waste problem. As we already know, hydrocarbons containing carbon and hydrogen are the principal constituent of both plastics and petroleum fuels. The pyrolysis process becomes a waste-to-energy technology option to deliver biofuel to replace fossil fuels. The pyrolysis process has an advantage in terms of its ability to handle mixed plastics and plastic that is contaminated. It's a simple process to treat the material. We've got to sort and dry the plastic. Unlike combustion, pyrolysis is neither a pollutant nor an environmentally harmless emission. The pyrolysis process is done using different types of plastic, which can be explained below.

India's Central Pollution Control Board estimates that every day over 15,000 tonnes of plastic waste are generated, with 27% recycled and the remaining 73% being disposed of in landfills. Ioannis et al., (2017) Waste plastics have been proposed to be a promising fuel for power and heat generation, which is more efficient than diesel engines. Sachin et al., (2015) have conducted experiments with a single cylinder diesel engine that is powered by plastics oil blends. The investigation showed a slight decrease in engine brake thermal efficiency and higher consumption of specific fuel for brakes compared to straight diesel. In Mani et al., (2011)’s experimental studies in the diesel engine 100% of waste plastic oil is tested and results show an extremely high NOx emissions for blends of plastics when compared to regular diesel fuel. Moreover, by applying cold exhaust gas recovery techniques it was possible to reduce the emissions of nitrogen oxides.

Pyrolysis Method of plastic oil extraction

Pyrolysis is usually regarded as a controlled heating of material that does not have oxygen. During the pyrolysis of plastic, polymers' molecular structures are reduced to little molecule or oligomers and sometimes monomeric units. Pyrolysis is usually considered to be the controlled heating of materials that do not have oxygen. The polymers' molecular structure is reduced in pyrolysis plastic to a few molecules or oligomers and sometimes monomeric units.

Fig. 1 Pyrolysis reaction



High energy Endothermic polyolefinolysis requires temperatures below 350 C. Noncatalytic and Thermal Pyrolysis of Polyolefin is a type of thermolysis, requiring temperature in the vicinity of 500 C. To attain a good product yield, the temperature must be increased to 700C in some studies. The degree and nature of these reactions depend on the reaction temperature and product density within the reaction zone, a factor which is particularly affected by the reactor's design. Furthermore, it plays a critical role to design reactors so as to overcome the problems associated with low thermal conductivity and high melting point of molten polymers. Several types of reactors have been described in the literature, the most common being fluid bed reactors, batch reactors and screw furnace reactors.

2 Materials and Methods

Mixed waste plastic was collected from the in and around Seshadri Rao Gudlavalleru Engineering college, Andhra Pradesh, Gudlavalleru. The collected plastic is washed with water and dried in sun light for 2 days, later it is shredded into small pieces and loaded into the batch type reactor with fly ash catalyst. As a result of heating, the organic vapours in plastics were comes out of the reactor and cooled in the condenser therefore crude oil is obtained. Later this crude oil is purified and blended with diesel with different proportions on volume base. Table 1 shows the different WPO blends and its composition on volume base.

Table 1 Designation of fuels and volumetric proportion of blends

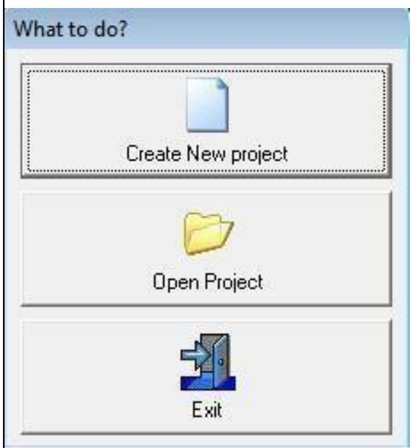
S.No	Designation of fuel	Composition	
		Diesel oil (%)	Plastic oil (%)
1.	Diesel oil	100	-
2.	PO25DI75	25	75
3.	PO50DI50	50	50
4.	PO75DI25	75	25
5.	Plastic oil	-	100

Full-cycle thermodynamic simulation software of the DIESEL-RK engine is intended for simulating and optimizing the work processes of two- and four-stroke internal combustion engines with all types of turbocharging. For engine models, the program can be used as follows:

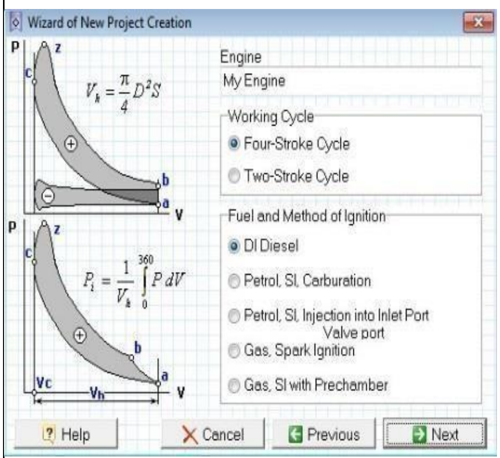
- DI Diesel engines (with PCCI/HCCI).
- SI petrol engines.
- SI gas engines including pre-chamber systems.

For two-stroke engines the DIESEL-RK supports the following scavenging schemes:

- Uniflow scavenging.
- Loop and cross scavenging.
- Junkers (OP) & OPOC schemes.
- Crankcase scavenging.



