Front. Environ. Sci. Eng. 2018, 12(4): 8
https://doi.org/10.1007/s11783-018-1063-6

RESEARCH ARTICLE

Study of engine performance, emission and combustion characteristics fueled with diesel-like fuel produced from waste engine oil and waste plastics

V. Edwin Geo (✉)[1], Ankit Sonthalia[2], Fethi Aloui[3], Femilda Josephin J. S.[4]

1 Department of Automobile Engineering, SRM Institute of Science and Technology, Kattankulathur-603203, India
2 Department of Mechanical and Automobile Engineering, SRM Institute of Science and Technology, NCR Campus, Modinagar-201204, India
3 Campus Mont Houy, F-5931 LAMIH UMR CNRS 8201, Department of Mechanical Engineering, University of Valenciennes (UVHC), Campus Mont-Houy, F-59313, Valenciennes Cedex 9, France
4 Department of Software Engineering, SRM Institute of Science and Technology, Kattankulathur-603203, India*

HIGHLIGHTS

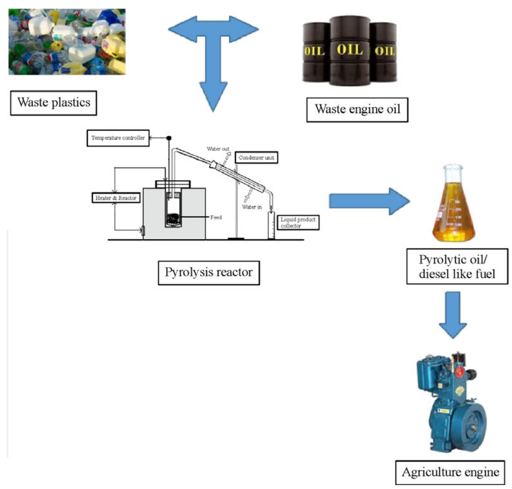
- To derive liquid fuel from waste engine oil and plastics thorough pyrolysis process
- To make equal blend of waste engine oil and plastics with diesel fuel
- To find the suitability of fuel from waste in diesel engine through performance, emission and combustion characteristics

ARTICLE INFO

Article history:
Received 2 February 2018
Revised 20 April 2018
Accepted 14 June 2018
Available online 29 July 2018

Keywords:
Waste engine oil
Waste plastic oil
Diesel fuel
Pyrolysis
Compression ignition engine

GRAPHIC ABSTRACT



ABSTRACT

Utilizing oil extracted from waste engine oil and waste plastics, by pyrolysis, as a fuel for internal combustion engines has been demonstrated to be one of the best available waste management methods. Separate blends of fuel from waste engine oil and waste plastic oil was prepared by mixing with diesel and experimental investigation is conducted to study engine performance, combustion and exhaust emissions. It is observed that carbon monoxide (CO) emission increases by 50% for 50% waste plastic oil (50WPO:50D) and by 58% for 50% waste engine oil (50WEO:50D) at full load as compared to diesel. Unburnt hydrocarbon (HC) emission increases by 16% for 50WPO:50D and by 32% for 50WEO:50D as compared to diesel at maximum load. Smoke is found to decrease at all loading conditions for 50WPO:50D operation, but it is comparatively higher for 50WEO:50D operation. 50WPO:50D operation shows higher brake thermal efficiency for all loads as compared to 50WEO:50D and diesel fuel operation. Exhaust gas temperature is higher at all loads for 50WPO:50D and 50WEO:50D as compared to diesel fuel operation.

1 Introduction

The use of compression ignition engines in India is not only limited to transportation and power generation, but it has also entered the passenger car segment. These engines

✉ Corresponding author
E-mail: vedwingeo@gmail.com

*Special Issue—Bio-based Technologies for Resource Recovery (Responsible Editors: Aijie Wang & David Stuckey)

use diesel as a fuel which after combustion produces carcinogenic pollutants that can harm the environment as well as humans. In the near future, due to increase in vehicle population, availability of fossil fuel may reduce. Hence, it is necessary to foray into alternative sources of energy. On the other way, all the countries of the world are reeling under the problem of waste management and disposal, especially India, which is a serious environmental concern because of change in food habits. The current solution for waste management is landfills which have their own problem of soil pollution, air pollution, water pollution and limited availability of the land. Recycling and extracting useful energy from waste are two main areas that the scientists in the world over are working on. In this work the focus is mainly on waste plastics and waste lubricant and its usefulness in running a diesel engine.

Waste engine lubricant oil, over a period of time loses its properties as it absorbs dust and carbon particles during its use. The production of lubricant is about 40 million metric ton annually and approximately 60% of the produced lubricant becomes waste (Go’mez-Rico et al., 2003). Most of the produced lubricant is petroleum based, and its rate of utilization is nearly 97% of the total lubricant production (Bhaskar et al., 2004). 800,000 L of water becomes unusable and 5,000,000 tonnes of clean water becomes undrinkable if one liter of waste engine oil is discharged to the environment (Arpa et al., 2010). This damage to the environment necessitates the recycling of waste engine oil. Pyrolysis can be used to convert the high volume of waste lubrication oil into valuable fuel. It is an economical and environment friendly way to dispose waste lubrication oil. In this process, the waste is thermally cracked in an inert environment, resulting in gases and oils which can be used as a fuel (Song et al., 2010). Conventional electric resistance and electric arc heating has been utilized by many researchers (Go’mez-Rico et al., 2003; Arpa et al., 2010a;2010b; Song et al., 2010) for the pyrolysis process. Pyrolysis can also be performed using microwave (Lam et al., 2012) and catalytic cracking over solid catalysts (Serrano et al., 2003; Bhaskar et al., 2004; Khowatimy et al., 2014) which yields different hydrocarbon fractions.

