Energy 85 (2015) 304–309

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Experimental investigation of performance, emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as fuel for diesel engine

J. Devaraj [a,*], Y. Robinson [b], P. Ganapathi [b]

[a] Sri Ranganathar Institute of Engineering and Technology, Coimbatore 641110, India
[b] RVS Technical Campus, Coimbatore 641402, India

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
13 February 2015
Accepted 16 March 2015
Available online 18 April 2015

Keywords:
Diesel engine
Waste plastic pyrolysis oil
Diethyl ether
Emission
Performance

ABSTRACT

The oil obtained by pyrolysis of waste plastics can be used as an alternate fuel for diesel engine without making any modification to the engine. The WPPO (waste plastic pyrolysis oil) mixed with 5% and 10% DEE (diethyl ether) were used as fuels for single cylinder water cooled, DI engine and its performance, emission and combustion characteristics were found. The experimental results indicated the reduction in smoke levels with that of baseline waste plastic pyrolysis oil. The BTE (brake thermal efficiency) increased when compared to pure plastic pyrolysis oil and diesel. The pollutants such as CO (carbon monoxide) and NO_x (nitrous oxide) were reduced in the blend. It was observed that addition of oxygenates had improved the combustion process and reduced the emissions. The investigation revealed that blending of DEE with plastic oil increases the Cetane rating which is superior to neat diesel.

1. Introduction

The steady increase in energy consumption coupled with environmental pollution has promoted research activities in alternative and renewable energy fuels. Many countries in the world are continually developing materials and methods for effectively utilizing the alternative fuel resources, available in their region [1]. Among the various alternative fuels, plastic pyrolysis oil has received significant attention in recent years, due to its environmental benefits. Plastics have woven their way into our daily lives and now poses a tremendous threat to the environment. Over 100 million tonnes of plastics are produced annually worldwide, and the used products have become a common feature at overflowing bins and landfills [2]. Plastic is a material used all over the world because of its desirable properties. But the main problem with it is the waste plastic will not decompose as other materials do. This led the world to have a consideration to avoid its usage. The plastic waste can be utilized to make fuel for the engine. The process of making fuel from plastic is called pyrolysis. The assorted waste plastic is fed into a reactor along with 1% (by weight) catalyst and 10% (by weight) coal and maintained at a temperature of 300–400 °C at atmospheric pressure for about 3–4 h. The pyrolysis process involves the breakdown of large molecules into smaller molecules produces hydrocarbons with small molecular mass (e.g. Ethane) that can be separated by fractional distillation and used as fuels and chemicals. This process gives on weight basis 75% of liquid hydrocarbon, which is a mixture of petrol, diesel and kerosene, 5–10% residual coke and the rest is LPG (liquid petroleum gas). Many researchers have investigated the feasibility of using the waste plastic oil in the diesel engine. It was concluded that the waste plastic oil has properties, similar to that of diesel fuel and could be used as a substitute to diesel [3,4]. Low auto ignition temperature and high Cetane number are the desirable properties of DEE (diethyl ether) to use as fuel in diesel engines [5]. The aim of our experiment is to investigate the relevance of the diesel-DEE blend for the diesel engine without any modification on the engine.

2. Experimental setup

The Single Cylinder, water cooled, 4 stroke diesel engine was coupled with an eddy current dynamometer. A control panel

Abbreviations: HC, unburned hydrocarbon; O_2, oxygen; CO, carbon monoxide; NO_x, nitrous oxide; CO_2, carbon dioxide; WD05, waste plastic pyrolysis oil blended with 5% diethyl ether; WD10, waste plastic pyrolysis oil blended with 10% diethyl ether; WPPO, waste plastic pyrolysis oil; DEE, diethyl ether; BSFC, brake specific fuel consumption; BT, brake torque; BP, brake power; TFC, total fuel consumption.

