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Experimental Investigation of CRDI Engine Characteristic using Waste Plastic Oil as Fuel.

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Abstract

Prices of fossil fuels are heightening day by day. Stringent emission norms, escalation in energy demand and depletion of traditional fuels, forced the researchers to find alternative for internal combustion engines. On the other hand utilization of plastic products in various fields has tremendously increased and globally it has contributed a lot for economic growth, but its indispensable nature confronting viable environment. Presence of hydrocarbons in waste plastic products grabs the attention of researchers in recycling and converting them into liquid fuel. Properties of oil derived from waste plastics are close to that of conventional fuels used in internal combustion engines. This experimental study attempts to investigate the performance emissions and combustion characterises of common rail direct injection (CRDI) engine fuelled with waste plastic oil and diesel blends. The experiments are carried out with 10, 20 and 30% of diesel blended with waste plastic oil on volume basis. The investigations are carried out at a constant speed of 2000 rpm with load varying from 20 to 80%. Results illustrate that 9.23 % decrement of brake thermal efficiency and increment of 16.35% in NOx emissions are perceived when contrasted with diesel.

Keywords: CRDI Engine, Waste Plastic Oil, Diesel, BTE, BSFC, NOx

Introduction

Conventional fuels are fading out notoriously to meet the needs of rapid industrialization. Immense usage of automobiles globally has increased the prices of fuels and likewise, the heightened emissions which are having a pessimistic effect on global warming, on another hand, Industrial, Transport, Agriculture, and many other sectors have owned diesel engines because of their versatile properties. Massive research was going on, to find an appropriate alternative to the conventional fuels; large varieties of vegetable seeds were converted as oils and used as fuels in the engines for experimental investigations. As the days passing by a debate came into the plot, whether the priority should be given for food or fuel, and the burdensome expenditure for converting and using palatable oils that led the researchers to work on non-edible oils, alcohols, and other alternates. In this scenario, energy from waste

has captivated the attention of researchers. Especially plastic wastes are getting accumulated in tonnes day by day, its inalienable and non-biodegradability properties are creating a burdensome affair for human beings, animals as well for sea creatures. This current research has attempted conversion of plastic wastes into fuel, which will be a promising solution for plastic waste deposition and as well addressing fuel scarcity problems [1].