The fuel obtained by the pyrolysis process was tested on diesel engine and the effect of the properties of fuel on engine performance was discussed by Arpa et al. (2010a). Distillation temperature is one such property of the fuel, it was found that the resultant fuel obtained after pyrolysis process has a lower distillation temperature. This indicates that the volatility of the fuel is higher than diesel, resulting in improved engine performance i.e. increase in brake thermal efficiency, torque and reduction in brake specific fuel consumption, on the other hand emissions for the fuel was found to be higher than that of diesel.

Plastics are used for industrial as well as domestic purposes because they have less weight, they do not rot or rust, they are inexpensive and reusable. World production of plastics reached 288 million tonnes in 2012. In India alone, the annual demand for plastic is about 14 million tonnes. It has unlimited applications. Plastics never degrade and it will remain on the landscape for many years. The recycled plastic is even more harmful to the environment because of addition of color, additives, stabilizers, flame retardants etc. Further, the plastic material can be recycled 2–3 times only. Since, every recycling reduces the strength of plastic material because of thermal degradation. 70% of total plastic produced is discarded as waste, thus approximately 5.6 million tonnes per annum of waste plastic is generated in the country, which is about 15,342 tonnes per day (Plastic Waste Management, 2013). It creates lot of environmental challenges because of disposal problems, as they are non-bio-degradable. Chemical recycling via pyrolysis method is used to recycle waste plastics at high temperatures in the absence of oxygen to produce fuels. The fuel produced has diesel like properties (Syamsiro et al., 2014). Many researchers tested neat waste plastic oil and its blends with diesel in compression ignition engines and found satisfactory results. Kumar et al. (2013) used catalytic cracking method to produce fuel from high density polyethylene (HDPE). The authors observed a decrease in brake thermal efficiency for the blend at all load conditions, the BSFC was also found to increase and so was the NO_x and CO emission with the increase in blend ratio. Mani et al., 2011 also observed the same trend of NO_x and CO emission increasing by 25% and 5% respectively for waste plastic oil when compared to diesel fuel. It was also observed that hydrocarbon emission increased by 15% and smoke by 40%. Mani et al. further studied the waste plastic oil’s effect on engine performance by varying engine parameters viz. change in injection timing (Mani and Nagarajan, 2009), and use of exhaust gas recirculation (Mani et al., 2010). By retarding the injection timing, at full load, 25% reduction in CO emission and 30% reduction in HC emission was observed, on the other hand, 35% increase in smoke intensity is observed with waste plastic oil as fuel. NO_x emission varies from 14.63 to 8.56 g/kWh without EGR and with recirculation of cooled exhaust gas (20% EGR) it varies from10.9 to 8.2 g/kWh. As NO_x decreases, smoke emission increases, smoke emission increased to 0.11 BSU to 5.5 BSU at 20% EGR. In the present study, separate pyrolytic distillation of waste engine oil and high density polyethylene (HDPE) granules was done to make diesel like fuel. The oil thus obtained was then mixed with diesel in 50:50 ratio, i.e. in 1 L of blend 50% is diesel and the rest is waste engine oil (50WEO:50D) or waste plastic oil (50WPO:50D). The effect of running a compression ignition engine using 50WEO:50D and 50WPO:50D as fuel was then studied. Only these two fuel blends were chosen for this study, since by mixing in equal quantities the overall cost of running the engine could be reduced. The tests were conducted at part load to full load only, since diesel engines are used mostly within these ranges.

2 Experimental setup

2.1 Setup for production of fuel

Pyrolytic distillation of waste engine oil and plastic was done using a system, whose schematic is given in Fig. 1. The setup mainly consists of an oil storage flask, a reactor, a condenser and a control unit. SAE 15W-40 used lubricant oil and HDPE granules were used as input to the reactor. In the reactor, the heat treatment of the oil/granules takes place. The reactor is a cylindrical chamber which is fully insulated and has a diameter of 180mm and height of 208mm. 3 kW electrical heater, which can heat the samples up to 500°C, was placed around the reactor container. The temperature in the reactor is kept at desired levels using the control unit. It is measured using a K- type thermocouple. The oil vaporized in the reactor is cooled using a cross-flow water cooled condenser. The condensate is then collected in the liquid collector. Separate tests were conducted for distilling waste engine oil and HDPE granules.

2.1.1 Production of fuel from waste engine oil

Waste engine oil was poured in the reactor at room temperature and then the chamber was sealed using gasket. The temperature of the reactor is steadily raised at the rate of 2°C per minute using electrical heater. At 110°C fumes were visible which did not condense on passing through the condenser. At 250°C the fumes stopped and it is visible again when the temperature reached 315°C, fumes started condensing at this temperature and first fuel droplets were visible. With the increase in temperature the rate of fumes increased and so did the fuel forming rate. At 390°C, continuous flow of fuel is observed; above this temperature the fumes stopped forming. From 4 L of waste engine oil approximately 3 L of diesel like fuel was obtained.

2.1.2 Production of fuel from HDPE granules

Granules were placed in the reactor at room temperature and then the chamber was sealed using gasket. The temperature of the reactor is steadily raised at the rate of 2°C per minute using electrical heater. At 210°C fumes were visible which do not condense, the fumes could be seen till the temperature reached 312°C, after which there were no visible fumes. As the temperature reached 376°C, again fumes were visible which started condensing and first fuel droplets could be seen in the conical flask. With further increase in temperature the rate of fumes increased and at 420°C continuous supply of fuel was found. In small quantity white color wax could also be seen accumulating at the outlet of the condenser. From 3 kg of granules, approximately 2.25 L of fuel was collected. The properties of waste engine oil and waste plastic oil along with diesel properties are listed in Table 1.