(a)



(b)

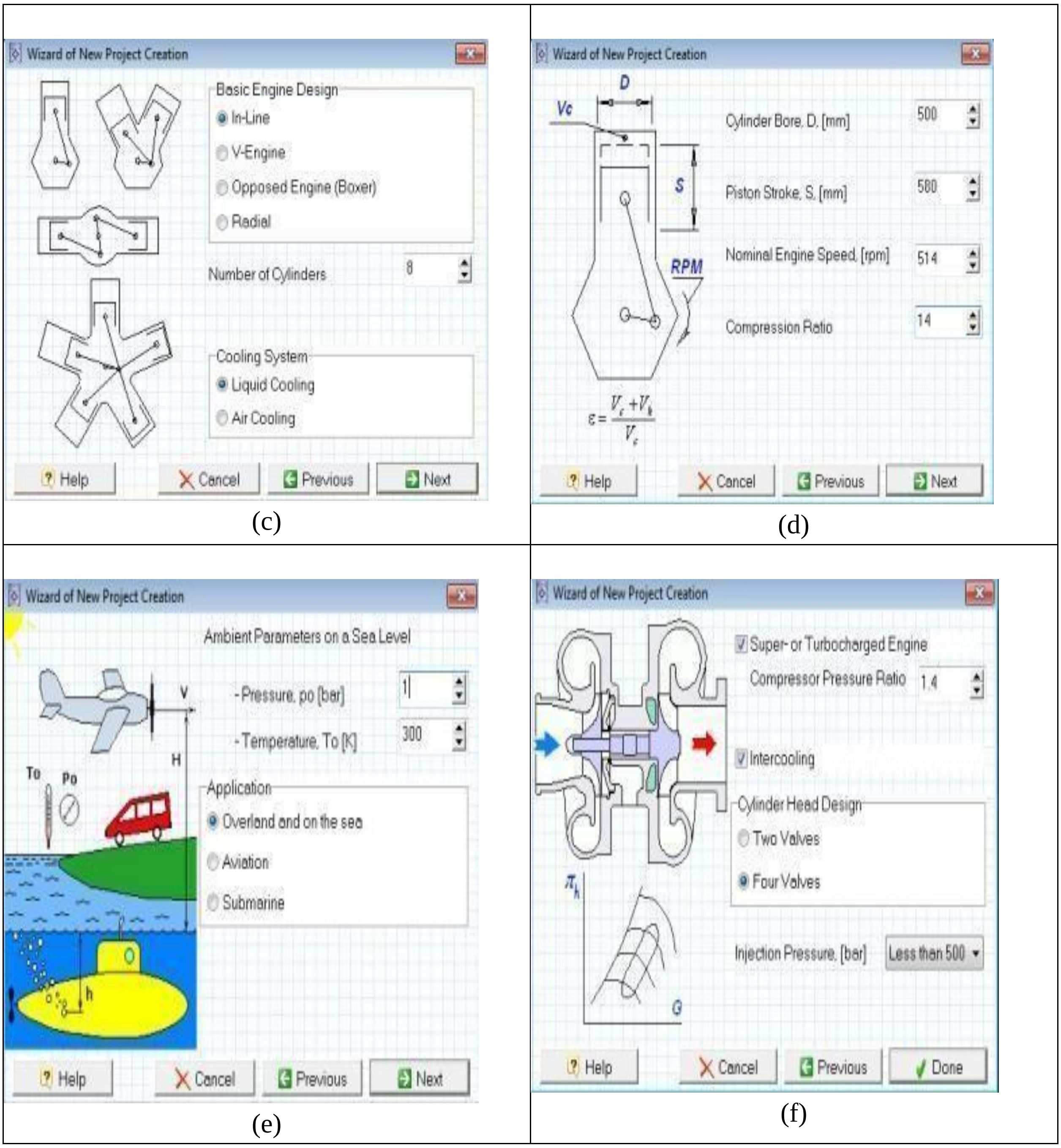
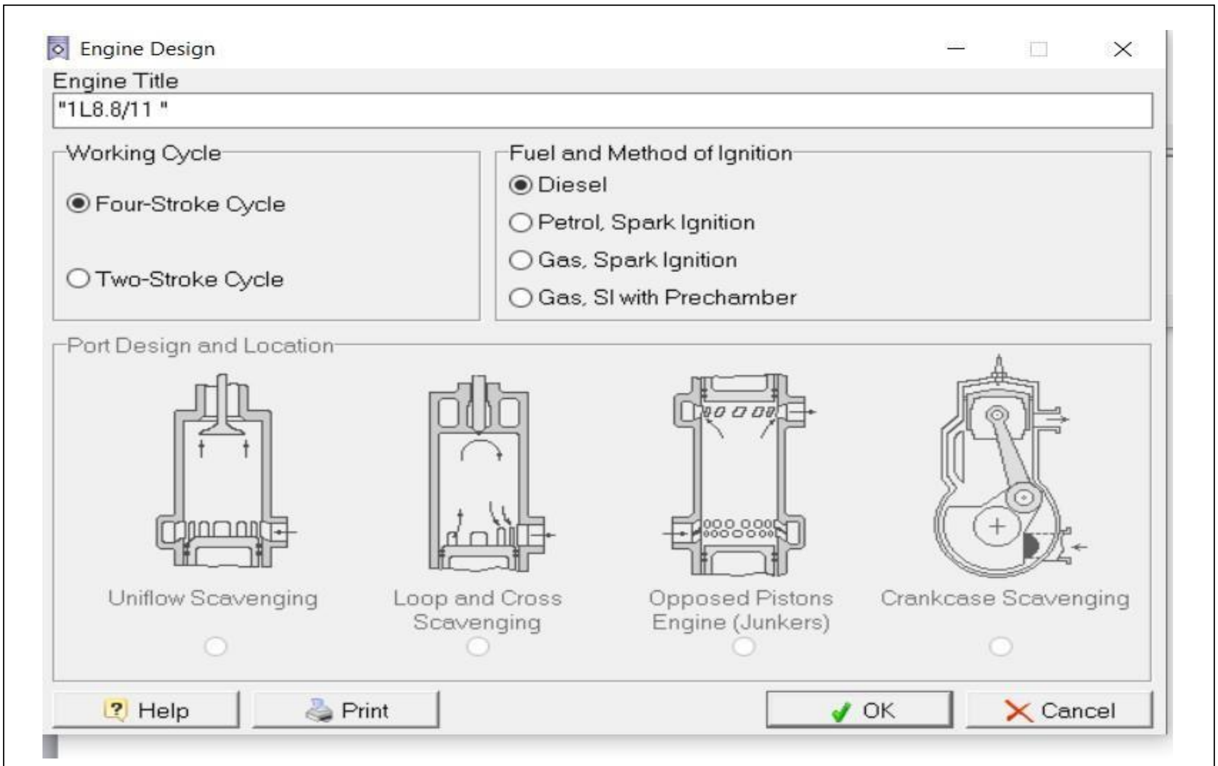
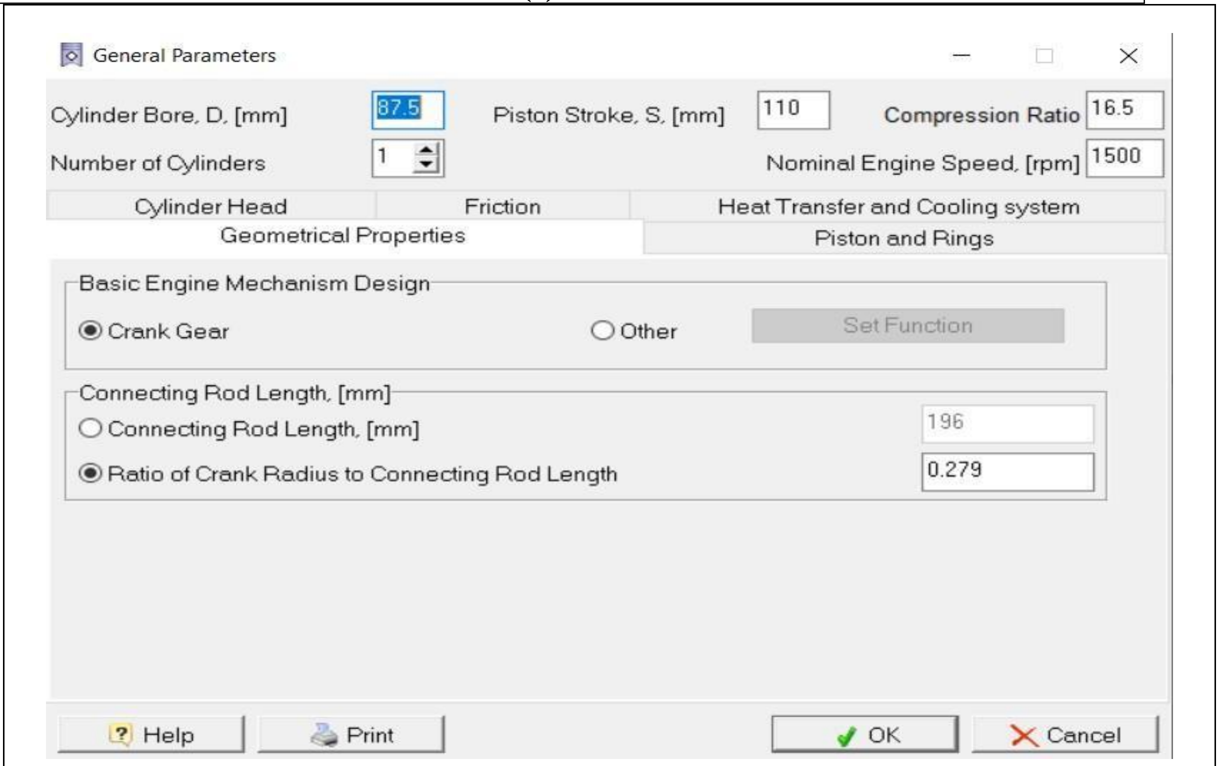


