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EXPERIMENTAL STUDY OF OXYGENATED ADDITIVE IN DIESEL-WASTE PLASTIC OIL-PROPANOL BLEND OPERATED IN A SINGLE-CYLINDER DIESEL ENGINE

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Novel fuel blend made of diesel, waste plastic oil, propanol, and di-tert-butyl peroxide (liquid additive) is used in diesel engine thereby diminishing diesel consumption and improving performance and emission characteristics. In this study, diesel was blended with waste plastic oil, propanol, and di-tert-butyl peroxide as liquid additive at different proportions in order to improve its physio-chemical properties. Blend ratios of test fuels used in this work were 100% of Diesel, 80% of Diesel-20% of Waste plastic oil (DW), 70% of Diesel-20% of Waste plastic oil-10% of Propanol (DWP), 60% of Diesel-20% of Waste plastic oil-10% of Propanol-10% of di-tert-butyl peroxide (Additive) (DWPA). On comparing with diesel fuel, average brake specific fuel consumption and brake thermal efficiency of DWPA blend increased by 11.96% and 8.78% respectively, It was also shown that the average brake specific CO and HC emissions of DWPA blend increased by 3.87% and 15.7% respectively, however brake specific NOx and smoke emissions of DWPA blend reduced by 8.08% and 35.36% respectively due to addition of liquid additive as di-tert-butyl peroxide.

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Keywords: Waste plastic oil, Propanol, Di-tert-butyl peroxide, Diesel engine, Emissions, Performance

1. Introduction

Alternate fuels obtained from various plants, vegetables, waste cooking oils, bio-alcohols, animal fats, and waste plastic oils are indispensable fuels used in diesel engines. Petroleum fuels are the major concern in the current and near-future particularly for those nations that are import crude oil [1-4]. Furthermore, it is essential to give attention on alternative energy sources and its biofuel production which replaces conventional petroleum fuels [5-6]. As the development of transportation increases, utilization of alternate fuels necessary for diesel engines in order to downscale the dependence of petroleum products and reduce engine emissions [7]. Diesel engines are renowned for higher brake thermal efficiency (BTE) and less specific fuel consumption (SFC). Bio-oils are widely used in diesel engines with and without engine modification for a longer period [1, 8].

Waste plastic oil (WPO) produced from waste plastics will undoubtedly handle the ecological pollution and issue of landfilling of waste plastics alongside conquering fuel crisis. The raw material cost is zero for WPO production, hence it is hailed to be prospective alternate fuel [9]. Thermochemical conversion, hydrocracking, and catalytic conversion are the widely used methods to produce waste plastic oils. The thermochemical conversion method is viable since it has less moisture content with organic matter. Plastics have low thermal conductivity and high kinematic viscosity which desists the energy and mass transfer in pyrolysis. Solvent addition helps to reduce viscosity from waste plastics [10]. Several studies have stated that the physical and chemical properties of waste plastic oil are close by neat diesel [11, 12]. Furthermore, Studies shows that waste plastic oil can be a fuel for compression ignition engine either by adding

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additives or suitable blending. In this respect, the use of waste plastic oil in diesel engines drive into an essential area of research.

The usage of neat waste plastic oil and its blends with diesel fuel in diesel engine showed very much conflicting results in combustion, performance and emission characteristics along with engine life. Devaraj et al. [13] and Ananthakumar et al. [14] have investigated diethyl ether as fuel additive to waste plastic oil-diesel blends brought about decline in nitrogen oxides, carbon monoxide and smoke emissions alongside reduction in brake thermal efficiency and rise in brake specific fuel consumption. Alcohols addition could decrease the aromatics and sulphur content of the fuel. There is a reduction in exhaust emissions with an additive of butanol to waste plastic oil-diesel blend [15]. Adding butanol also helps to improve spray characteristics, thereby the engine performance has improved. Though, NOx emission increased promptly with an increase in the percentage of butanol [16]. Utilization of dimethoxymethane with neat diesel exhibited a diminishing in particulate matters but, brake thermal efficiency of the diesel engine is low. Difficulties in utilizing waste plastic oil as fuel are lower cetane number, lower calorific value, poor atomization characteristics, high viscosity, and high aromatic content. Furthermore, these difficulties horribly impact performance and emissions [17].