2.2 Engine setup

The engine used for this study is a four stroke, single cylinder, water cooled direct injection compression ignition engine. The schematic diagram of the test engine setup is given in Fig. 2 and the technical specifications of the engine are given in Table 2. A water cooled eddy current dynamometer was used for loading the engine. An air box was used to measure the air flow rate to the engine. A burette and a stop watch is used to measure the fuel consumed by the engine. A chromel alumel thermocouple was used to measure the exhaust gas temperature, using a digital temperature indicator. A pressure transducer (mounted on the cylinder head) is connected to a charge amplifier which in turn is connected to a personal computer is used to measure the cylinder pressure. A crank angle encoder is used to find crank angle with 1° revolution. An AVL exhaust gas analyzer is used to measure HC, CO and

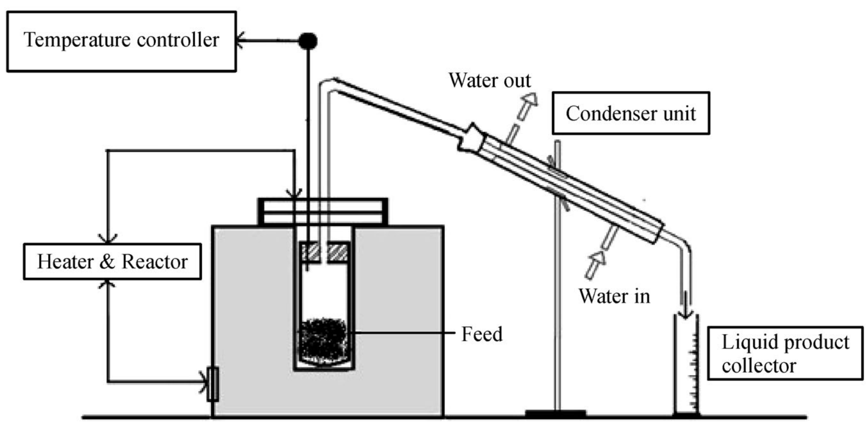


Fig. 1 Schematic of pyrolysis process

Table 1 Property of waste lubricant oil, waste plastic oil and diesel

Property	Waste engine oil	Waste plastic oil	Diesel	50WPO:50D	50WEO:50D
Density (g/cc)	0.985	0.917	0.850	0.894	0.932
Kinematic viscosity @ 40°C	7.2 cst	5.86 cst	3.05 cst	4.63 cst	5.32 cst
Calorific value	38425 kJ/kg	42890 kJ/kg	42000 kJ/kg	42540 kJ/kg	41212.5 KJ/kg
Flash point	88°C	142°C	50°C	104°C	71°C
Fire point	103°C	159°C	56°C	113°C	92°C
Cetane number	41	48	45–55	52	44
Sulphur content	0.22 mg/kg	2.85 mg/kg	< 0.035 mg/kg	1.12 mg/kg	0.14 mg/kg

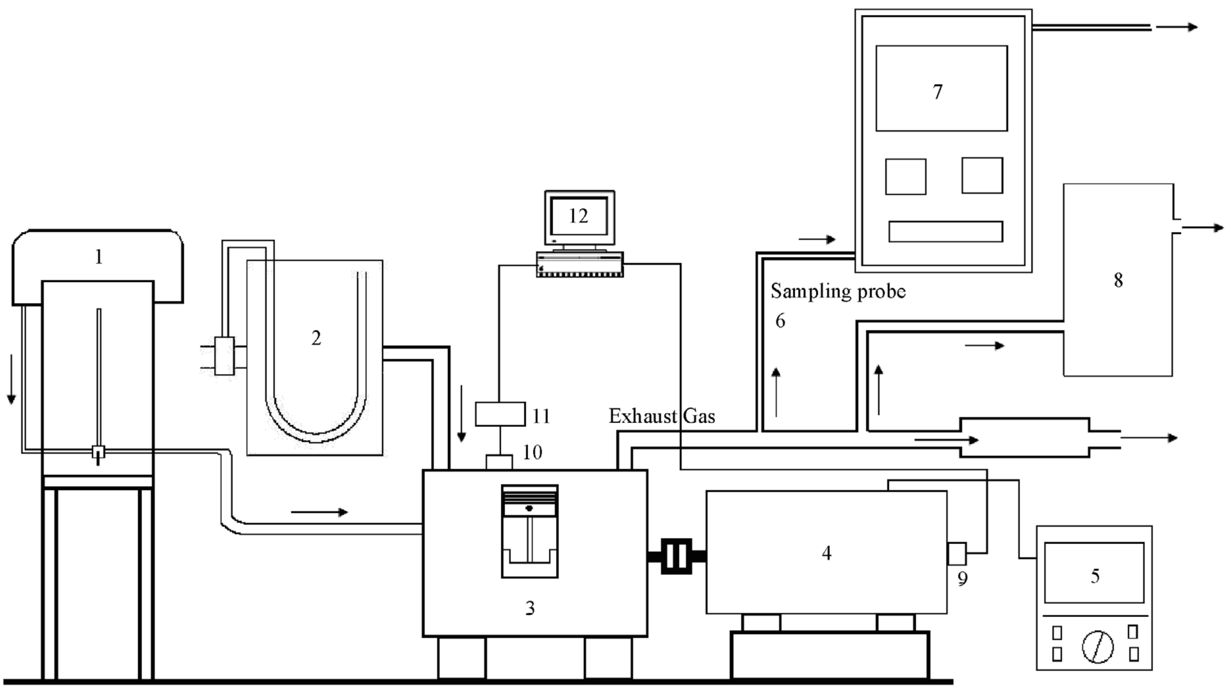


Fig. 2 Schematic of the engine setup
1) Fuel Tank; 2) Air Box; 3) Diesel Engine; 4) Eddy Current Dynamometer; 5) Dynamometer Controller; 6) Sampling Probe; 7) AVL Exhaust Gas Analyser; 8) AVL Smoke Meter; 9) Crank Angle Encoder; 10) Pressure Sensor; 11) Charge Amplifier; 12) Personal Computer