Figure 3 (a-f) Selection of engine, loading of basic data of engine


Engine Design
Engine Title
"1L8.8/11 "
Working Cycle
Four-Stroke Cycle
Two-Stroke Cycle
Fuel and Method of Ignition
Diesel
Petrol, Spark Ignition
Gas, Spark Ignition
Gas, SI with Prechamber
Port Design and Location
Uniflow Scavenging
Loop and Cross Scavenging
Opposed Pistons Engine (Junkers)
Crankcase Scavenging
Help
Print
OK
Cancel

(a)


General Parameters
Cylinder Bore, D, [mm]
87.5
Piston Stroke, S, [mm]
110
Compression Ratio
16.5
Number of Cylinders
1
Nominal Engine Speed, [rpm]
1500
Cylinder Head
Friction
Heat Transfer and Cooling system
Geometrical Properties
Piston and Rings
Basic Engine Mechanism Design
Crank Gear
Other
Set Function
Connecting Rod Length, [mm]
Connecting Rod Length, [mm]
196
Ratio of Crank Radius to Connecting Rod Length
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Help
Print
OK
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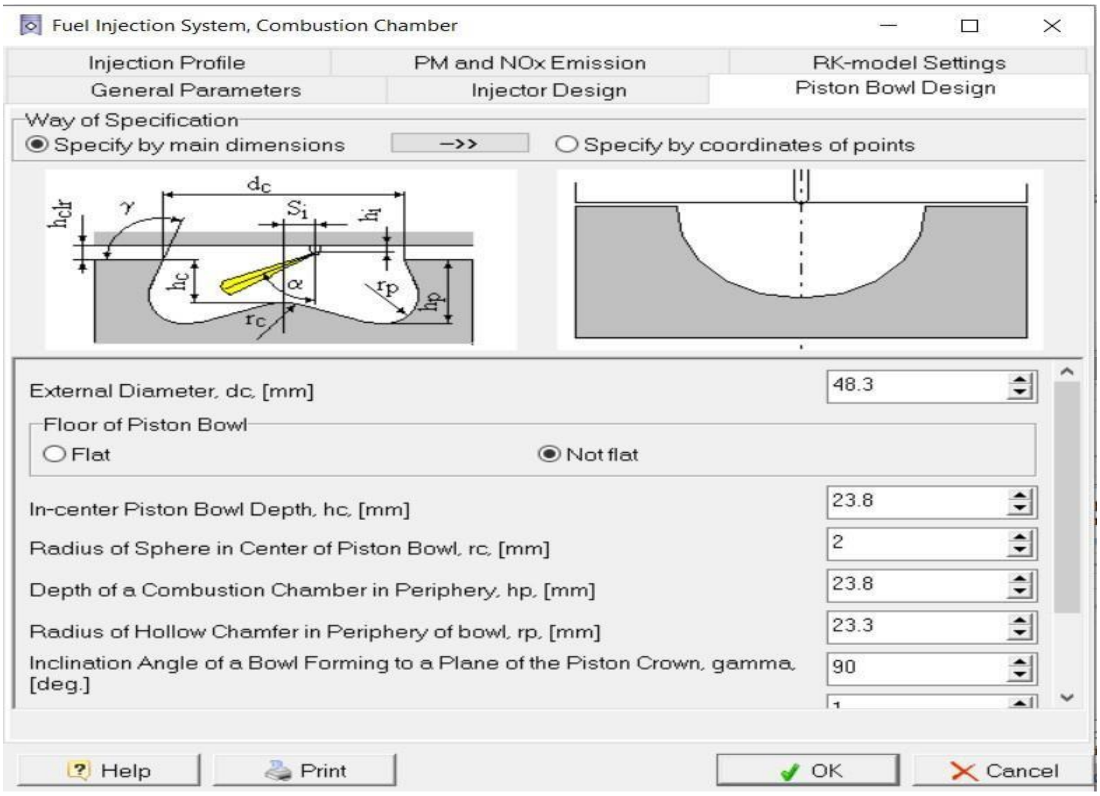
(b)