For the economic evolution of any country transportation plays a major role and in that sector, most of the automobiles are mechanized by direct injection diesel engines. Due to diverse benefits like admirable fuel economy and high power to density ratio than indirect injection systems and spark ignition engines [2]. Further improvements in the CI engine can be done by escalating the fuel injection pressures and optimizing injection strategies. The affability of changing injection strategies was not possible in a mechanical fuel injection system. Common Rail Direct Injection (CRDI) engines are very advantageous over a mechanical, unit and other injection systems; it comprises a high-pressure reservoir which delivers the fuel at lofty pressures using a high-pressure fuel pump. Fuel from the reservoir will be directed to all the cylinders by high-pressure pipes and solenoid injectors, which willbe monitored by the Engine Control Unit [3]. Ali Turkcan et al [4] investigated the influence of high ethanol proportion in Animal-Based (AB) and Vegetable-Based (VB) biodiesel-diesel blends in CRDI engine and stated that there was an increment in brake specific fuel consumption of VB ternary blend of about 11% for E25VB20 (20% of vegetable biodiesel with blend and 25% bioethanol in diesel) and 13.5% for E35VB20 (20% of vegetable biodiesel with blend and 35% bioethanol respectively in diesel). Despite the increase inBSFC the thermal efficiency of the blends was escalated to 3% and 4.4% for the blends respectively were contrasted to diesel. Declining of Oxides of Nitrogen (NOx), smoke emissions are noticed while the engine is operating with AB blends under high load conditions. Carbon Monoxide (CO) emissions were escalated by increasing bioethanol concentration in the blend. Kim et al [5] from their experiments on CRDI engine has noticed that triple blended fuel gave lesser Total Hydrocarbons (THC) emissions than dual blends, blend used was B15E5D80 (15% biodiesel, 5% ethanol, 80% diesel) and B20D80 (20% biodiesel and 80% diesel). Yang et al [6] carried his research by using Tung oil-diesel- ethanol- microemulsion fuel in CRDI diesel engine, from the results he noticed that micro emulsification was an optimum technique to bring down the viscosity of Tung-diesel-ethanol blend which is adjacent to diesel fuel, Brake Thermal Efficiency (BTE) for DT30E40(The Tung oil/ diesel blend is the baseline fuel, in which the volume fraction of Tung oil is 30% (denoted as DT30) and ethanol is 40%), and DT30E20(Diesel tung blend a30%, Ethanol 20%) was little higher because of higher oxygen content and micro-explosion effect. The smoke emissions for micro emulsion fuel were low at high engine speeds but almost similarto diesel fuel at lower engine speeds. NOx emissions were increased at higher engine speeds whereas the CO and HC emissions were similar to that of diesel. Anil Bhaurao Wakale et al [7] studied the effects of different injection strategies of a CRDI engine by using n-butanol and diesel blends at various proportions like 5%, 10%, and 20% by volume; from his baseline experiments, he has noticed that little drop of peak cylinder pressure by using the n-butanol blend. With the aid of spilt- injection strategy, the ignition delay got reducedand this lead to a 35% diminishment of NOx emissions at 20% blend concentration. Chemical sensitivity scrutiny determines that n-butanol acts as an important sink of OH radicals, hence it delays OH inducted ignition peak by 2 0CA, which leads to a reduction of flame temperatures, and that helps in the suppression of NOx emissions. Archit S. Ayodhya et al [8] has conducted experimental investigations with waste plastic oil fuel blends by using the Selective Catalytic Reduction (SCR) technique on CRDI engine and has noticed that rhodium coated ceramic SCR can be successfully imparted on the diesel engine for reduction of NOx emissions, operating temperature range of SCR was about 2400-25000 C, which means it can be used on light motor vehicles effectively. Anand Ramanathan et al [9] has investigated on the usage of waste engine oil as a fuel in CRDI engine by using Microwave-Assisted Pyrolysis Process (MAP), from the results he concluded that BTE augmented by 3.6% and 4.4% in CDRI contrasted to diesel and Microwave pyrolysis oil (MPO) in mechanical injection, NOx and smoke emissions came down drastically by 50% and 54%. Radheshyam et al [10] have witnessed the effects of 1- pentanol addition and Exhaust Gas Analyser(EGR) in CDRI engine, from results he has concluded that in-cylinder pressure, Mean Gas Temperature (MGT), Net Heat release rate (NHR) got declined at lower loads and NOx emissions came down by the addition of 1- pentanol additive in CRDI Diesel engine. Shair et al [11] carried out experiments on the CRDI engine by using animal fat biodiesel blends; BTE of the biodiesel was higher till the blend proportion reached 30%. Emission parameters such as CO, HC, and NOx were escalating to the higher side by increasing the percentage of biodiesel content in the blend. Yilmaz et al [12] has conducted their experimental investigations on CRDI engine by using ethanol-diesel blends as fuel, ethanol concentration in blends were ranging from 3%, 5% 15%, and up to 25% respectively.CO and HC emissions were escalating to a higher rate as the ethanol percentage increased in the blend. However, NOx emissions were appreciably decreased for the blends when correlated to diesel fuel. Krishna Chaitanya et al [13] has conducted experiments on 4-stroke 4-cylinder CRDI by using waste plastic oil and diesel blends as fuel. Results depict that a slight increment of BTE was noticed for the blend WPO30D70 (30% Waste Plastic oil + 70% diesel). Peak in-cylinder pressures and higher heat release rates were noticed for the blend P100 (100% Waste plastic oil) because of the prolonged ignition delay period which in turn leads to an increase in NOx emissions. As the proportion of WPO increased in the blend, the HC and CO emissions escalated to a higher level when contrasted to neat diesel. Santhosh et al [14] carried out experiments on the CRDI engine by using 1-Pentanol-diesel blends with Exhaust Gas Recirculation (EGR) technique and estimated the performance and emission characteristics. Results depict that the influence of EGR was having a pessimistic effect on BTE and maximum diminishment was noticed for the blend P30D70 (30% of 1-pentanol+ 70% of diesel). HC and CO emissions were increased as the 1-pentanol proportion increased in the blend; this may be attributed to a lower cetane number of alcohol fuels. However effect of EGR was having a positive effect on NOx emissions, it got drastically decreased for all the 1-Pentanol blends when correlated to neat diesel. Table: 1 Summary of works on Performance and Emissions of CRDI Engine.

Table: 1 Summary of works on Performance and Emissions of CRDI Engine.

Re f no	ngineused	Fuel used	3T E	SFC	NO x	HC	CO	IRR	Smoke opaci Ty	Remarks
[4]	CRDI Diesel engine	Animal based and Vegetablebased biodiesel blends	↑	↑	↑	↓	↓	↑	↓	Bioethanol-biodiesel-diesel ternary