Alcohols are considered as clean fuels since of hydroxyl in their sub-atomic structures. These can be blended with biodiesel, diesel, and vegetable oil. It helps to improve their stability of phase at low temperature [18]. Furthermore, less dense and lower viscous alcohols and vegetable oils blends used in CI engines have increased the usage of microemulsion which is facile process and low cost than transesterification [19, 20]. Lower cetane number is the undesirable property of alcohols, particularly ethanol and methanol are not good alternate fuels [21, 22]. But higher alcohols have a number of carbons which improves overall fuel properties. Thus higher alcohols can be blended with biodiesel more effectively due to higher carbon numbers and it can be better mixing with diesel than lower alcohols [23, 24]. In spite of the fact that alcohols can't be utilized directly in diesel engines, a few fuel properties of alcohols make them appropriate additives for diesel/biodiesel blends [25]. Consequently, alcohols reduce the disfavors of nanoparticle fuel additives, thus replaces nanoparticle additives [26-28]. Hence, it is important to examine every possible alternative fuel in diesel engines.

Butanol (C_4H_9OH) as higher alcohol has oftentimes been used in diesel engines and identified as better mixing with diesel/biodiesel blends [29]. Balamurugan et al. [30] evaluated the influence of blends of butanol-diesel and propanol-diesel on emission and performance characteristics of a diesel engine. Butanol and propanol were blended with diesel of 8% and 4% by volume respectively. Experimental results indicated that brake thermal efficiency increased by 1.6% for butanol, smoke increased by 12.5% and NOx emission decreased by 6.1% for propanol. Li et. al. [31] examined emission and combustion parameters of pentanol-biodiesel-diesel blend fuelled diesel engine. Test results showed that reduction in NOx emission and particulate matters at half loads, whereas there was an increase in NOx emission at full loads when compared with neat diesel.

Use of higher alcohols, waste plastic oil, with diesel fuel reduces the consumption of diesel fuel. Higher alcohols overwhelm the drawbacks of using biodiesel/vegetable oil. Yilmaz et al. [32] experimentally investigated performance and emission parameters of diesel/biodiesel/vegetable oil/alcohol blends fuelled diesel engine. Test fuel used was 70% diesel, 20% biodiesel, 5% vegetable oil, 5% alcohol blend. The tested fuel blend was escalated CO and HC emission, but plunge of NOx emission when compared to diesel fuel, and also it is observed that improved lubricity due to the addition of vegetable oil.

A few investigations was conducted to study the impacts of di-tert-butyl peroxide (DTBP) as a liquid additive. Di-tert-butyl peroxide has low bonding strength which can expedite the auto-ignition process, it also acts as a cetane improver for both gasoline and diesel engines [33]. Mack et al. [34] investigated di-tert-butyl peroxide as an additive blended with ethanol in homogeneous charge compression ignition engine combustion and established that reactivity greatly improved by adding DTBP as additive. Dempsey et al. [35] investigated the effects of di-tert-butyl peroxide on reactivity controlled compression ignition engine and homogeneous charge compression ignition engine combustion processes with ethanol and methanol. Few researchers have also been done kinetic studies of DTBP. Gong et al. [36] and Eng et al. [37] accredited the DTBP as ignition promoter to chemical effects by giving a minute reactive radical at the underlying stage.