* Corresponding author. Tel.: +91 9994688377.
E-mail address: devajayam@yahoo.com (J. Devaraj).

http://dx.doi.org/10.1016/j.energy.2015.03.075
0360-5442/

having a burette was used to measure the quantity of fuel which goes into the engine. The dynamometer controls are there in the control panel. It has a device to show the temperature measured at different places in the engine. The AVL Digas' 444 Exhaust Gas Analyzer was connected to the tailpipe to find the constituents of CO, CO_2, HC, NO_x and O_2 in the exhaust gas which interfaces with RS 232 C pickup coil temperature probe. AVL 437C smoke meter was used to measure the smoke opacity and to find the exhaust temperature. The AVL Digas' 444Analyzer and AVL 437C smoke meter was interfaced with a computer with the help of A/D convertor. The readings were taken after running the engine in diesel mode for half an hour in order to get stabilized values. The exhaust gas Analyzer was calibrated with zero gas before the experiment. The engine setup is shown in Fig. 1 and the engine specifications are given below in Table 1. The fuels used were diesel, WPPO (waste plastic pyrolysis oil), WD05 (waste plastic pyrolysis oil blended with 5% diethyl ether), WD10 (waste plastic pyrolysis oil blended with 10% diethyl ether). The fuel blends were prepared just before starting experiments to provide homogenous mixture. A mixer was mounted inside the fuel tank in order to prevent phase separation. The properties of fuel used are given in Table 2.

3. Performance and emission

3.1. Brake thermal efficiency

Brake thermal efficiency indicates the ability of combustion system to accept the experimental fuel and provides a comparable means of assessing how efficiently the fuel was converted into mechanical output [6]. Low heat release rate during the premixed combustion phase, is the reason for lower thermal efficiency for tyre pyrolysis oil with diethyl ether operation up to part load [7]. Fig. 2 shows the curve between the load and brake thermal efficiency. The brake thermal efficiency at high loads for diesel and waste plastic pyrolysis oil is 28% and 27.75%, whereas for WD05 and WD10 is 27.51% and 29.12%. The thermal efficiency is higher for WD10. The addition of DEE increased the BTE (brake thermal efficiency) [8,9]. The presence of oxygen in the DEE helps in the complete combustion of the fuel raising the BTE. The BTE is almost same at the lower loads for all combinations of WPPO and DEE and then increases slightly with increase in concentration of DEE to WPPO. At higher concentration of DEE, the increase in BTE may be due to the ability of DEE to reduce the surface tension or interfacial tension between two or more interacting immiscible liquids helped the better atomization of fuel, which improves the combustion.

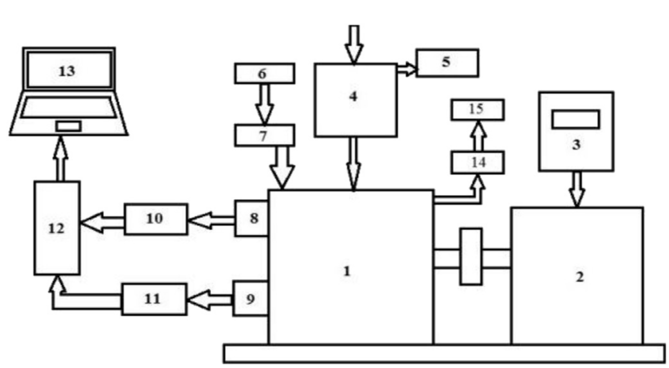

Fig. 1. Experimental setup. 1. Diesel engine; 2. Alternator; 3. Dynamometer control; 4. Airbox; 5. U-Tube manometer; 6. Fuel tank; 7. Fuel measurement flask; 8. Pressure pickup; 9. TDC position sensor; 10. Charge amplifier; 11. TDC amplifier circuit; 12. A/D card; 13. Personal computer; 14. Exhaust gas analyzer; 15. AVL smoke meter.

Also the lower fuel consumption may be one of the reasons for increased brake thermal efficiency.

3.2. Brake specific fuel consumption

Fig. 3 shows the curve between Brake Specific Fuel Consumption with the load. This figure reveals that pure diesel fuel has the BSFC (brake specific fuel consumption) of 0.560 kg/kW h at 20% load and 0.276 kg/kW h at full load. For WPPO, the value is 0.616 kg/kW h at 20% and 0.292 kg/kW h at full load. The BSFC for WD05 is 0.605 kg/kW h at 20% and 0.294 kg/kW h at full load. The BSFC for WD10 is 0.591 kg/kW h at 20% and 0.301 kg/kW h at full load. At high speeds of the engine, the differences between BSFC values of fuel blends become smaller, due to the short combustion period in spite of the increased fuel amount. By excess oxygen and fast burning ethanol molecules, combustion temperature increases. All these factors affect combustion in a better way. As a result of this, BSFC values of WD blends become closer to pure diesel fuel BSFC at high engine speeds. The variation in brake specific fuel consumption with load for different fuels shows decline with increase in load. One possible explanation for this could be due to more increase in brake power with load as compared with fuel consumption. The BSFC in case of blends was higher compared to diesel in the entire load range, due to its lower heating value, greater density and hence higher bulk modulus. The higher bulk modulus results in more discharge of fuel for same displacement of the plunger in injection pump, thereby resulting increase in BSF. As the heating values are higher for blends compared to diesel with further increase in the concentration of additive it is clearly observed that the values of BSFC tend to decrease.