Table 2 Engine specifications

Engine parameter	Specification
Make and model	Kirloskar TV1
Engine type	Four Stroke, water cooled, single cylinder, DI diesel engine
Bore (mm)	87.5
Stroke (mm)	110
Rated power @1500 r/min (kW)	5.2
Compression ratio	17.5:1

NO_x, emission in the exhaust. The smoke is measured by an AVL smoke meter. The experiments were conducted at a constant engine speed of 1500 r/min. The engine was initially started with diesel and later on the fuel was switched to the blends of waste engine oil or waste plastic oil. After completing the test, diesel was again used to run the engine so that the fuel can be flushed out from the fuel line and injection system.

3 Results and discussion

3.1 Combustion characteristics

3.1.1 Cylinder pressure

Figure 3 shows the cylinder pressure with crank angle diagram for 50WPO:50D (50% waste plastic oil and 50% diesel by volume) and 50WEO:50D (50% waste engine oil

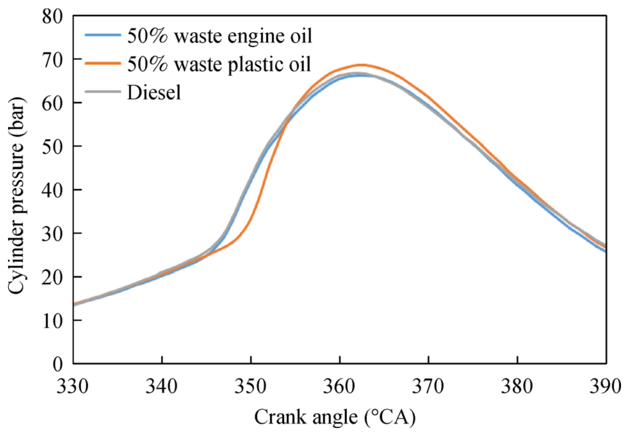


Fig. 3 Variation of cylinder pressure with crank angle at 75% load

and 50% diesel by volume) and diesel at rated power. The peak cylinder pressure at full load, for 50WPO:50D is 69 bar, in case of diesel the peak pressure is 67 bar and in case of 50WEO:50D the peak pressure is 66 bar. In a diesel engine, the peak cylinder pressure depends on the rate of combustion during the early stages, which is governed by the delay period. The longer the ignition delay, the later combustion which results higher peak pressure for 50WPO:50D fuel operation. Due to longer ignition delay shift in peak pressure away from TDC is also observed.

3.1.2 Heat release rate (HRR)

The heat release rate of 50WPO:50D, 50WEO:50D and diesel operation at full load is given in Fig. 4. The HRR is divided into two stages, the first stage (premixed combustion) starts from the point of ignition to the point where rate of heat release decreases, which can be attributed to the air-fuel mixture present during the delay period. The second stage (diffusion combustion) starts from the end of first stage to the end of combustion. Diesel and 50WEO:50D have almost similar heat release curve during the first stage of combustion, also the maximum heat release rate is lower

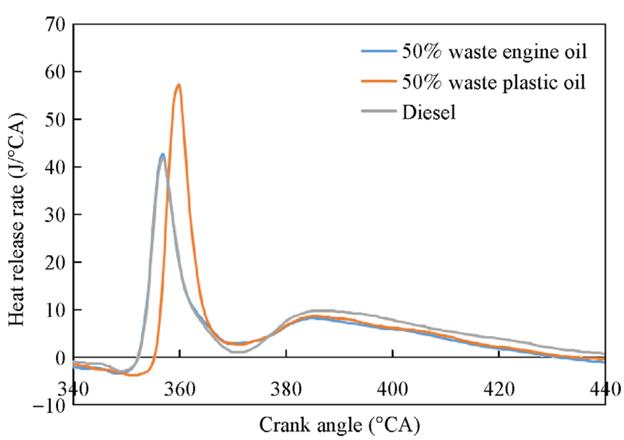


Fig. 4 Variation of heat release rate with crank angle at 75% load

than 50WPO:50D. In case of 50WPO:50D, due to longer ignition delay and evaporation of fuel inside the cylinder, the heat release rate is higher in the first stage. In the second stage, the heat release rate of 50WEO:50D and 50WPO:50D is found to be similar but diesel has higher heat release rate.

3.1.3 Combustion duration

The variation of combustion duration with engine load for 50%, 75% and 100% load is shown in Fig. 5. Combustion duration varied from 46° crank angle (CA) at 50% load to 51°CA at maximum load for diesel, it varies from 51°CA at 50% load to 56°CA at full load for 50WEO:50D, whereas for 50WPO:50D the variation in combustion duration is 48°CA at 50% load to 53°CA at full load. With the increase in power output, the combustion duration is found to be higher compared to diesel. As the power output increases, the amount fuel supplied increases to maintain the power output compared to diesel. This additional quantity of fuel need more time to complete the combustion. This may lead to increase in combustion duration than diesel. 50WEO:50D has maximum combustion duration for all loads as compared to 50WPO:50D and diesel. Due to slower combustion of the fuel supplied and also due to longer second phase of combustion (Fig. 4), the increase in combustion duration is observed. Also lower cetane number and high viscosity of WEO lead to higher combustion duration compared to WPO blend.