1.1. Research objective

Waste plastic oils have a high potential for production and it can be alternate fuel for a diesel engine. Based on the results, it can be implicit that utilizing waste plastic oils can partially replace diesel fuel and can also be lower fossil fuel consumption. The main aim of the present work is to evaluate performance and emission characteristics operating with blends of diesel, waste plastic oil, higher alcohol and a liquid additive which can be a novel alternative fuel blend in an unmodified diesel engine. With this strategic outset, Bio-alcohols, and di-tert-butyl peroxide act as suitable additives and it can be utilized with diesel-waste plastic oils blends which improve the fuel properties. This work explores the combined effect of di-tert-butyl peroxide and propanol to acclimate waste plastic oil-diesel blend as fuel on a single-cylinder diesel engine to analyse performance and emission characteristics of single-cylinder direct injection diesel engine.

2. Test fuels preparation and properties

Waste plastic oil, Propanol, and di-tert-butyl peroxide were procured from Rasha Petroleum (Pvt.) Ltd., Anna Nagar, Chennai. The properties of Diesel, Waste Plastic oil, Propanol, and Di-tert-butyl peroxide were given in Table 1. Many kinds of research recommended the optimum biodiesel blend was 20% [38-40], based on the literature Propanol, and di-tert-butyl peroxide blended with Diesel-20% Waste plastic oil to improve fuel properties [33, 41-43]. Accordingly the following test fuel blends used for experimentation were prepared by the composition 100% of Diesel, 80% of Diesel-20% Waste plastic oil (DW), 70% of Diesel-20% Waste plastic oil-10% of Propanol (DWP), 60% of Diesel-20% Waste plastic oil-10% of Propanol-10% of di-tert-butyl peroxide as liquid Additive (DWPA).

Table 1. Properties of Diesel, Waste Plastic oil, Propanol, Di-tert-butyl peroxide.

Properties	Diesel	Waste Plastic oil	Propanol	Di-tert-butyl peroxide	ASTM Method
Density in gm/cm^3 (at 20ºC)	0.84	0.813	0.809	0.8	D4052
Calorific value in MJ/kg	42	40.35	34	31	D240
Flash point (ºC)	58	38	36	6	D93
Kinematic viscosity in mm^2/s (at 35ºC)	2.81	4.53	2.95	-	D445
Cetane Number	46	54	25	-	D976

The test blends were named as Diesel, DW, DWP and DWPA. Splash blending method (widely used and cheapest) was employed for the preparation of test blends and the test blends were found to be stable mixture at room temperature for 10 days without any phase difference. However, magnetic stirring was performed to the test blends before engine testing. The prepared test fuel blends were tested for physiochemical properties (ASTM standards). Properties of test fuels are shown in Table 2. It is observed that Waste Plastic oil has higher viscosity and density as compared to diesel because of the intricate chemical structure and sizable molecular weight. Cetane number is also one of the significant parameter affecting performance in a diesel engine. Propanol cannot be used in diesel engines directly because of low cetane number. Conversely, waste plastic oil cetane number is higher than propanol and diesel. Similarly, waste plastic oil and propanol have lower calorific values due to presence of oxygen in their molecular structures, which lead the test fuel blends to have lower heating content than neat diesel (DW>DWP>DWPA). The test fuel properties of DWPA were almost similar to neat diesel inferring that the DWPA blend can be an effective alternative fuel for an unmodified diesel engine.

Table 2. Properties of test fuels.

Properties	Diesel	DW	DWP	DWPA	ASTM Method
Density in gm/cm^3 (at 20ºC)	0.84	0.853	0.828	0.833	D4052
Calorific value in MJ/kg	42	40.5	39	37.5	D240
Kinematic viscosity in mm^2/s (at 35ºC)	2.81	3.4	3.2	3.12	D445
Flash point (ºC)	58	90	78	68	D93
Cetane Index (CI)	46	49	47	45	D976

3. Experimental methodology and specifications

The different experiments were carried out on a four-stroke, single-cylinder, water-cooled, direct injection diesel engine (make: Kirloskar) loaded by eddy current dynamometer. Engine specifications are shown in Table 3. Fuel consumption was calculated by stopwatch and burette arrangement. It records the fuel consumption by the time taken for 100cc of fuel in burette during operation. Thermocouples (K-type) were fixed to measure exhaust gas temperatures. Exhaust emissions such as CO, HC, and NOx measured by AVL (444 di-gas) analyzer. Smoke was measure by AVL 437C Smoke meter. All the measuring instruments were calibrated well before experimentation. The test engine setup is illustrated in fig. 1. Experiments were conducted for 20 min in order to meet steady-state conditions between two test fuel operations. Gas analyzer and smoke meter range, accuracy and uncertainties details are given in Table 4. Experiments were repeated three times (average values are engaged in this research work) so as to increase assurance in readings of engine performance and emission parameters.