3.3. Unburned hydrocarbon

Unburned hydrocarbon consists of fuel that is incompletely burned. The term hydrocarbon means organic compounds in the gaseous state and solid hydrocarbons are the particulate matter [10]. Unburned hydrocarbon emissions are caused by incomplete combustion of fuel–air mixture. Fig. 4 shows the emissions of HC (hydrocarbon) with increasing loads. For Diesel, unburned hydrocarbon varies from 32 ppm at 20% load and 57 ppm at full load. For WPPO, the values are 53 ppm at 20% load and 91 ppm at full load. For WD05 and WD10, the values are 60 and 76 ppm, at 20% load and 93 ppm and 96 ppm at full load. The addition of DEE with WPPO increases the HC emissions than diesel. The reason behind increased unburned hydrocarbon in waste plastic oil, may be due to higher fumigation rate. The increase in HC emissions with the use of WD10 can be attributed to the leakage of the fuel through the injector nozzle due to the considerably low viscosity of the fuel [11]. DEE additive has a low charge temperature and decreases combustion temperature due to its high heat of evaporation. Additionally, some of the DEE additive mixes with air during fuel injection and accumulates in the ring space between the piston and cylinder. Consequently, the combustion flame cannot effectively reach these spaces, thus yielding high HC emissions [12].

3.4. Oxides of nitrogen

Oxides of nitrogen result from reaction of nitrogen and oxygen at relatively high temperatures. NO is a major component in the NO_x emission [13]. The formation of NO_x for diesel, WPPO, WD05 and WD10 are shown in Fig. 5. The NO_x values for diesel, vary from 129 ppm at 20% load and 855 ppm at full load. For WPPO, it varies from 150 ppm at 20% load and 904 ppm at full load. . For WD05 and WD10, it varies from 91 to 71 ppm at 20% load and 529 ppm and 473 ppm at full load. The NO_x formed is increasing as the load

Table 1
Engine specifications.

Engine model	Kirlosker AV1
Engine type	Vertical, single cylinder, Four stroke, direct injection, Water cooled, and Compression ignition
Rated power	3.7 kW
BHP	5BHP
Compression ratio	16.5:1
Injection pressure	215 bar
Bore/stroke	80/110
Start of injection	27° BTDC
Engine rated speed	1500 rpm

Table 2
Properties of diesel, waste plastic oil and diethyl ether.

Properties	Standard test methods	Diesel	WPPO	DEE	WD05	WD10
Calorific value (J/kg)	ASTM D 445	46,500	45,216[a]	33,900	44,650[a]	44,084[a]
Specific gravity	ASTM D 2217	0.840	0.798[a]	0.713	0.794[a]	0.754[a]
Flash point (°C)	ASTM D93	50	42[a]	45	43[a]	43.5[a]
Fire point (°C)	ASTM D93	56	45[a]	55	48[a]	47[a]
Chemical structure		$C_{12}H_{26}$	C_nH_{2n-1}	$C_2H_5{-}O{-}C_2H_5$	–	–
Cetane number		40–45	51	126	–	–

[a] Calculated in the laboratory under standard test methods and other values are taken from reference.