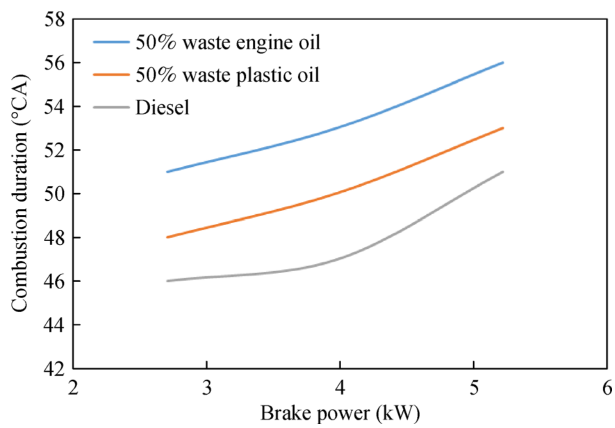


Fig. 5 Variation of combustion duration with engine load

3.1.4 Coefficient of variance for maximum pressure

It is ratio of standard deviation in maximum pressure and mean of maximum pressure. 100 cycles data was recorded to find the coefficient of variance for maximum pressure. Figure 6 shows variation of COV P_{max} with engine load. It can be observed that for 50WEO:50DCOV varies from 0.75% at 50% load to 0.82% at full load and is very less as compared to 50WPO:50D, where it varies from 1.25% at

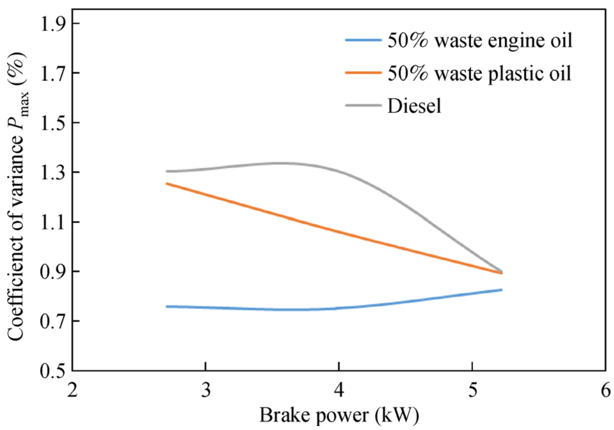


Fig. 6 Variation of coefficient of variance P_{max} with engine load

50% load to 0.89% at full load and diesel operation, where it varies from 1.3% at 50% load to 0.9% at full load. With increase in load the variation in maximum pressure reduces for 50WPO:50D and diesel operation but in case of 50WPO:50D it increases. This variable signifies the cycle-by-cycle variation occurring during the combustion process. If the cyclic variation is small then the engine operation will be smooth.

3.2 Performance characteristics

3.2.1 Brake thermal efficiency

The variation of brake thermal efficiency with brake power for 50WPO:50D, 50WEO:50D and diesel is shown in Fig. 7. Maximum brake thermal efficiency of 30.5% is observed for diesel operation at 75% load. 50WEO:50D has lowest brake thermal efficiency of 30.2%, at 75% load, which can be attributed to lower total heat release as compared to diesel. 50WPO:50D has higher brake thermal efficiency is higher at all loads compared to diesel. At 75% load, the heat release rate for 50WPO:50D is higher than diesel (Fig. 4) resulting in large amount of heat carried by

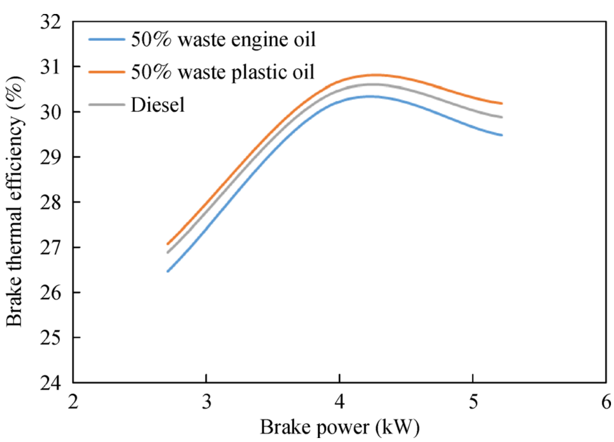


Fig. 7 Variation of brake thermal efficiency with engine load

the exhaust gases and reduction in efficiency. However, at part load the peak heat release rate is less and the effective pressure to do work is higher. Therefore, the brake thermal efficiency will be higher.

3.2.2 Brake specific energy consumption (BSEC)

BSEC gives a better understanding of fuel consumption when fuels of different heating values, viscosities and densities are blended together. Figure 8 shows the variation of BSEC with loads for 50WPO:50D, 50WEO:50D and diesel. It varies from 13.3 MJ/kWh at 50% load to 11.9 MJ/kWh at full load for 50WPO:50D, for diesel it varies from 13.4 MJ/kWh at 50% load to 12 MJ/kWh and it varies from 13.6 MJ/kWh at 50% load to 12.2 MJ/kWh for 50WEO:50D. A decreasing trend in energy consumption was observed for all the test fuels with increase in load. 50WEO:50D consumes more fuel for producing the same power as compared to 50WPO:50D and diesel. Lower heat release and lower calorific value of 50WEO:50D can be the possible reason for this trend. 50WPO:50D has lower BSEC as compared to diesel for 50% and 75% load and higher BSEC for full load. This trend is exactly opposite to that of brake thermal efficiency trend.