Table 3. Specification of test engine.

Parameters	Specification
Made	Kirloskar
Cylinder/stroke	Single cylinder, 4S, diesel engine
Type of cooling	Water cooled
Type of injection	Direct injection (DI)
Position	Vertical
Dynamometer	Eddy current
Rated power	5.2 kW
Rated speed	1500 rpm
Compression ratio	17.5:1
Stroke length	110 mm
Bore diameter	87.5 mm
Normal injection pressure	210 bar
Normal injection timing	23^o BTDC

Table 4. Gas analyzer and smoke meter: range, accuracy and uncertainties details.

Gas analyzer type	AVL 444 Di-Gas analyzer range		
Measured Quantity	Range	Accuracy	Uncertainties
CO	0-5000 ppm	0.01%	±0.5 (%)
HC	0-20000	± 10 ppm	±0.1 (%)
NOx	0-5000 ppm	± 10 ppm	±0.3 (%)
Smoke	AVL 437C Smoke meter	0.01%	±1.0 (%)

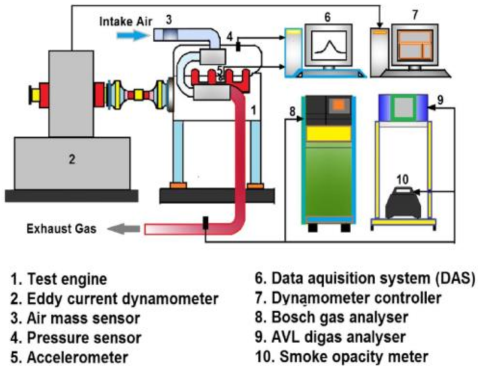

Fig. 1. Test engine setup [54].

4. Results and discussion

In this work, Influence of di-tert-butyl peroxide as a liquid additive in diesel-waste plastic oil-propanol blend operated in a single-cylinder diesel engine performance and emissions was studied experimentally. Research findings with respect to engine load were discussed and reported in detail for performance parameters of brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, and emission parameters of brake specific CO emission, brake specific HC emission, brake specific NOx emission, smoke opacity.

4.1. Brake specific fuel consumption (BSFC)

Fig. 2 shows the variation of brake specific fuel consumption versus engine load. It was found that brake specific fuel consumption decreased with increase in engine loads. Similar trends of BSFCs of DW, DWP and DWPA showed at full load engine operation. Brake specific fuel consumption of diesel, DW, DWP, and DWPA were about 0.254, 0.281, 0.278, and 0.274 kg/kWh respectively at 100% engine load, Due to lower calorific values (see Table 1) of waste plastic oils, propanol and di-tert-butyl peroxide attained BSFCs of DW, DWP and DWPA were higher than neat diesel at all engine loads. Average brake specific fuel consumption of DWP and DWPA increased by 10.2% and 11.9% compared to diesel fuel. The addition of propanol and di-tert-butyl peroxide in the blend have slightly decreasing brake specific fuel consumption. It was due to inherent oxygen molecules in both propanol and di-tert-butyl peroxide additive which enhances the combustion process. Mean BSFC of DWP and DWPA decreased by 5.5% and 4.06% compared to DW fuel because di-tert-butyl peroxide has a lower calorific value (refer Table 1) as compared to propanol. Compared to neat diesel, DWPA requires a higher amount of fuel to produce the same brake power [28]. Furthermore, propanol increases the ignition delay period due to low cetane number, causing better heat transfer to the combustion chamber cylinder wall. Consequently, the available energy can be converted to power output inside the engine cylinder decreased, which leads to higher BSFC [44-45].