		E25VB20 E35VB20								blends can reduce the particulate matter, diesel smoke simultaneously without sacrificing the thermal efficiency
[5]	CRDI Diesel engine	Biodiesel& bioethanol blended diesel fuel with nano particle additives B15E5D80, B20D80	↑	↑	↑	↓	↓	↑	↑	Triple blended fuelgave better BTE & lower hydrocarbo n emissionsthan dual blended fuel
[6]	Turbo charged CRDI Engine	Tung oil-diesel Ethanol blends (DT30E20,DT30E40)	↑	↑	↑	=	=	↑	↓	Micro emulsification is the method used to reduce the viscosity of the blends
[7]	CRDI Diesel Engine	n-butanol /diesel blends 5%,10%,20% (by vol)	↓	↑	↓	↓	↓	↓	↓	Advanced injection strategy reduces the emissions and makes the engine performanc e better
[8]	CRDI Diesel engine	1-Pentanol Diesel Blends 10%,20% 30%	↓	↑	↓	↑	↑	↓	↑	EGR helpsin diminishment of NOx emissions drastically
[9]	Single Cylinder , Four Stroke	waste engine oil	↑	↓	↓	↑	↑	↓	↓	CRDI improves atomization and

	,CRDI assisted Diesel engine									escalates the injection duration period leadsto decreaseof heat release rate
[10]	CRDI Diesel Engine	1-pentanol with diesel, at 5%, 10%, 20%, 30% and 40%,	↓	↑	↓	↑	↑	↓	↑	Increase in pentanol concentration and EGR rate, delay period increases for all the blends.
[11]	CRDI Diesel Engine	Animal fat basedbio-diesel B10 B20 B30 B40 B50	↑	↓	↑	↓	↓	↑	↑	30% Concentrati on of animalfat bio- diesel was found to be an optimumone. CO, NOx, HC values were escalating by increasing concentration of bio- diesel in the blend
[12]	CRDI Diesel Engine	Diesel Ethanol blends, 3%,5%, 15% and 25%	↑	↓	↓	↑	↑	↓	↓	As the blend concentration increases, viscosity increases, which leadsto higher heat release rates
[13]	4-S 4-Cylindered CRDI	Waste Plastic oil-diesel Blends.	↑	↓	↓	↑	↑	↓	↑	Due to higher viscosity of

	Diesel Engine									the blend, combustion was not proper
[14]	Single Cylinder4-SCRDI Engine	1-Pentanol P10,P20,P30 + EGR Technique	↓	↑	↓	↑	↑	↓	↑	BTE decreased because ofthe influence of EGR

From the literature survey it is known that various vegetable oils, alcohols and additives are blended with diesel in minor proportions and used as an alternative fuels. The objective of this experimental investigation is to use waste plastic oil in major portions along with diesel in minor proportions and estimate the performance, emissions and combustion characteristics of common rail direct injection (CRDI) engine.

Materials and methods

Preparing of Waste Plastic oil by Pyrolysis Process

In recent times, applications of plastic products have tremendously heightened because of its versatile properties. Endurance, design flexibility and lighter weight of plastics havecontributed a lot in industrial sector. On the other hand, plastic wastes are shaping up a serious environmental issue, because of its non-biodegradable nature. Rather participatingin bio-degradation, plastic wastes are converting into plastic dust and entering into food chain and building complicated health issues.