Fuel Injection System, Combustion Chamber
Injection Profile
PM and NOx Emission
RK-model Settings
General Parameters
Injector Design
Piston Bowl Design
Way of Specification
Specify by main dimensions
-->>
Specify by coordinates of points
External Diameter, dc, [mm]
48.3
Floor of Piston Bowl
Flat
Not flat
In-center Piston Bowl Depth, hc, [mm]
23.8
Radius of Sphere in Center of Piston Bowl, rc, [mm]
2
Depth of a Combustion Chamber in Periphery, hp, [mm]
23.8
Radius of Hollow Chamfer in Periphery of bowl, rp, [mm]
23.3
Inclination Angle of a Bowl Forming to a Plane of the Piston Crown, gamma, [deg.]
90
Help
Print
OK
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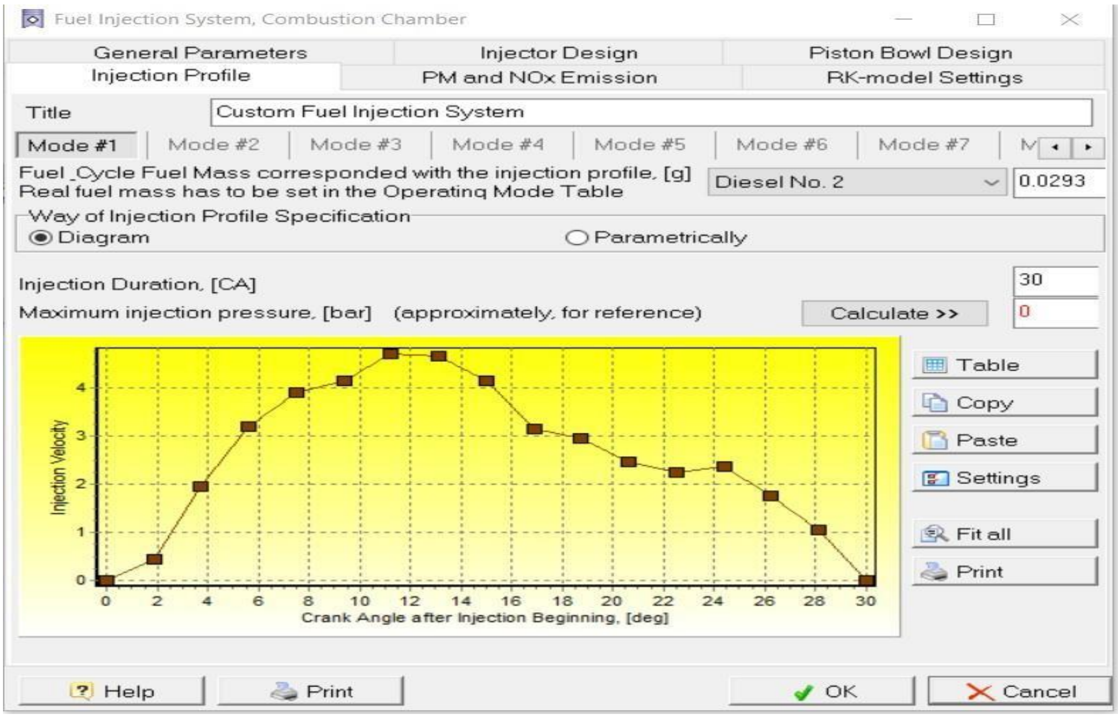
(c)