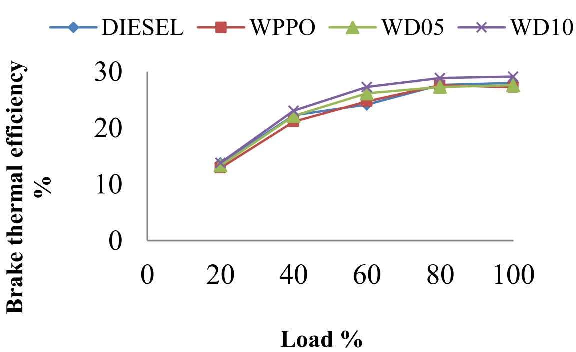

Fig. 2. Brake thermal efficiency % vs. Load %.

increases. The NO_x emissions of the blends were found to reduce with increasing blend percentage of DEE with WPPO. Since DEE is a cetane improver and any increase in cetane number decreases NO_x emission. DEE has high oxygen content and high heat of evaporation [14,15]. It is easy to ignite the fuel–air mixture and it yields shorter combustion duration. By addition of DEE, heat release decreases in the stage of diffusion controlled combustion, thereby leading to lower NO_x emissions. Another factor which causes lower NO_x emissions is high heat of evaporation of DEE. Because DEE has a considerably high cetane number, oxygen content and high heat of evaporation, it is easy to ignite the fuel–air mixture, and it yields shorter combustion duration. By adding DEE, heat release decreases in the stage of diffusion controlled combustion, thereby leading to lower NO emissions. Moreover, an experimental study using various fuel blends with oxygen content showed that the NO emissions decrease due to the lower high temperature duration that the combustion gases experience. Furthermore, the use of fuel additives with high cetane number causes lower NO_x emissions

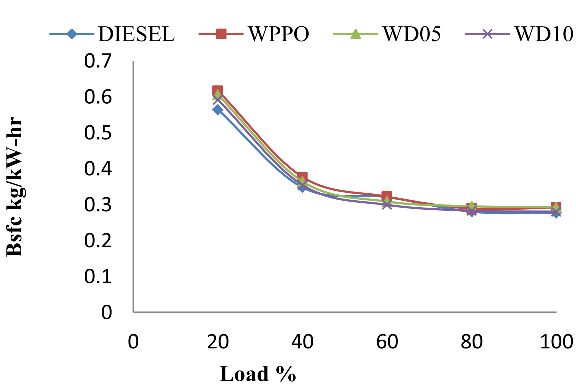

Fig. 3. BSFC kg/kW-h vs. Load %.

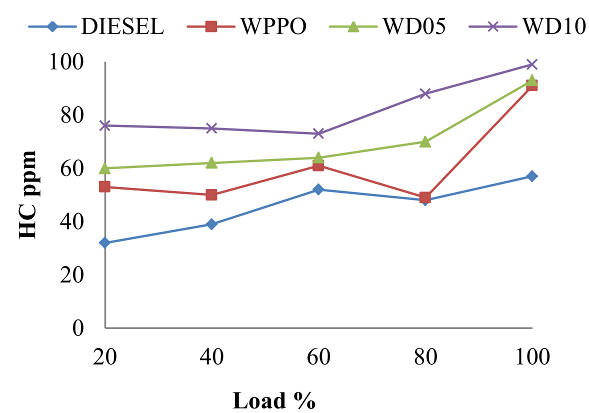

Fig. 4. HC (ppm) vs. Load %.

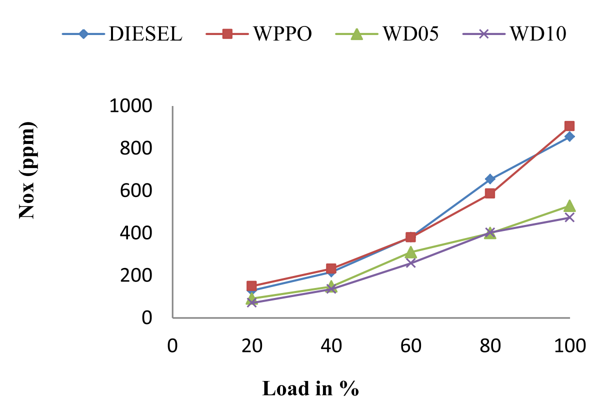

Fig. 5. NO_x (ppm) vs. Load %.

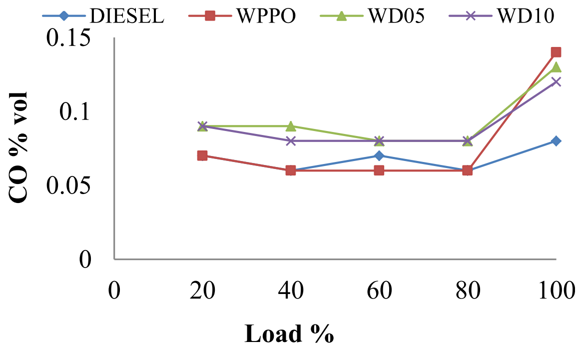

Fig. 6. CO (% vol) vs. Load %.