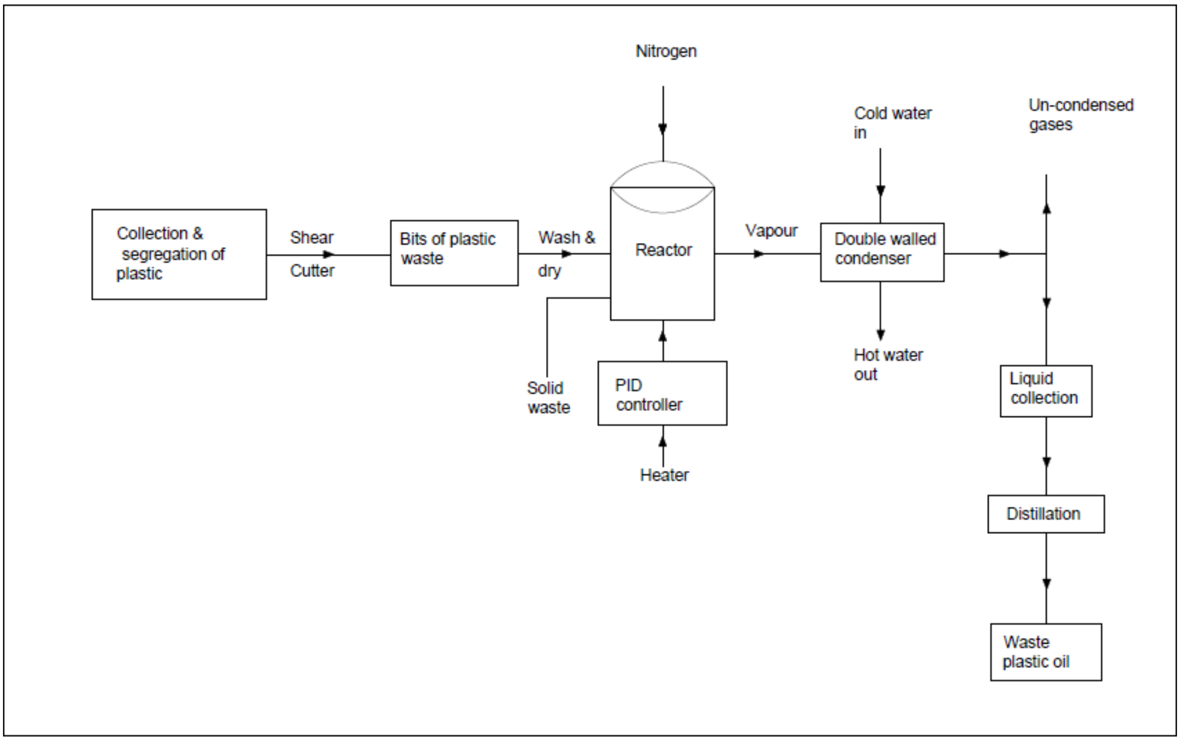

Figure 1: Layout of Waste Plastic Oil Production

A Chemical process named pyrolysis is safest practice to convert waste plastic into hydrocarbon fuel. Plastic wastes collected from different resources are shredded into pieces and cleansed thoroughly before pyrolysis process. The shredded pieces are headed towards a reactor, where it undergoes a thermal degradation process in the absence of oxygen. The plastic wastes are treated with a temperature range of 400-480^{0}C, and a catalyst named Zeolite Socony Mobil-5 (ZSM-5) is added to carry the process. Vapours are entrapped from the reactor and sent to the double- walled condenser, where water is used as a coolant. The condensate received from the condenser is collected and stored in a separate tank. The Schematic diagram of productionof WPO is shown in figure 1.

Preparation of blends

Three blends are prepared by adding diesel to waste plastic oil at various volume proportions of 10, 20 and 30%. Blends are named as D30WPO70, D20WPO80, and D10WPO90. In which the blend (D30WPO70) contains 30% of diesel and 70% of waste plastic oil by volume and likewise the other blends follows. The blends are prepared by usingboth the through mixing of diesel and waste plastic oil upto 30 minutes. No Phase separationwas identified for the blends during the experimental investigation. Properties of diesel and waste plastic oil are listed in the table 2.

Table-2 Properties of Blended Fuels

Fuel Properties	**Test Methods**	**Diesel**	**Waste PlasticOil (WPO).**	**D30WPO70**	**D20WPO80**	**D10WPO90**
Density (kg/m3)	ASTM D4052	834	910	842	857	868
alorific value (MJ/kg)	ASTMD240	45.4	38.3	42.5	40.4	39
Kinematic viscosity (cSt)	ASTMD445	2.72	3.68	2.86	3.12	3.4
Flash Point (°C)	ASTM D93	51	62	53	56	58
Cetane Number	ASTM D 613 05	53	44	48	46.2	45.4

Experimental setup:

Experimental Investigations are conducted on a 4-stroke four cylindered CRDI (Common Rail Direct Injection) diesel engine coupled by ECU (Electronic Control Unit), which aids in operating and controlling different parameters. Engine is loaded with eddy current dynamometer and software named "Enginesoft" is supported to record the performance and combustion characteristics. K type and PT-100 are the two temperatures sensors equipped to record high and low temperatures of the engine respectively. Engine speed is read by a proximity sensor in rpm. Rotameters are arranged in the engine to estimate the water flow rate in Lpm. The schematic diagram of experimental setup is shown in Figure 2. The detailed technical specifications of the engine are provided in Table 3. An AVL 444-5 gas analyser is used to analyse exhaust gas emissions with suitable filters. To ward off the engine from enigmatic conditions loading is restricted to 80%.