Fuel Injection System, Combustion Chamber
General Parameters
Injector Design
Piston Bowl Design
Injection Profile
PM and NOx Emission
RK-model Settings
Title
Custom Fuel Injection System
Mode #1
Mode #2
Mode #3
Mode #4
Mode #5
Mode #6
Mode #7
Fuel Cycle Fuel Mass corresponded with the injection profile, [g]
Real fuel mass has to be set in the Operating Mode Table
Diesel No. 2
0.0293
Way of Injection Profile Specification
Diagram
Parametrically
Injection Duration, [CA]
30
Maximum injection pressure, [bar] (approximately, for reference)
Calculate >>
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Injection Velocity
Crank Angle after Injection Beginning, [deg]
Table
Copy
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Settings
Fit all
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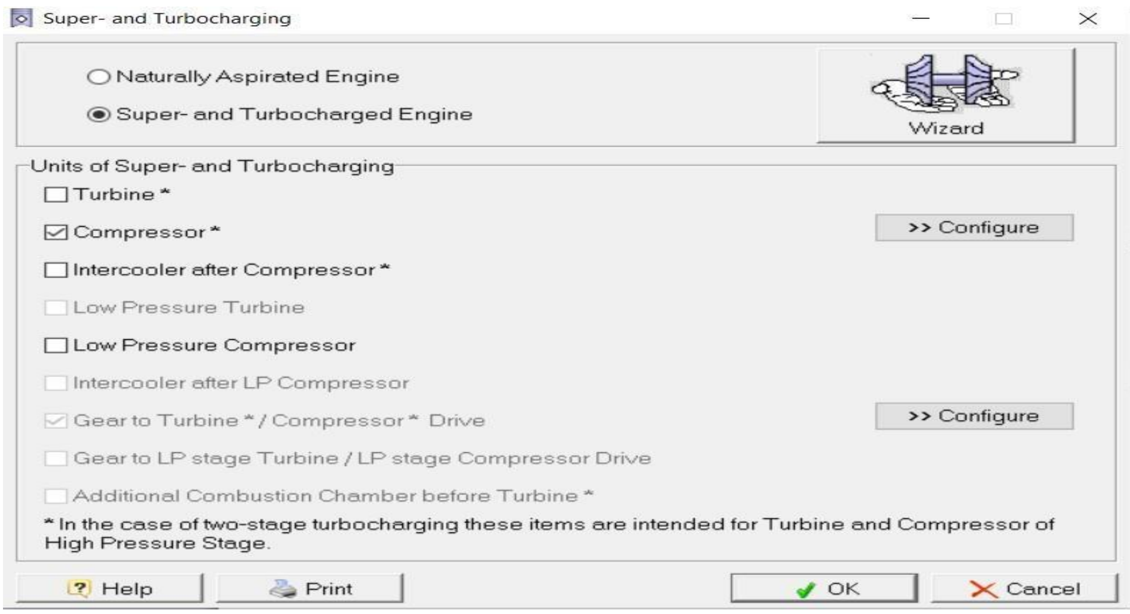
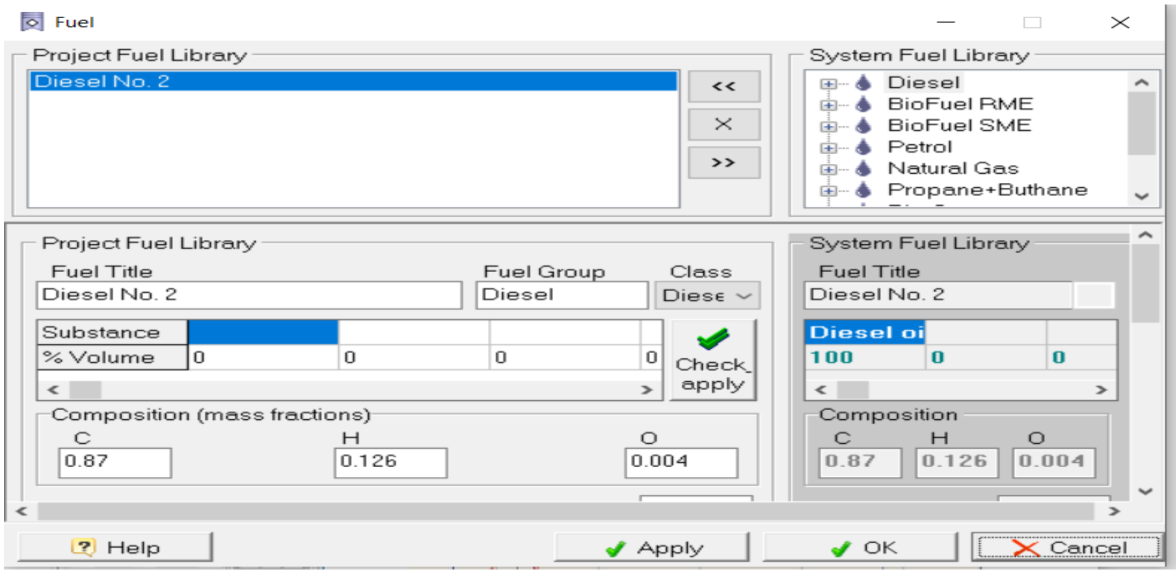
(d)



(e)



(f)

Figure 4 (a-f) Engine design, Fuel injection pressure, selection of fuel and loading of fuel properties into the fuel library

3. Results and discussion

Simulation of engine is carried out in order to study its Performance and emission characteristics for the following test fuels Diesel, PO25DI75, PO50DI50, PO75DI25 and Plastic oil. The entire simulation performed at a compression ratio of 16.5:1 and a constant speed of 1500 rpm.

Table 2 Performance and combustion simulation Results

Test Fuel	**BP (kW)**	**BTE (%)**	**SFC (kg/kwh)**	**P_{max} (bar)**	**$_{max}$ (k)**	**ID (deg)**
Diesel	5.4321	0.35032	0.2362	93.76	1979.8	10.589
PO25DI 75	5.4473	0.35044	0.2356	93.84	1980.2	10.881
PO50DI50	5.4816	0.35130	0.2339	93.98	1985.2	11.187
PO75 DI25	5.5260	0.35238	0.2320	94.05	1990.0	11.575
Plastic Oil	5.5885	0.35356	0.2262	94.30	2001.1	11.930

Table 3 Emission results

Test Fuel	**CO_2 (PPM)**	**NO_X (PPM)**	**PM (g/kW-h)**	**BSI**
Diesel	761.21	2519.4	0.24566	1.1388
PO25DI 75	759.21	2517.4	0.26456	1.1447
PO50DI50	753.88	2556.1	0.24476	1.14451
PO75 DI25	747.83	2582.0	0.24345	1.1468
Plastic Oil	712.33	2595.0	0.22690	1.0956

Performance Analysis:

The figure 5 shows the variation of brake power for the different test fuels, from the figure it was observed that brake power is maximum for the neat plastic oil and minimum for diesel. Furthermore, the brake power increases in blending ratio from 25% to 100%. Brake thermal efficiency is the ratio of energy in the brake power, BP, to the input fuel energy in appropriate units. For instance, figure 6 shows the variation of brake thermal efficiency for the different test fuel, from the figure it was observed that brake thermal efficiency is maximum for the neat plastic oil and minimum for the diesel. The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilometer watt. For instance, figure 7 shows the variation of specific fuel consumption for different test fuel, from the figure it was observed that specific fuel consumption is minimum for the neat plastic oil and maximum for diesel oil. Specific fuel consumption decreases with increase in blending ratio from 25% to 100%. Results obtained are in agreement with Sachin et al., (2013) and Mani et al., (2011)