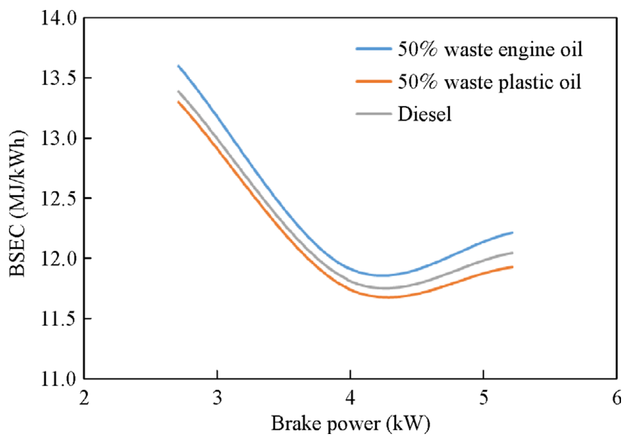


Fig. 8 Variation of brake specific energy consumption with engine load

3.2.3 Exhaust gas temperature

Figure 9 shows the variation of exhaust gas temperature with load for the three fuel samples. It is observed that the temperature of exhaust gas increases with increase in load, since more fuel is burnt to produce the required power. The exhaust temperature in the case of 50WEO:50D varies from 303°C at 50% load to 435°C at full load, in case of 50WPO:50D it varies from 276°C at 50% load to 417°C at maximum load and in case of diesel operation, it ranges from 251°C at 50% load to 405°C at maximum load. The reason for higher exhaust gas temperature of 50WEO:50D fuel is the higher heat loss to exhaust gas as can be seen in Fig. 7 that the brake thermal efficiency for 50WEO:50D

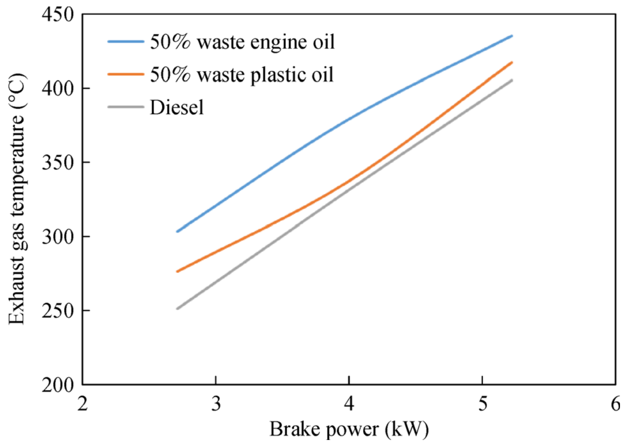


Fig. 9 Variation of exhaust gas temperature with engine load

operation is lower. This will result in poor performance of the engine and higher emissions. Lower temperature in the exhaust gas for 50WPO:50D as compared to 50WEO:50D operation is due to faster combustion of 50WPO:50D.

3.3 Emissions characteristics

3.3.1 Carbon monoxide

As shown in Fig. 10 carbon monoxide emission for 50WPO:50D and 50WEO:50D is higher than diesel fuel operation. At 50% load, the CO emission is 0.07%, but at full load the CO emission shoots up to a maximum of 0.19% for 50WEO:50D, while for 50WPO:50D it is 0.16% and for diesel it is only 0.08% at full load. Higher carbon monoxide emission could be mainly due to local fuel rich regions causing incomplete combustion. It can be observed that CO emission increases with 50WEO:50D and 50WPO:50D compared to diesel. This may due to poor atomization characteristics of WEO and WPO leading to poor combustion.