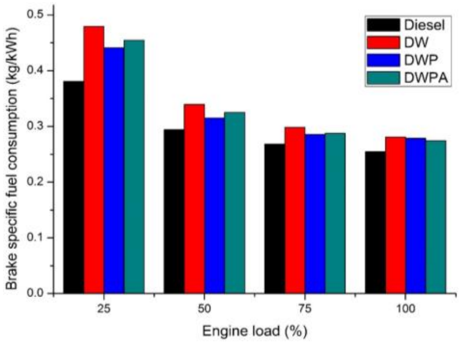

Fig. 2. The variations of BSFC vs engine load.

4.2. Brake thermal efficiency

Brake thermal efficiency (BTE) implies that the engine efficiency to convert the chemical energy of fuel converted into useful engine work output. BTE is closely related to BSFC. Thus, brake thermal efficiency decreases with respect to load as brake specific fuel consumption increases [46]. It is also found that BTE increases with an increase in engine loads, due to lower frictional losses and higher combustion efficiency at peak engine loads. Fig. 3 depicts the variation of brake thermal efficiency versus engine load. Brake thermal efficiency of DWP decreased by 5.36% while DWPA increased by 8.78% than diesel fuel. Brake thermal efficiency values for diesel, DW, DWP, and DWPA are 27.88%, 28.44%, 27.27%, and 29.5% respectively at 100% engine load. From the figure, it is found that the average brake thermal efficiency of DWP is similar to DW, while DWPA increased by 5.15% compared to DW. DWPA exhibit better BTE than DWP because DWP shows lower BSFC (refer Fig. 3). This may be attributed to the higher oxygen contents of di-tert-butyl peroxide, which enhances combustion in the cylinder. Among other test blends, DWPA blend ensued in high BTE due to inherent oxygen could improve the heating capacity and improve premixed combustion. Additionally, the BTE reduces diesel consumption and it is found that DWPA resulted in highest BTE of 29.5% at full load condition. Bencheikh et al. [43] have found similar BTE trend and reported that biodiesel–diesel–propanol blends have higher brake thermal efficiency than diesel fuel.

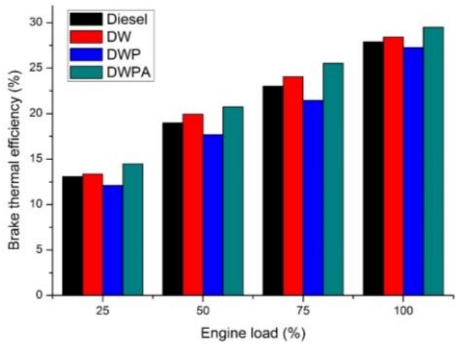

Fig. 3. The variations of BTE vs engine load.

4.3. Exhaust gas temperature

Exhaust gas temperature from diesel engines depends on heat released rate during operation in the combustion chamber within the cylinder which attributes the formation of pollutants. EGT can also be a measure of performance of the engine, available O2 content, and air-fuel ratio. Fig. 4 shows the variations of exhaust gas temperature versus engine load for all test fuels. Exhaust gas temperatures (EGT) of all test fuels were increased with increase in engine load. It is because of higher in-cylinder temperatures owing to higher fuel injection during combustion.

Exhaust gas temperatures of neat diesel, DW, DWP, and DWPA exhibit a similar trend at all engine loads (refer Fig. 4). The mean exhaust gas temperatures of DWP and DWPA increased by 5.81% and 13.8% respectively than diesel fuel owing to the higher oxygen content of chemical structures of propanol. The addition of di-tert-butyl peroxide to DWP blends enhances combustion due to presence of oxygen content which increases exhaust gas temperatures. Exhaust gas temperatures of DWP decreased by 1.13% compared to DW fuel. Higher exhaust gas temperatures rates inside the engine cylinder cause dilution of residual gases resulting in lowered exhaust gas temperatures [51].