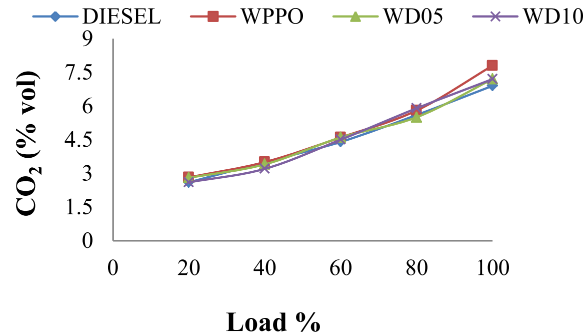

Fig. 8. CO_2 (% vol) vs. Load %.

particularly at medium–high loads, and decreases ignition time and maximum rate of heat release [16–18]. Another factor which causes lower NO emissions is high heat of evaporation of DEE.

3.5. Carbon monoxide

The carbon monoxide, a toxic gas produced during the combustion process, is mainly due to the lack of oxygen, poor air entrainment, mixture preparation and incomplete combustion during the combustion process. The carbon monoxide decreases with increase in blend percentage at full loads due to improved spray atomization [19]. The variation of carbon monoxide with load for diesel, WPPO, WD05, and WD10 are shown in Fig. 6. The amount of CO emitted from diesel varies from 0.07% at 20 percent load and 0.08% at full load. For WPPO, it varies from 0.06% at 20 percent load and 0.14% at full load. For WD05 and WD10, the values are same 0.09% at 20 percent load and at full load are 0.13% and 0.12% respectively. For WPPO, the amount of CO is increasing with the increment in the load. The reason for the increase in CO in case of WPPO, is less in cylinder temperature. The decrease in CO at full load when the mixture is getting increased from WD05 to WD10. This may be due to the availability of oxygen is more, when DEE is added to WPPO.

3.6. Smoke opacity

The soot emitted by all diethyl ether diesel fuel blends is lower than the corresponding neat diesel fuel case, with the reduction being higher, the higher the percentage of DEE in the blend. This may be attributed to the engine running overall leaner, with the combustion being now assisted by the presence of the fuel-bound oxygen of the DEE, even in locally rich zones, which seems to have the dominating influence [20,21]. The smoke opacity of any fuel increases with the increase in load. The smoke opacity of WPPO is higher than that of diesel due to heavier molecules. Fig. 7 shows the curves for smoke opacity with load for diesel, WPPO, WD05, and WD10. The smoke opacity level is 1.7% for 20% load and 53.5% at full load, in case of diesel. In case of WPPO, the value is 2% at 20% load and 55.1% at full load. The smoke opacity for WD05 and WD10 at 20% load is 9.5% and 9.9% and at full load, it is 49.2% and 55.1%. The addition of DEE with WPPO shows reduction in smoke opacity. This is due to the higher oxygen content of DEE depromotes the formation of smoke during the diffusion phase of combustion. The smoke opacity at high load obtained for WD05 and WD10 shows that there is an increment in smoke opacity. This indicates that beyond certain limit the addition of DEE has no effect in reduction of smoke opacity.

3.7. Carbon dioxide

The formation of carbon dioxide at different loads for diesel, WPPO, WD05 and WD10 are shown in Fig. 8. For diesel, it is 2.6% at 20% load and 6.9% at full load. For WPPO, it is 2.87% at 20% load and 7.8% at full load. For WD05 and WD10, it is 2.8% and 2.6% at 20% load and at full load it reaches 7.2% for both. From this, it can be observed that the CO_2 % is increasing in case of WPPO, when compared to diesel. But for WD05 and WD10 the values are not changing at higher loads. This indicates that, the increase in the amount of DEE beyond a certain limit do not affect the formation of CO_2 at higher loads is, due to the presence of reduced amount of carbon to hydrogen ratio and excess oxygen.