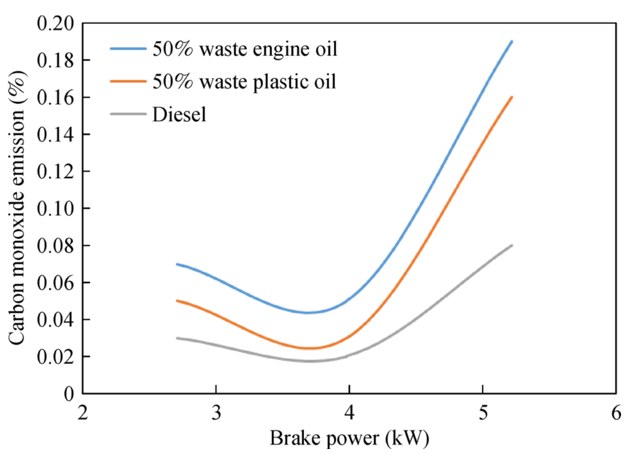


Fig. 10 Variation of carbon monoxide emission with engine load

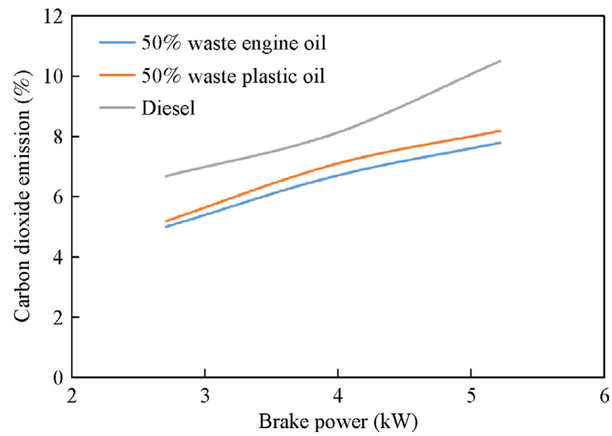


Fig. 11 Variation of carbon dioxide emission with engine load

3.3.2 Carbon Dioxide

Figure 11 illustrates the variation of carbon dioxide emission with load for the tested fuels. It can be observed that the emission varies from 5.2% at 50% load to 8.2% at maximum load for 50WPO:50D, it varies from 5% at 50% load to 7.8% at maximum load for 50WEO:50D and for diesel the variation is from 6.1% at 50% load to 10.1% at maximum load. The trend of carbon dioxide emission is exactly opposite to that of carbon monoxide emission. The reason for the trend is improvement in combustion resulting in more carbon dioxide formation. Thus diesel fuel operation produced higher carbon dioxide emission than 50WEO:50D and 50WPO:50D which shows that diesel fuel has good combustion characteristics than other test fuels.

3.3.3 Unburned hydrocarbon emission

Unburned hydrocarbon emission is a measure of combustion. Figure 12 shows the variation of unburned hydro-

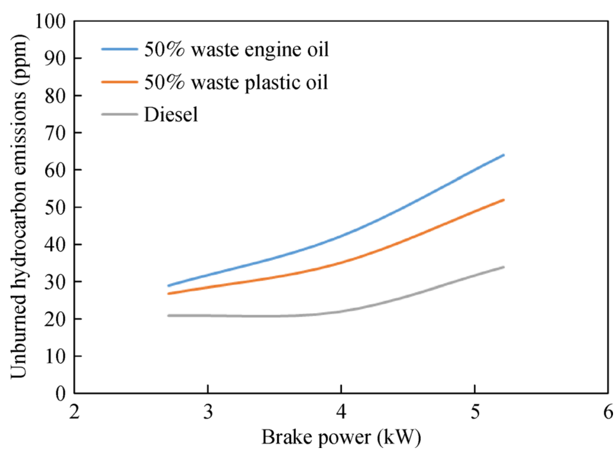


Fig. 12 Variation of unburned hydrocarbon emission with engine load

carbon with load for tested fuels. The emission ranges from 29 ppm at 50% load to 64 ppm at maximum load for 50WEO:50D operation. For 50WPO:50D operation, it ranges from 27 ppm at 50% load to 52 ppm at maximum load. For diesel operation, the range of emission is 21 ppm at 50% load to 34 ppm at maximum load. From the experimental results it is observed that with increase in load, the unburned hydrocarbon emission increases for all the fuels. At lower loads, the fuel consumed is less, resulting in lower emissions whereas at higher loads the fuel consumed is higher resulting in higher emissions. At all loads, 50WEO:50D has higher emission than 50WPO:50D and diesel. Since the combustion duration (Fig. 5) for 50WEO:50D is longer than the other two fuels, more amount of fuel leaves without taking part of combustion, resulting in incomplete combustion and higher unburned hydrocarbon emission.

3.3.4 NO_x emissions

It can be seen in Fig. 13 that NO_x emissions vary from 1032 ppm at 50% load to 1432 ppm at full load for diesel, for 50WPO:50D it varies from 1066 ppm at 50% load to 1492 ppm at full load and for 50WEO:50D the variation is from 954 ppm at 50% load to 1306 ppm at full load. The predominant factors for the oxidation of nitrogen are air-fuel ratio and the temperature of the combustion chamber. With adequate burning, the in-cylinder combustion temperature rises and subsequently, more free oxygen atoms combine with nitrogen, increasing the formation rate of NO_x. 50WPO:50D and diesel have almost same NO_x emissions at full load. This may be due to better combustion of WPO and diesel.

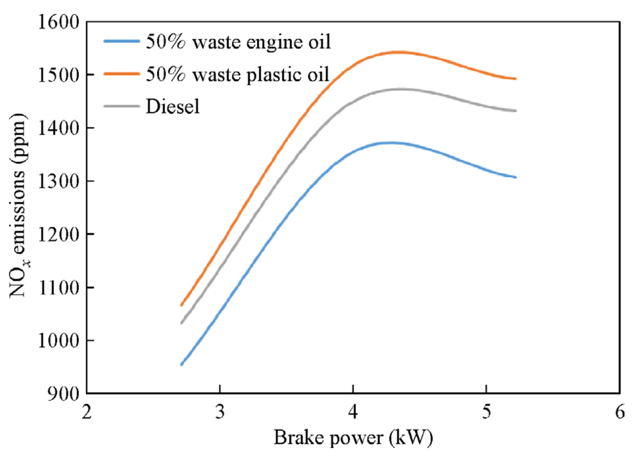


Fig. 13 Variation of NO_x emissions with engine load

3.3.5 Smoke opacity

Figure 14 shows the variation of smoke emission with brake power. Smoke opacity varies from 25% at 50% load to 44% at full load for diesel operation, it varies from 30% at 50% load to 55% at full load for 50WEO:50D, whereas for 50WPO:50D the variation can be seen from 21% at 50% load to 42% at full load. It can be seen that the smoke emission is higher for 50WEO:50D than diesel but the emission from 50WPO:50D operation is lesser than diesel. The reason for reduced smoke for 50WPO:50D can be early evaporation of fuel leading to premixed or homogeneous charge inside the cylinder. This would lead to higher heat release and near complete combustion. Higher smoke values for 50WEO:50D could be due to unburnt and partially reacted hydrocarbons.