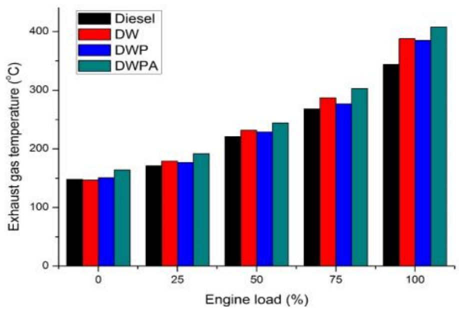

Fig. 4. The variations of EGT vs engine load.

4.4. CO emission

Deficiency of oxygen inside the combustion chamber during operation or insufficient air/fuel ratio are the major reasons for the formation of CO emission. [46, 47]. Fig. 5 depicts the variation of brake specific CO emission versus engine load. Average CO emission of DWPA increased by 3.87% than diesel fuel, it is because of its higher density and kinematic viscosity. Ignition delay also increased due to the increase in the size of fuel droplets, which leads to lower evaporation rate causes formation of CO emission [48, 49]. Brake specific CO emission of DWP decreased by 5.54% while DWPA increased by 3.87% than diesel fuel. Brake specific CO emission values for diesel, DW, DWP, and DWPA are 2.82, 2.52, 2.56, and 2.9 g/kWh respectively at 100% engine load. From the figure, it is found that average brake CO emission of DWP is similar to DW, while DWPA increased by 14.15% compared to DW. DWP gives less CO emission than DWPA because additives have higher latent heat of evaporation causes better combustion. Sharon et al. [50], obtained similar results on single-cylinder diesel engine and reported that higher brake specific CO emissions at high loads and lower at low loads for palm oil biodiesel-butanol-diesel blends than neat diesel. It is due to the higher latent heat of evaporation of higher alcohol and high kinematic viscosity of palm oil biodiesel. The addition of di-tert-butyl peroxide to DWPA gives more oxygen content to the DWP blends, which helps increasing in-cylinder temperature, result in higher brake specific CO emissions.

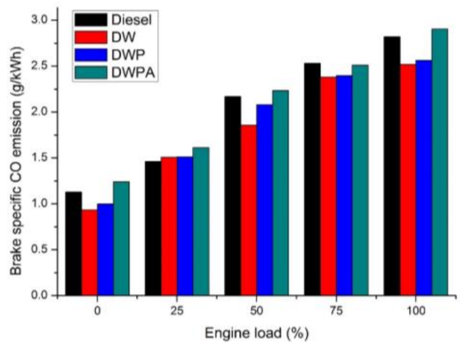

Fig. 5. The variations of brake specific CO emission vs engine load.

4.5. HC emission

Unburnt hydrocarbons are harmful emission due to unburnt residues in the combustion chamber which causes incomplete combustion. Other reasons for formation of hydrocarbons are misfires, deposits in wall quenching, crevice volumes flame quenching and absorption of oil. Fig. 6 shows the variations of brake specific HC emission versus engine load for all test fuels. Similar to carbon monoxide emissions, Brake specific HC emission of DWP increased by 15.78% while DWPA increased by 25.38% than diesel fuel. Brake specific CO emission values for diesel, DW, DWP, and DWPA are 0.316, 0.299, 0.389, and 0.442 g/kWh respectively at 100% engine load. From the figure, it is found that the average brake HC emission of DWA and DWPA are higher than diesel. DWP gives less HC emission than DWPA because blended di-tert-butyl peroxide additives make higher latent heat of evaporation. Sharon et al. [50], obtained similar results on single-cylinder diesel engine and reported that higher brake specific HC emissions at high loads and lower at low loads for palm oil biodiesel-butanol-diesel blends than neat diesel. Higher cetane number of propanol, which prompts intense fuel penetration over cylinder wall amid the long period of ignition delay causing quenching effect which furthermore results in higher hydrocarbon emissions. Test fuels with higher viscosity impair the atomization process and result in higher HC emissions [52].