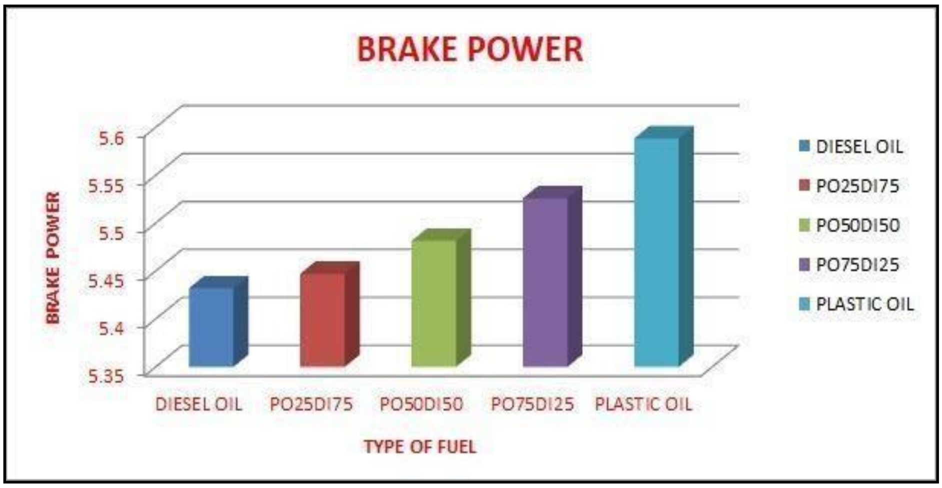


Fig. 5 Variation of Brake Power for WPO blends

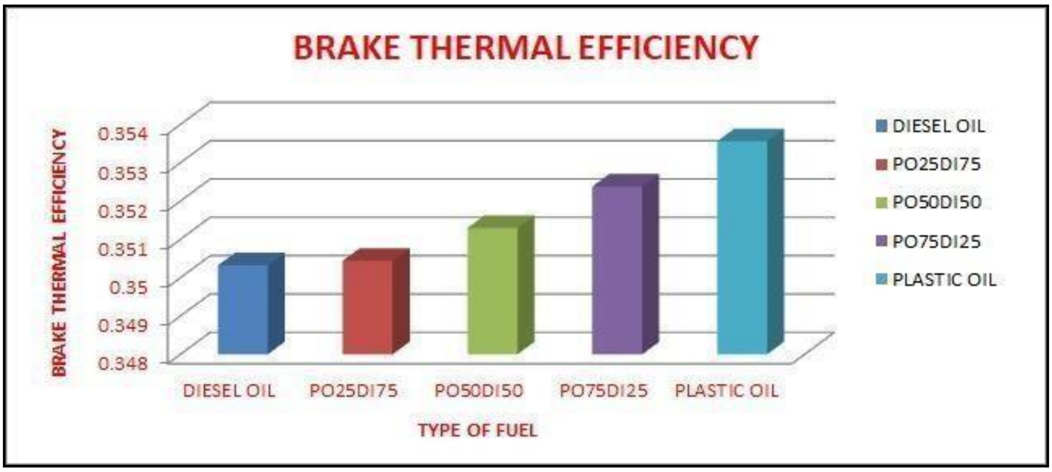


Figure 6 Variation of Brake Thermal Efficiency for WPO blends

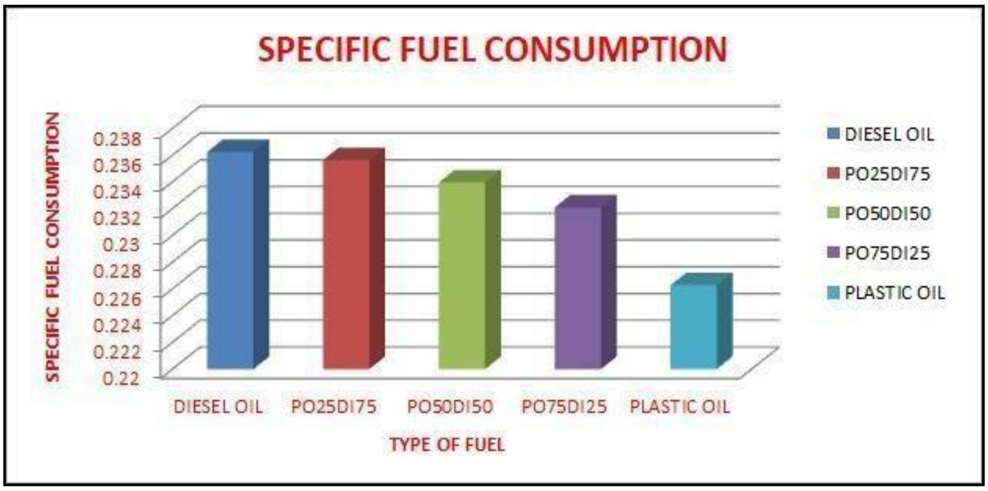


Fig.7Variation of Specific Fuel Combustion for WPO blends

Combustion Characteristics

The figure 9 shows the variation of maximum temperature for different test fuel, from the figure it was observed that temperature is maximum for neat plastic oil and minimum for diesel oil. Furthermore, the temperature increases with increase in blending ratio 25% to 100%.

The figure 10 shows the variation of ignition lag for different test fuel, from the figure it was observed that ignition lag I maximum for neat plastic oil and minimum for diesel oil. Furthermore, the ignition lag is increasing with increase in blending ratio from 25% to 100%. For instance, figure 8 shows the variation of maximum pressure of different test fuel, from the figure it was observed that maximum pressure for neat plastic is maximum and minimum for diesel. Pressure increases with increase in blending ratio from 25% to 100%. Results obtained from simulation are in agreement with Devaraj et al., (2015).