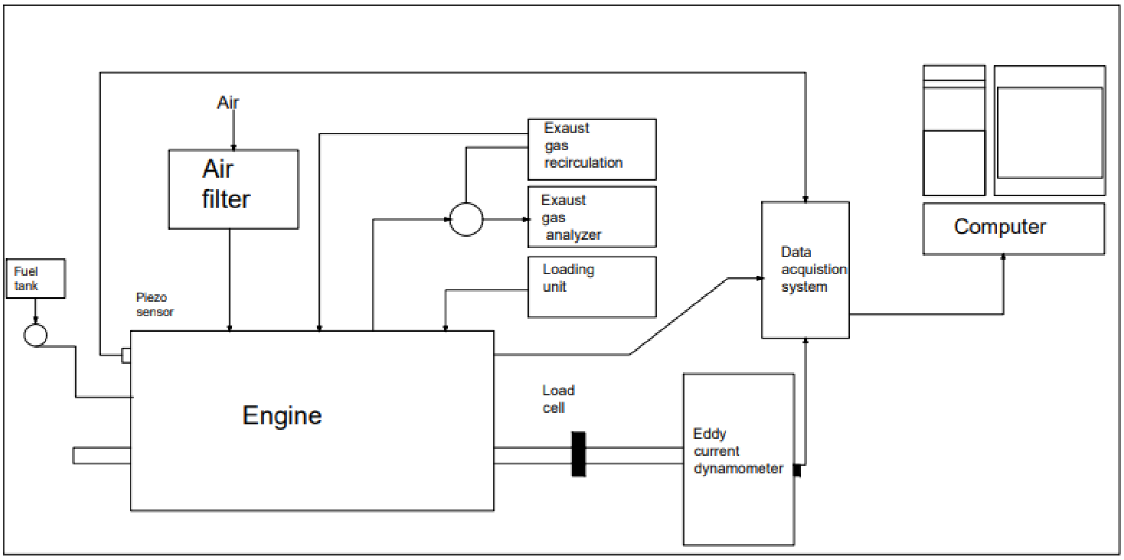

Figure 2: Schematic Diagram of Test Rig

Table 3: Detailed technical specification of Experimental setup

Parameter	Specification
Make	Maruti
Model	Swift Dzire
No of Cylinder	4 cylinder
Swept Volume	1248 CC
Power Rating	190Nm @ 2000RPM
Compression Ratio	18:1
Injection Timing	13^0 BTDC
Injection Type	Common Rail (CRDI)
Dynamometer	Eddy Current Dynamometer

Results and Discussions

Cylinder Pressure

Figure 3 depicts the variation of cylinder pressure with crank angle at 80% load for dieseland WPO blends. The cylinder pressures obtained for WPO, D30WPO70, D20WPO80, and D10WPO90 are high when contrasted with neat diesel fuel. From the figure moratorium of combustion is perceived for WPO-Diesel blends when correlated to diesel fuel, and this might be the reason for attaining peak cylinder pressures for WPO-Diesel Blends. Peak cylinder pressures such as 74.3 bar, 75.9 bar, 77.8 bar, 79.2 bar and 85.4 bar is obtained for diesel, D30WPO70, D20WPO80, D10WPO90 and WPO respectively. Peak cylinder pressures for WPO-Diesel blends are majorly due to the higher viscosity, lower

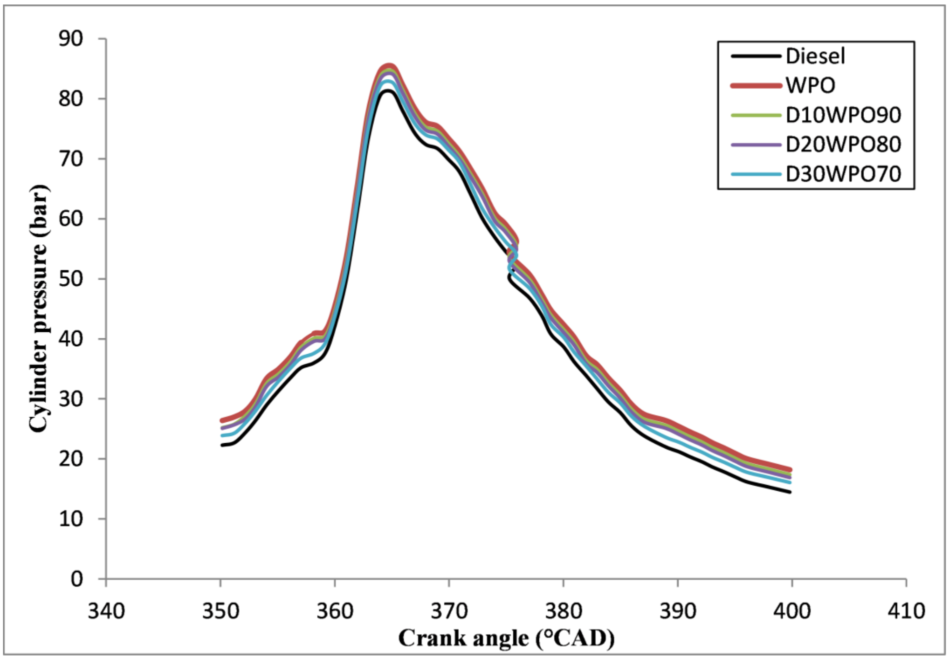

Figure 3: Variation of Cylinder Pressure Vs Crank Angle

cetane number. Higher viscosity of WPO offers poor atomization and spraying of fuel at the time of fuel injection and lower cetane number broadens the ignition delay period that differs in beginning of combustion when contrasted to diesel and drives the cylinder pressures to a higher range when correlated with diesel [15].