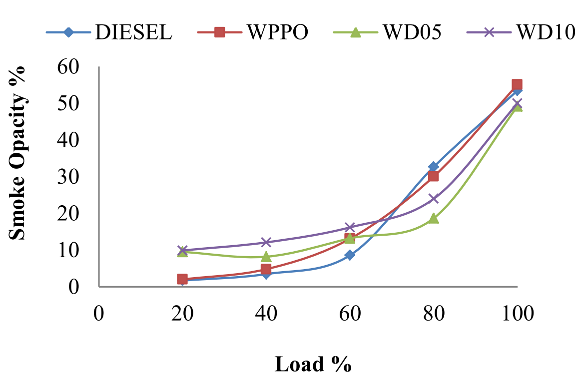

Fig. 7. Smoke opacity % vs. Load %.

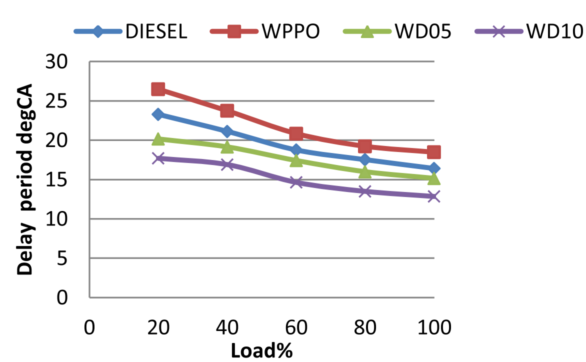

Fig. 9. Delay period °CA vs. Load %.

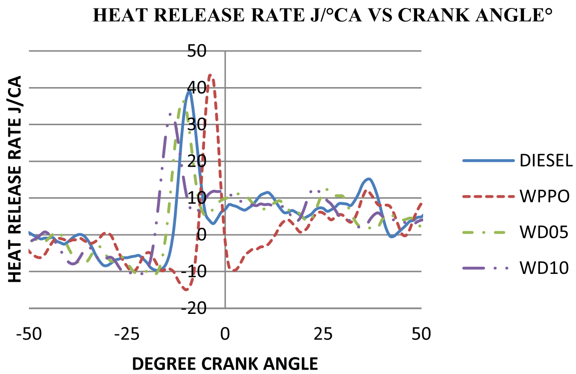

Fig. 10. Heat release rate (J) vs. Crank angle.

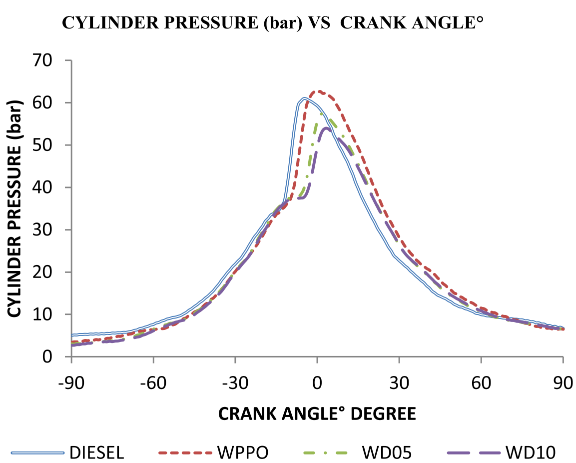

Fig. 11. Cylinder pressure vs. Crank angle deg.

4. Combustion characteristics

4.1. Delay period

The delay period at different engine loads for diesel, WPPO, W05 and WD10 are shown in Fig. 9. As the percentage of DEE in the fuel blend is increased there is decrease in the ignition delay period, this is more pronounced at higher engine loads compared with light loads. The factor which attributes to this may be the higher cetane number of DEE and higher latent heat of vaporization. The higher latent heat of vaporization may become the dominant factor. DEE evaporation will have a great influence on the increase in cylinder temperature and decreased ignition delay. The premixed mixture will increase during the shorter ignition delay and it will lead to an increase in peak pressure of DEE blend. The delay period of waste plastic pyrolysis oil is longer than other fuels and it may be due to high cylinder pressure.

4.2. Heat release rate

The variation of heat release rate at maximum load with crank angle for diesel, WPPO, WD05 and WD10, has shown in Fig. 10. It is observed from the graph that, the maximum heat release rate for Diesel is 39.00 J/deg CA and for WPPO is 43.28 J/deg CA, whereas, for WD05 and WD10, the maximum heat release rate is 36.57 J/deg CA and 32.85 J/deg CA respectively. The maximum heat released in waste plastic oil is high compared to diesel. It can be noticed that in waste plastic oil, most of the heat release occurs only during the premixed combustion. Longer ignition delay results in higher heat release during the premixed combustion phase. The heat release rate is higher in the case of waste plastic oil due to the higher fuel–air ratio. The change in cylinder temperature will also change the ignition delay. This reduction in ignition delay period minimizes the heat release rate. It is observed that the premixed combustion (area under the first 'sharp' peak in the diagram) seems to decline with increasing percentage of DEE, thus leading to lower temperatures during the initial part of the combustion process.