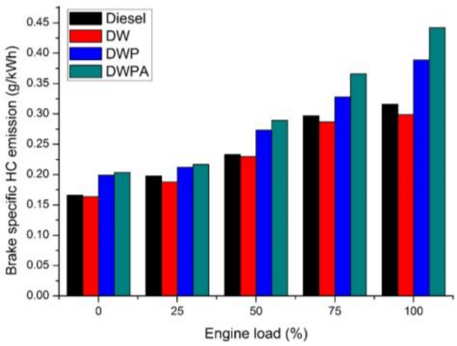

Fig. 6. The variations of brake specific HC emission vs engine load.

4.6. NOx emission

Nitrogen oxides are composed of nitric oxide (90%), nitrogen dioxide (5%), and nitric oxide (5%). Formation of NOx mainly in three ways, (i) by oxidation, (ii) by thermal NOx, (iii) by intermediate species. Oxides of nitrogen emission is also a function of combustion temperature, oxygen concentration and retention time [53]. Formation of oxides of nitrogen emission increases with increase in peak temperatures. Fig. 7 indicates the variations of brake specific NOx emission versus engine load for all test fuels. NOx emissions of all test fuels were increased with increase in engine load. It is because of higher in-cylinder temperatures results in higher NOx emissions. Brake specific NOx emission of DWP and DWPA decreased by 7.26% and 2.2% respectively than diesel fuel. Similarly, Brake specific NOx emission of DWP and DWPA decreased by 13.23% and 8.08% respectively than DW fuel Comparing these two results DWP test fuel offer a better reduction in NOx emission. This is because more heat absorbed during vaporization of propanol and di-tert-butyl peroxide additives have high latent heat and lower calorific value. Consequently, combustion peak temperatures decreased, which controlled NOx emission of DWP than DWPA. Brake specific NOx emission values for diesel, DW, DWP, and DWPA are 10.588, 11.378, 9.017, and 10.193 g/kWh respectively at 100% engine load. From the figure, it is also found that average brake NOx emission of DWA and DWPA are much lower than diesel. DWP gives less NOx emission than DWPA because blended additives make higher latent heat of evaporation causes higher peak temperature. The principle purpose behind this can be credited to the low cetane number of DWPA. Low cetane number prompts injection of more fuel into engine cylinder on the grounds that the grouping of NOx is dependent on oxygen availability. NOx emissions of DWPA and DWP show almost similar trends for all engine loads compared with neat diesel.

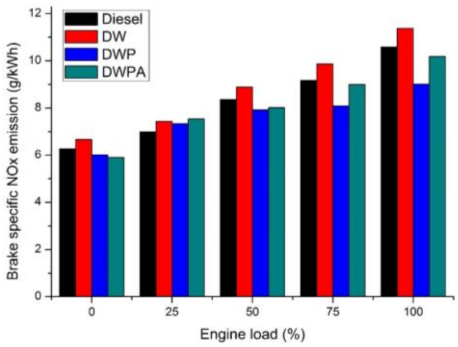

Fig. 7. The variations of brake specific NOx emission vs engine load.