Heat Release Rates

Figure 4 shows the variation of heat release rates with crank angle for diesel and WPO blends at 80% load. At initial conditions the duration of combustion was long and lower heat release rates were obtained for diesel and WPO-Blends. Peak heat release rates such as
86.4 J/deg, 93.3 J/deg, 104.2 J/deg, 110.5 J/deg and 117.3 J/deg is obtained for diesel, D30WPO70, D20WPO80, D10WPO90 and WPO respectively. Maximum heat release ratefor pure WPO is perceived when contrasted to other blends and neat diesel because of longer ignition delay period. Premixed combustion is another important factor that influences the heat release rates for WPO to maximum. As the WPO percentage escalates in the blend oxygen content also increases and leads to increase of cylinder temperatures and thereby hikes the heat release rates [16].

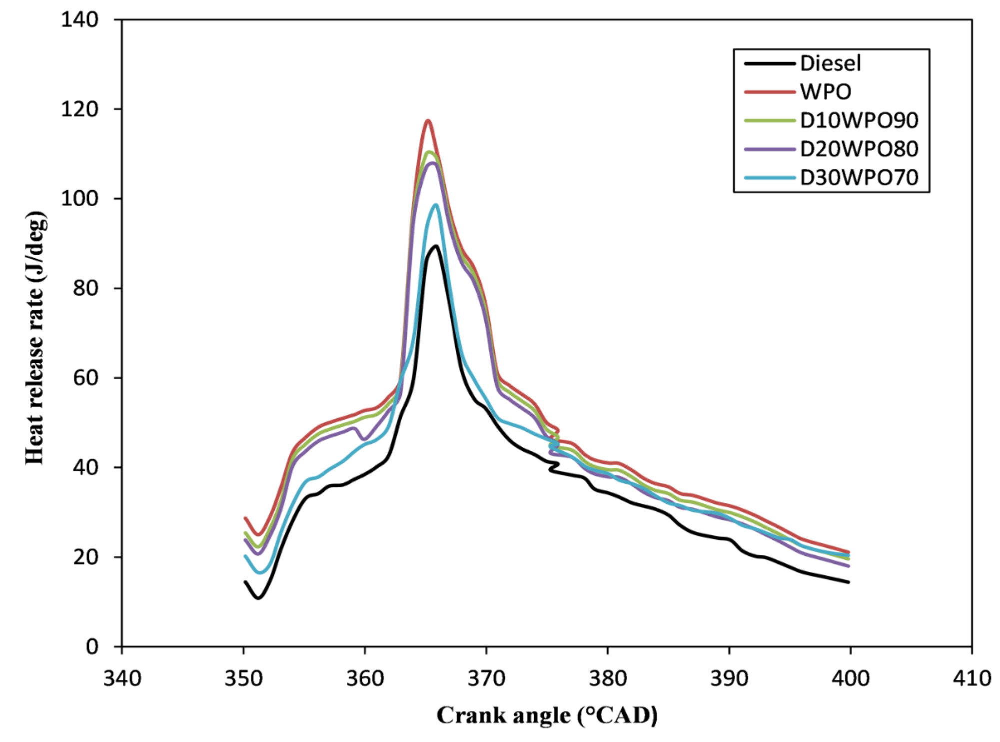

Figure 4: Variation of Heat Release Rates Vs Crank Angle

Ignition Delay

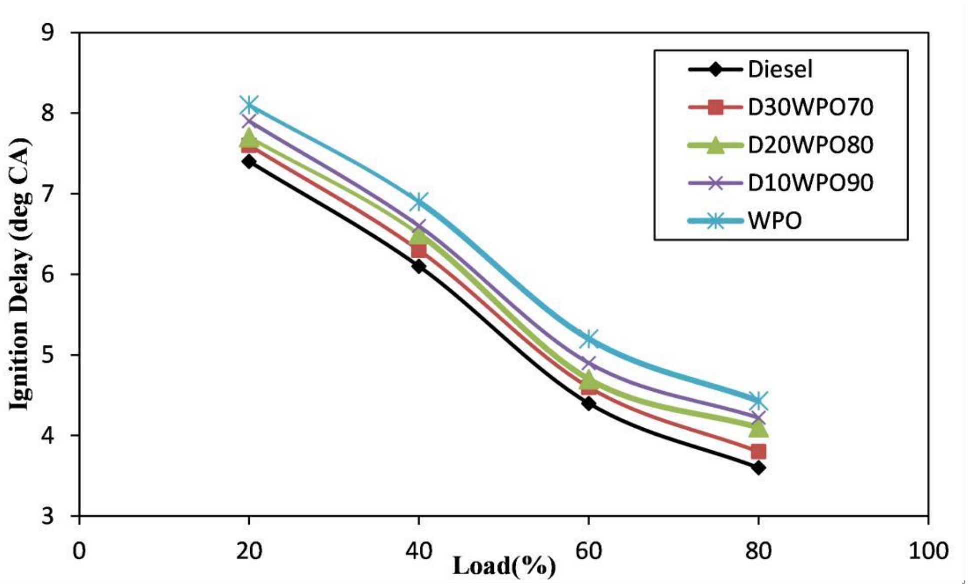

Figure 5: Variation of Ignition Delay Period with Load

Variations of ignition delay with respect to load for diesel and WPO-diesel blends are shown in the figure 5. It is defined as the time delay (indicated in crank angle) between the inception of injection and the dawning of combustion. Ignition delay is highly influenced by cetane number, viscosity and density of the fuel. From the figure it is observed that ignition delay for WPO and WPO-diesel blends are substantially longer than diesel fuel. As the load on the