4.3. Cylinder pressure

The variation of cylinder pressure at maximum load at an injection pressure of 215 bar with crank angle for Diesel, WPPO, WD05 and WD10, are shown in Fig. 11. The higher cetane number of DEE shortens ignition delay period when added to fuel [22]. One can observe that with increasing percentage of DEE in the blend, the start of combustion occurs later (the pressure rise due to combustion starts later), while the maximum pressure falls and occurs later. The start of combustion is delayed as a consequence of synergy of the lower dynamic injection timing and increased ignition delay. In a CI engine, the peak pressure depends on the combustion rate in the initial stages, which is influenced by the amount of fuel taking part in the uncontrolled combustion phase that is governed by the delay period. It is also affected by the fuel mixture preparation during the delay period.

5. Error analysis and uncertainty

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. The percentage uncertainties of various parameters like brake power and brake thermal efficiency were calculated using the percentage uncertainties of various instruments given in Table 3. An uncertainty analysis was performed

Table 3
List of instruments used and its uncertainties.

Instruments	Range	Accuracy	Measurement techniques	Percentage uncertainties
AVL Digas 444 Gas Analyzer	CO 0–10%	±0.02%	NDIR	±0.2%
	CO_2 0–20%	±0.03%	NDIR	±0.15%
	HC 0–10,000	±20 ppm	Electro chemical sensor	±0.2%
	NOx 0–5000	±10 ppm	Electro chemical sensor	±0.2%
AVL 437 Smoke Meter smoke	Smoke-BSN 0–10	±0.1		±1%
	Absorption *k m*-10–99.99	±0.01		
Tachometer (speed)	0–10,000 rpm	±10 rpm	Magnetic pickup type	±0.1%
Load	0–100 kg	±0.1 kg	Stain gauge type	±0.2%
Burette		±0.1 cc		±1%
Pressure pickup	0–100 bar	±0.1 kg		±1%
Crank angle encoder		±1°	Magnetic pickup type	±0.2%
Ignition delay				±0.3%

using Equation Total percentage of uncertainty = Square root of {(Uncertainty of TFC)^2 + (Uncertainty of load)^2 + (Uncertainty of brake thermal efficiency)^2 + (Uncertainty of CO)^2 + (Uncertainty of unburned hydrocarbon)^2 + (Uncertainty of CO_2)^2 + (Uncertainty of NO_x)^2 + (Uncertainty of smoke meter)^2 + (Uncertainty of Pressure)^2 + (Uncertainty of speed)^2 + (Uncertainty of burette)^2. The Total percentage of uncertainty is calculated as $\pm$1.612.

6. Results and conclusion

Tests were conducted in a diesel engine, with Diesel, Waste Plastic Pyrolysis Oil, Waste Plastic Pyrolysis Oil mixed with Diethyl Ether and the following conclusions were arrived.

- The waste plastic pyrolysis oil is a suitable fuel for a diesel engine, without any modification made on the engine, and it has the property equivalent to diesel. Addition of DEE with WPPO decreased the viscosity and thereby increased the atomization of air fuel mixture. This was the cause for the enhancement of BTE. The higher BTE was obtained for WD10, than the WD05. The BTE of WD10, at full load was higher than WPPO.
- The brake power for waste plastic oil, is more than that of diesel and for the blends WD05 and WD10, it is little lower than that of WPPO.
- BSFC values of WD blends, become closer to pure diesel fuel BSFC, at high engine speeds.
- HC emissions were found to increase with the addition of DEE with WPPO.
- Higher values of Cetane numbers and high heat of evaporation of DEE parameters led the reduction in the emission of NO_x.
- The CO emissions are lower in the case of DEE blends than that of WPPO.
- Reduced peak pressure and heat release rate were found by increasing the percentage of DEE blended with WPPO.