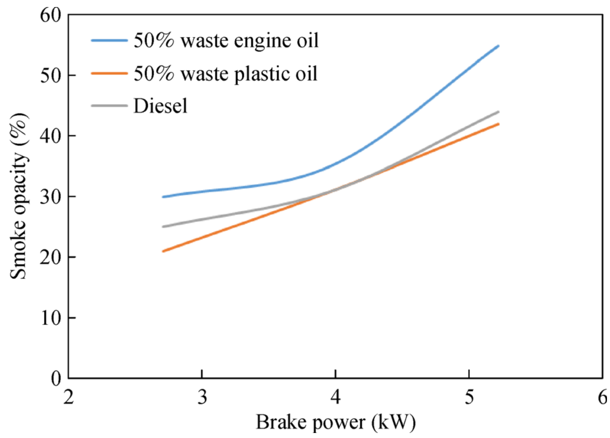


Fig. 14 Variation of smoke opacity emission with engine load

4 Conclusions

The influence of blends of waste plastic oil and waste engine oil with diesel on a diesel engine operation was studied and compared with neat diesel operation. The following major conclusions can be drawn from this experimental work:

- Cylinder pressure was similar for 50WEO:50D and diesel fuel operation, but 50WPO:50D has higher cylinder pressure than both. Consequently heat release rate is higher for 50WPO:50D.
- Brake thermal efficiency of the engine fuelled with 50WPO:50D is higher than diesel. Higher heat release rate and lower exhaust gas temperature is the reason for higher BTE at full load for 50WPO:50D.
- 50WPO:50D has higher brake specific energy consumption as compared to diesel, 50WPO:50D has lower energy consumption than diesel at all loads. This is due to lower and higher heating value of WEO and WPO respectively.
- Diesel has lower CO emission at all loads compared to test fuels. Between 50WPO:50D and 50WEO:50D, the CO emission is lower for 50WPO:50D.
- Diesel has lowest HC emission for all loads as compared to 50WPO:50D and 50WEO:50D operation. At

full load 34% increase in emission is observed for 50WEO:50D and 16% increase for 50WPO:50D operation is observed.

• 50WPO:50D has marginally higher NO_x emissions compared to diesel, but 50WEO:50D has comparatively lower emission. At full load, 13% decrease is observed for 50WEO:50D operation.

• Smoke opacity for 50WPO:50D is lower at all loads as compared to 50WEO:50D and diesel. 50WEO:50D has comparatively higher smoke opacity as compared to diesel. For 50WEO:50D, 24% decrease in smoke emission is observed at full load as compared to 50WPO:50D.

It can thus be concluded that 50% blends of waste plastic oil and waste engine oil with diesel can be used CI engine with any modifications. Further engine performance may be improved by making small modifications include retarding the injection timing, use of exhaust gas recirculation and lastly by derating the engine.

Acknowledgements The authors acknowledge SRM Institute of Science and Technology, Chennai for providing funds for this research work under selective excellence program.

References

Arpa O, Yumrutaş R, Argunhan Z (2010a). Experimental investigation of the effects of diesel-like fuel obtained from waste lubrication oil on engine performance and exhaust emission. Fuel Processing Technology, 91(10): 1241–1249

Arpa O, Yumrutas R, Demirbas A (2010b). Production of diesel-like fuel from waste engine oil by pyrolitic distillation. Applied Energy, 87(1): 122–127

Bhaskar T, Uddin M A, Muto A, Sakata Y, Omura Y, Kimura Y, Kawakami Y (2004). Recycling of waste lubricant oil into chemical feedstock or fuel oil over supported iron oxide catalysts. fuel, 83: 9–15

Go'mez-Rico M F, Martı'n-Gullo'n I, Fullana A, Conesa J A, Font R (2003). Pyrolysis and combustion kinetics and emissions of waste lube oils. Journal of Analytical and Applied Pyrolysis, 68: 527–546

Khowatimy F A, Priastomo Y, Febriyanti E, Riyantoko H, Trisunaryanti W (2014). Study of waste lubricant hydrocracking into fuel fraction over the combination of Y-zeolite and ZnO catalyst. Procedia Environmental Sciences, 20: 225–234

Kumar S, Prakash R, Murugan S, Singh R K (2013). Performance and emission analysis of blends of waste plastic oil obtained by catalytic pyrolysis of waste HDPE with diesel in a CI engine. Energy Conversion and Management, 74: 323–331

Lam S S, Russell A D, Lee C L, Chase H A (2012). Microwave-heated pyrolysis of waste automotive engine oil: Influence of operation parameters on the yield, composition, and fuel properties of pyrolysis oil. Fuel, 92(1): 327–339

Mani M, 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

Mani M, Nagarajan G, Sampath S (2010). An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation. Fuel, 89(8): 1826–1832

Mani M, Nagarajan G, Sampath S (2011). Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine. Energy, 36(1): 212–219

Plastic Waste Management (2013). Central Pollution Control Board

Serrano D P, Aguado J, Escola M, Garagorri E (2003). Performance of a continuous screw kiln reactor for the thermal and catalytic conversion of polyethylene- lubricating oil base mixtures. Applied Catalyst B: Environmental, 44: 95–105

Song G J, Seo Y C, Pudasainee D, Kim I T (2010). Characteristics of gas and residues produced from electric arc pyrolysis of waste lubricating oil. Waste Management (New York, N.Y.), 30(7): 1230–1237

Syamsiro M, Saptoadi H, Norsujianto T, Noviasri P, Cheng S, Alimuddin Z, Yoshikawa K (2014). Fuel oil production from municipal plastic wastes in sequential pyrolysis and catalytic reforming reactors. Energy Procedia, 47: 180–188