engine increased the ignition delay was shortened. At 80% load the ignition delay is noticed as 3.6 ^{0}CA, 3.8 ^{0}CA. 4.1 ^{0}CA, 4.3 ^{0}CA and 4.43 ^{0}CA for diesel, D30WPO70, D20WPO80,
D10WPO90 and WPO respectively. Higher viscosity and density of WPO affects the vaporization and atomization of fuel at the instance of combustion and leads to delay in combustion. As the WPO content in the blend increased the depression in cetane number further elevated, which is also a reason for prolonged ignition delay when contrasted to diesel [17].

Brake Thermal Efficiency

Figure 6 depicts the variations of Brake Thermal Efficiency (BTE) with load for diesel, WPO- diesel blends. BTE evaluates how efficiently an engine transforms the heat from a fuel to mechanical energy [13]. As the load on the engine escalates the BTE also increases for the test fuels. At 80% load BTE for diesel, D30WPO70, D20WPO80, D10WPO90 and WPO is perceived as 42.4%, 38.1%, 35.9%, 33.2% and 32% respectively. As the WPO content increases in the blend the reduction of BTE is noticed, this is mainly due to higher

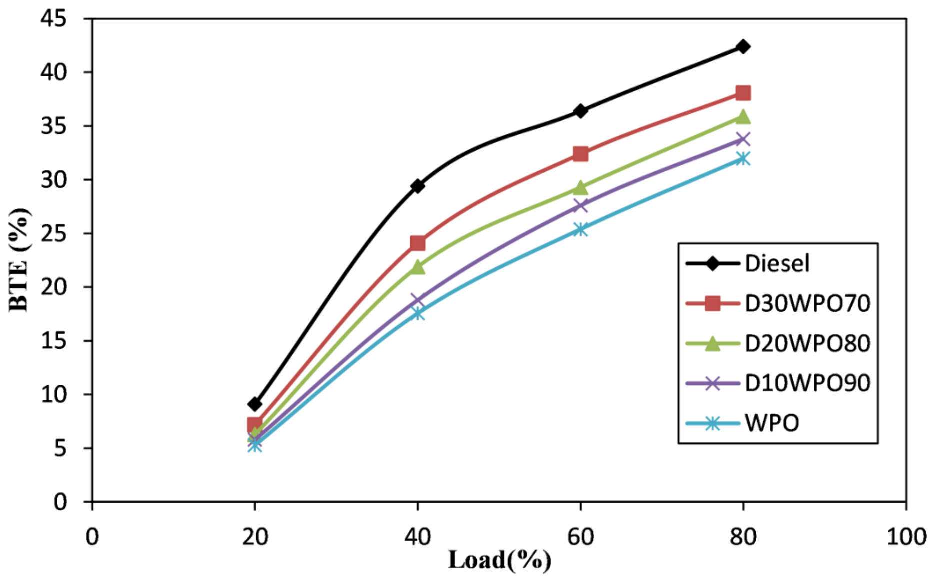

Figure 6: Variations of BTE with load

viscosity of WPO when contrasted to diesel, which affects the atomization and vaporization of fuel during combustion and in turn leads to lower BTE [18].From the figure 2 it is observed that WPO attains higher heat release rates than other blends, major amount of heat is carried away by exhaust gases, this might be the other reason for reduction of BTE for neat WPO when correlated with other blends.