References

[1] Pugazhvadivu M, Rajagopan S. Investigations on a diesel engine fuelled with biodiesel blends and diethyl ether as an additive. Indian J Sci Technol May 2009;2(5):32–5.
[2] Raja Antony, Murali Advaith. Conversion of plastic wastes into fuels. J Mater Sci Eng 2011;B1:86–9.
[3] Mani M, Subash C, Nagarajan G. Performance, emission and combustion characteristics of a diesel engine using waste plastic oil. Appl Therm Eng 2009;29:2738–44.
[4] Ganapathi P, Robinson Y. Experimental investigation on the performance, emission and combustion characteristics of a diesel engine fuelled with polymer oil–ethanol blends. Int Rev Mech Eng 2013;5(7):919–24.
[5] Cinar Can, Can Özer, Sahin Fatih, Serdar Yucesu H. Effects of premixed diethyl ether (DEE) on combustion and exhaust emissions in an HCCI-DI diesel engine. Appl Therm Eng 2010;30:360–5.
[6] Sayin C, Ilhan M, Canakci M, Gumus M. Effect of injection timing on the exhaust emission of a diesel engine using diesel methanol blends. Renew Energy 2009;82:1367–75.
[7] Hariharan S, Murugan S, Nagarajan G. The effect of diethyl ether on tire pyrolysis oil fueled diesel engine. Fuel 2013;104:109–15.
[8] Jawre Sandip S, Lawankar SM. Performance analysis of Kusim methyl ester as alternative bio fuel in diesel engine with diethyl ether as additive. Int J Innov Res Dev 2014;3:139–44.
[9] Iranmanesh M, Subrahmanyam JP, Babu MKG. The potential of diethyl ether as a blended supplementary oxygenated fuel with biodiesel to improve combustion and emission characteristics of a diesel engine. 2008. SAE Paper 2008-01-1805.
[10] Walendzieuwski Jerzy. Engine fuel derived from waste plastics by thermal treatment. Fuel 2002;81:473–81.
[11] Qi DH, Chen H, Geng LM. Effect of diethyl ether and ethanol additives on the combustion and emission characteristics of biodiesel–diesel blended fuel engine. Renew Energy 2011;36:1252–8.
[12] Purushothaman K, Nagarajan G. Experimental investigation on a C.I. engine using orange oil and orange oil with DEE. Fuel 2009;88:1732–40.
[13] Heywood JB. Internal combustion engine fundamentals. New York, NY: McGraw-Hill Inc.; 1988. 491–514, 676–682.
[14] Karabektas Murat, Ergen Cokhan, Hosoz Murat. The effects of using diethyl ether as additive on the performance and emissions of diesel engine fuelled with CNG. Fuel 2013.
[15] Nagdeote DD, Deshmukh MM. Experimental study of diethyl ether and ethanol additives with biodiesel–diesel blended fuel engine. Int J Emerg Technol Adv Eng 2012;2:195–9.
[16] Akshata DS, Nabavebdra G, Kumarappa S. Performance evaluation of neem biodiesel on CI engine with diethyl ether as additive. Int J Innov Res Sci Eng Technol 2013;8:3729–37.
[17] Kannan TK, Marappan R. Study of performance and emission characteristics of a diesel engine using Thevetia Peruviana biodiesel with diethyl ether blends. Eur J Sci Res 2010;43:563–70.
[18] Xing-Cai L, Jian-Guang Y, Wu-Gao Z, Zhen H. Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel. Fuel 2004;83:2013–20.
[19] Sivalakshmi S, Balusamy T. Effect of biodiesel and its blends with diethyl ether on the combustion, performance and emissions from a diesel engine. Fuel 2013;106:106–10.
[20] Rakopoulos Dimitrios C, Rakopoulos Constantine D, Giakoumis Evangelos G, Dimaratos Athanasios M. Characteristics of performance and emissions in high-speed direct injection diesel engine fueled with diethyl ether/diesel fuel blends. Energy 2012;43:214–24.
[21] Rakopoulos CD, Antonopoulos KA, Rakopoulos DC. Multizone modeling of diesel engine fuels spray development with vegetable oil, biodiesel or diesel fuels. Energy Convers Manag 2006;47:1550–73.
[22] Sachuthananthan B, Jeyachandran K. Combustion performance and emission characteristics of water biodiesel emulsion as fuel with DEE as ignition improver in a DI diesel engine. J Environ Res Dev 2007;2:164–72.