4.7. Smoke opacity

There are different factors accountable for the formation of smoke emission in diesel engines. They are poor combustion, atomization, injection parameters and oxygen deficiency. Fig. 8 shows the variations of smoke opacity versus engine load for all the test fuels. Smoke emission of DWPA and DWP decreased by 35.36% and 24.39% respectively than diesel fuel. Similarly, Smoke emission of DWPA and DWP decreased by 24.28% and 11.43% respectively than DW fuel. Comparing these two results DWPA test fuel offer a better reduction in smoke emission. Smoke emission values for diesel, DW, DWP, and DWPA are 1.3, 1.2, 1.1, and 0.9 BSU respectively at 100% engine load. It is inferred that at lower loads, the smoke emission is lower due to O_2 enriched zones during engine operation, whereas at higher loads, at higher load, more fuel atomization increases the smoke emission considerably. Smoke emissions of all test fuels were increased with increase in engine load due to the average fuel droplet size increases which consequently influences smoke emission formation. Propanol and di-tert-butyl peroxide additive blends have oxygen inherently in their molecular structure guiding to a lower fraction of unburnt fuel during engine operation. As the di-tert-butyl peroxide additive increases in the diesel-waste plastic oil-propanol blend, there is more reduction in smoke emission observed. Venu et al. [51] obtained similar results by addition of alcohols to ternary blends in a direct injection diesel engine eventually reducing smoke emissions due to oxygenated additives in fuel blends.

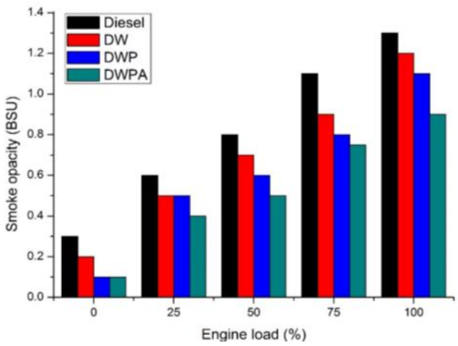

Fig. 8. The variations of smoke opacity vs engine load.

5. Conclusions

The present experimental investigation deals with diesel-waste plastic oil-propanol fuel blend operation in engine with di-tert-butyl peroxide liquid additive blends. A higher percentage of alternative fuels used in diesel engines along with diesel is appreciated from economic and environmental aspects. Thus, propanol and di-tert-butyl peroxide act as suitable additives and it can be utilized with diesel-waste plastic oils blends which improve the fuel properties. This work also explores the combined effect of di-tert-butyl peroxide and propanol to acclimate waste plastic oil-diesel blend as fuel on a single-cylinder diesel engine to analyse performance and emission characteristics of single-cylinder direct injection diesel engine. The experimental results were compared with DW and diesel fuel. Major conclusions were observed from this study are:

- The diesel engine operated with DWPA and DWP fuel could be a better alternative fuel without any negative effects during engine operation.
- The addition of di-tert-butyl peroxide and propanol to diesel-waste plastic oil-propanol blends forbid high kinematic viscosity and high density which improves the fuel properties.
- Average brake specific fuel consumption of DWP and DWPA increased by 10.2% and 11.9% than neat diesel.
- The mean exhaust gas temperatures of DWP and DWPA increased by 5.81% and 13.8% respectively than diesel fuel owing to the higher oxygen content of chemical structures of di-tert-butyl peroxide.
- The addition of di-tert-butyl peroxide to diesel-waste plastic oil-propanol blends causes CO and HC emissions increased by 3.87% and 25.38% respectively due to liquid additive has lower cetane numbers and higher latent heat of evaporation.
- While NOx emission and smoke opacity of DWPA found to be decreased by 13.23% and 35.36% respectively.

Based on the experimental findings, DWPA fuel gives better performance characteristics and reduced NOx emission, whereas DWP fuel is well suitable for NOx and smoke emission reduction. Hence it is concluded that both DWPA and DWP could be alternative fuel to diesel fuel.

Nomenclature

DW	: 80% Diesel-20% Waste plastic oil
DWP	: 70% Diesel-20% Waste plastic oil-10% Propanol
DWPA	: 60% Diesel-20% Waste plastic oil-10% Propanol-10% Di-tert-butyl peroxide
CO	: Carbon Monoxide
HC	: Hydrocarbon
NOx	: Oxides of nitrogen
BTE	: Brake thermal efficiency
BSFC	: Brake specific fuel consumption
WPO	: Waste plastic oil
DTBP	: Di-tert-butyl peroxide
ASTM	: American Society for Testing and Materials
EGT	: Exhaust gas temperatures

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