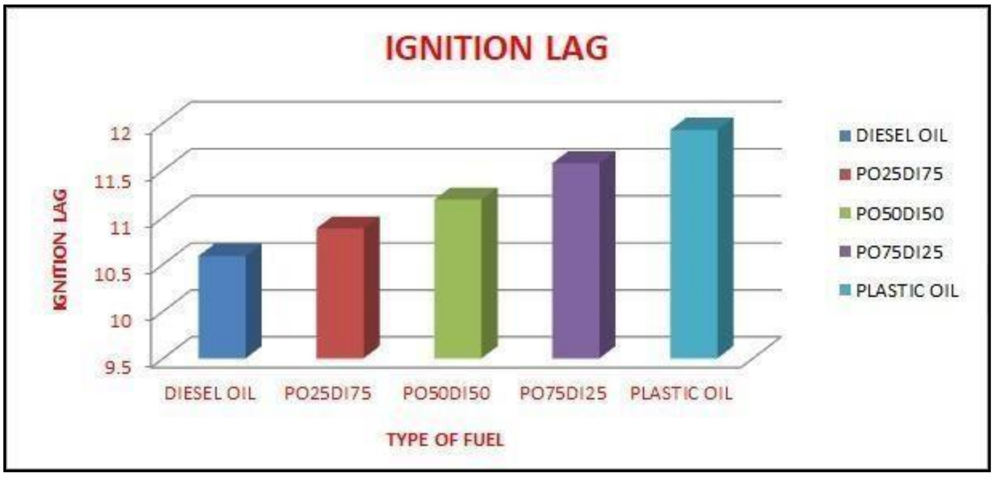


Fig. 8 Variation of Ignition delay for WPO blends

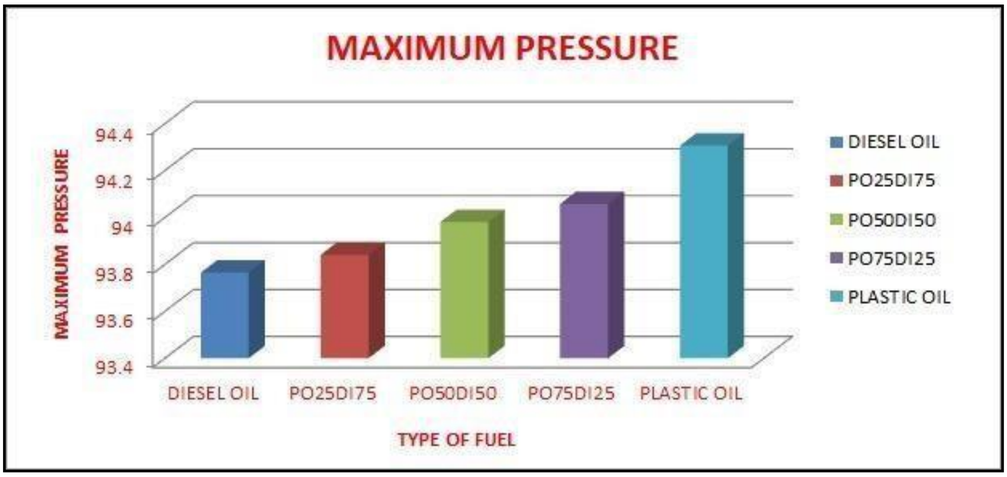


Fig. 9 Variation of maximum pressure for WPO blends

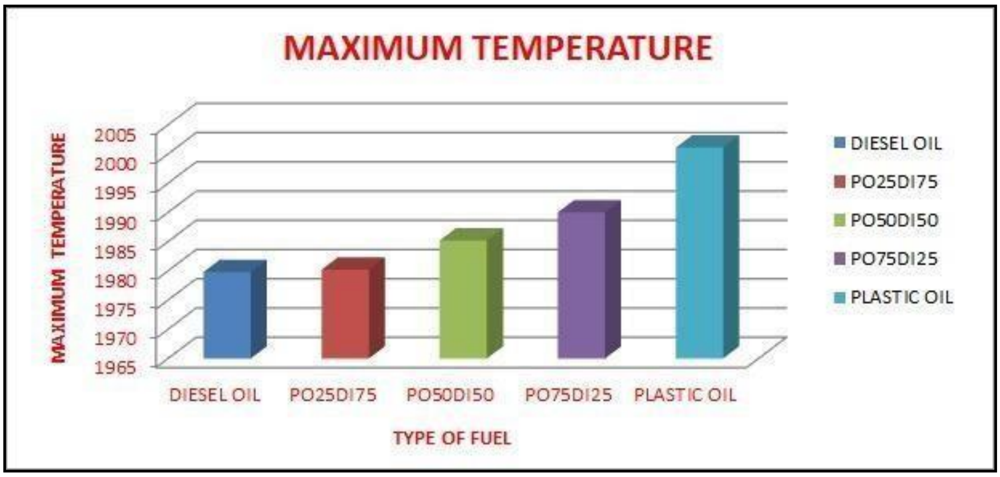


Fig. 10 Variation of maximum temperature for WPO blends

Emission Characteristics

From the figure 11 we can observe that PM is decreasing when blending ratio is increasing from 25% to 100%. from figure we can observe the variation of different test fuel, PM is maximum for diesel oil and minimum for plastic oil. From the figure 12 we can observe that the CO_2 emissions are maximum for diesel oil and minimum for plastic oil. With increase in blending ratio CO_2 emission decrease for different test fuels. From the figure 13 we can observe that the NO_X emissions are increasing with increase in blending ratio, NO_x emissions is maximum for plastic oil due to higher temperature in the cylinder and minimum for diesel oil. The figure 14 shows the variation of Bosch smoke number for different test fuel, from the figure it was observed that Bosch smoke number is maximum for PO75DI25 and minimum for diesel oil. Results obtained from simulation are in agreement with Hariram et al., (2017) and Ioannis et al., (2017).

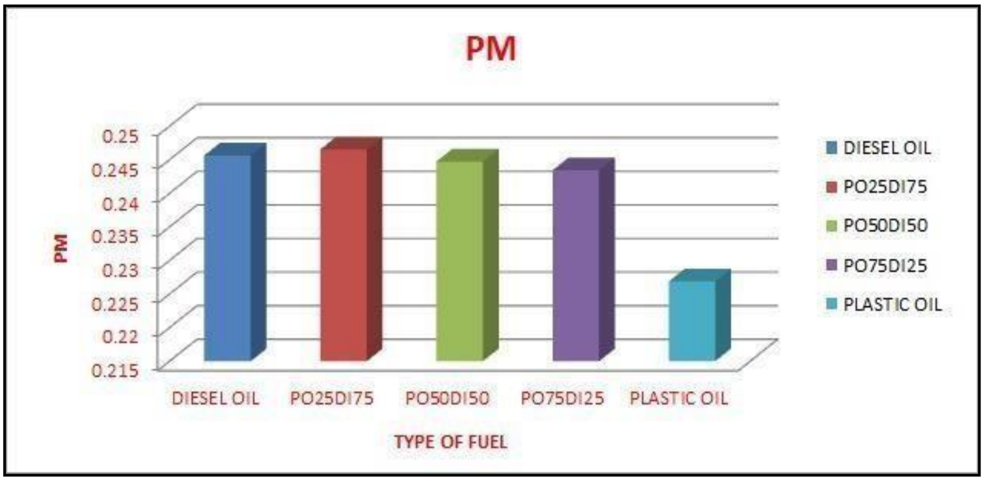


Fig. 11 Variation of Particulate matter for WPO blends

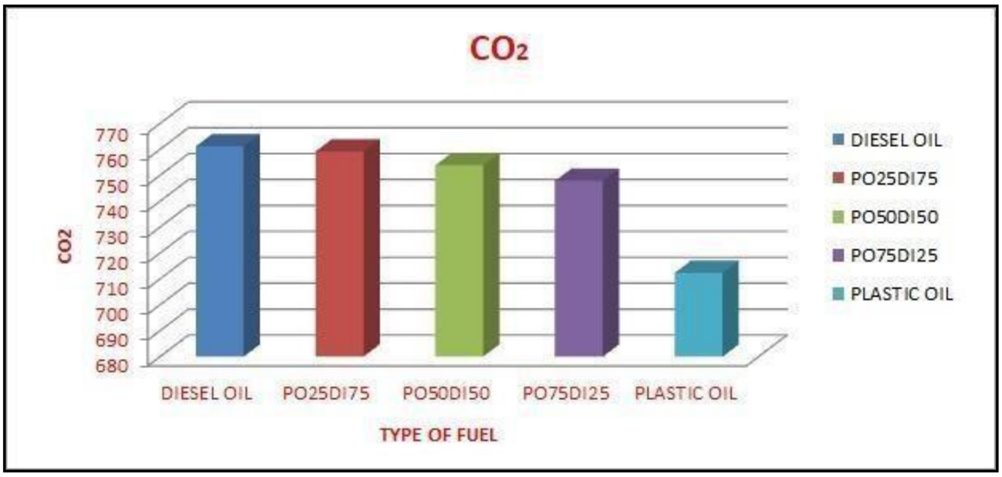


Fig. 12 Variation of CO_2 emissions for WPO blends

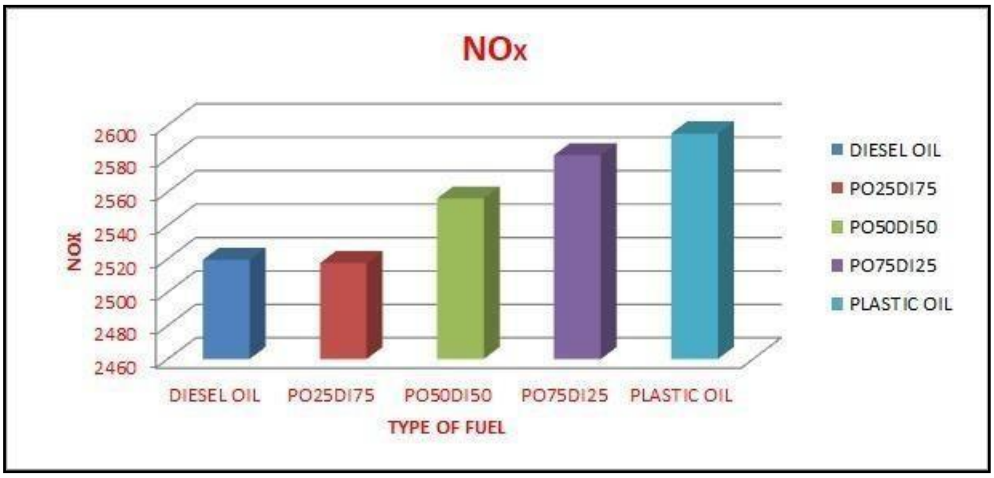


Fig. 13 Variation of NOx emissions for WPO blends

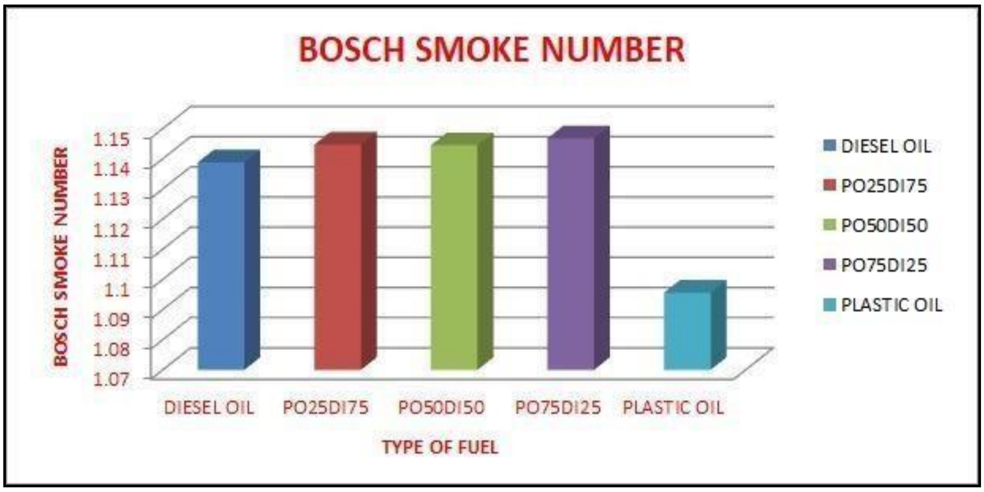


Fig. 14 Variation of Bosch Smoke number for WPO blends

CONCLUSION

- Simulation study on DI Diesel engine operating with plastic oil was successfully completed with the aid of Diesel RK.
- The study indicates that both brake power and brake thermal efficiency increased slightly, also the marginal reduction in SFC was observed for the all-plastic oil blends compared to diesel.
- Peak cylinder pressure, Ignition lag period, heat release rate are increased with increase in blending ratio.
- CO_2 and Particulate matter (PM) get reduced when engine is running with plastic oil blends compared to base line fuel, however a slight increase in NO_x was observed in waste plastic oil blends and concentration of NO_x increased with increase in blending ratio.

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