Brake Specific Fuel Consumption

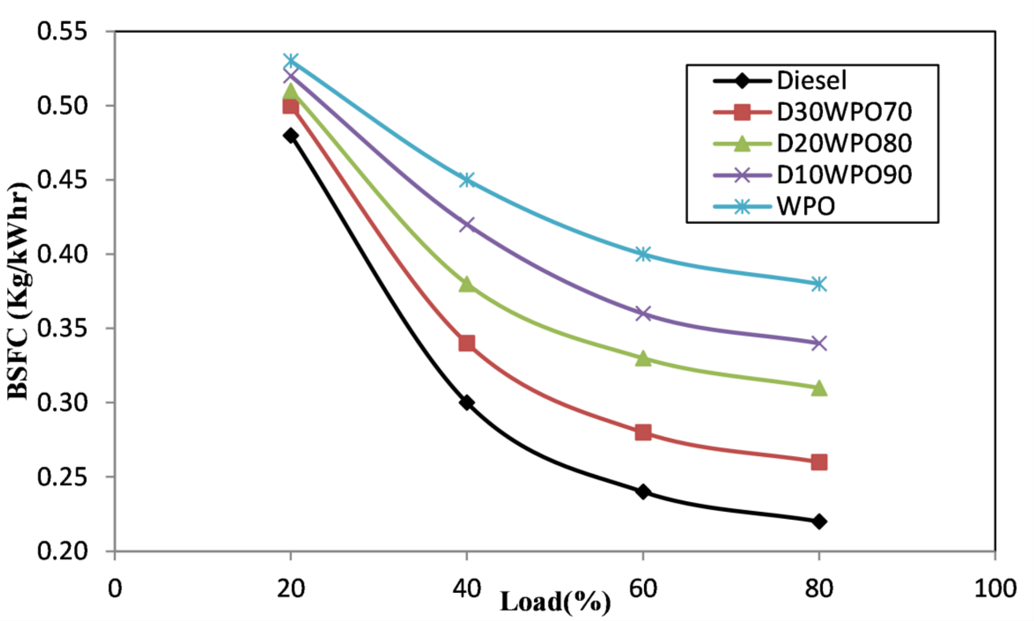

Figure 7: Variations of BSFC with load

Variations of Brake Specific Fuel Consumption (BSFC) with respect to load for diesel and WPO-diesel blends are shown in the figure 7. At 80% load BSFC for diesel, D30WPO70, D20WPO80, D10WPO90 and WPO is noticed as 0.22 kg/kWh, 0.26 kg/kWh, 0.31 kg/kWh,
0.34 kg/kWh and 0.38 kg/kWh respectively. As the WPO concentration in the blend increases, increment in BSFC is perceived; this is due to lower cetane number and high density of WPO when contrasted with diesel. Pure WPO attains higher BSFC because it consumes more amount of fuel to produce similar output as compared with WPO-blends anddiesel [13].

Hydrocarbon Emissions

Figure 8 depicts the variations of Hydrocarbons with load for diesel, WPO-diesel blends. Occurrence of Hydrocarbon emissions is mainly due to presence of gaseous hydrocarbons on the cylinder walls and in crevices, they remain unburned because of improper flame propagation is those areas. Variations of HC emissions with respect to load for diesel and WPO-diesel blends are shown in figure. As the load on the engine increase, reduction of HC emissions is noticed for all the test fuels. At higher loads HC emissions for diesel,

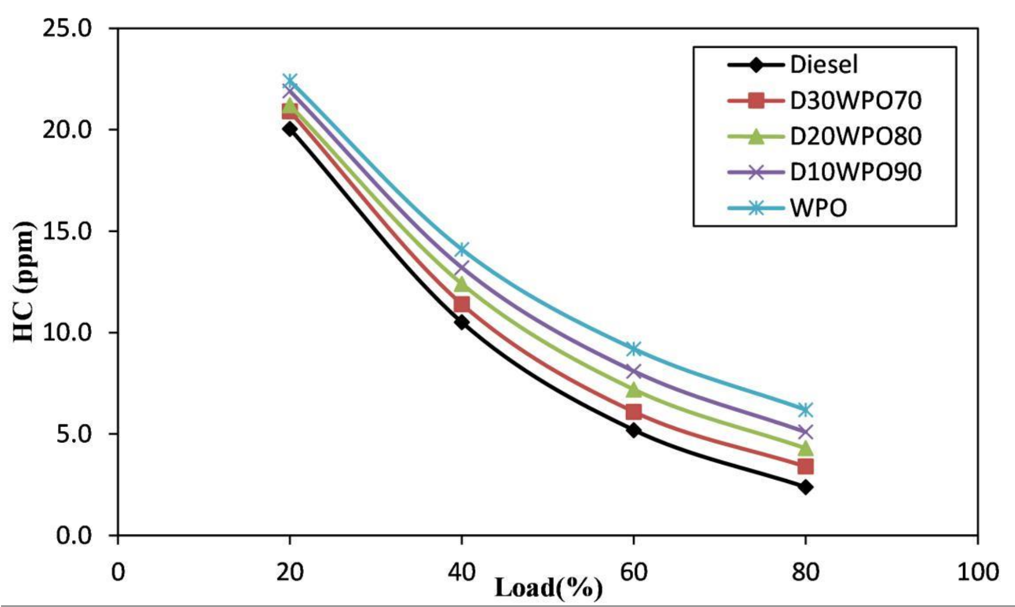

Figure 8: Variations of HC with load

D30WPO70, D20WPO80, D10WPO90 and WPO is observed as 2.4PPM, 3.3PPM, 4.3PPM.5.1PPM and 6.2PPM respectively. HC emissions for neat WPO is high when compared with other blends, this is due to aromatic nature of WPO and in addition to thisrich and lean air fuel mixtures with insufficient oxygen might be the reason for higher HC emissions [17].

Carbon monoxide Emissions

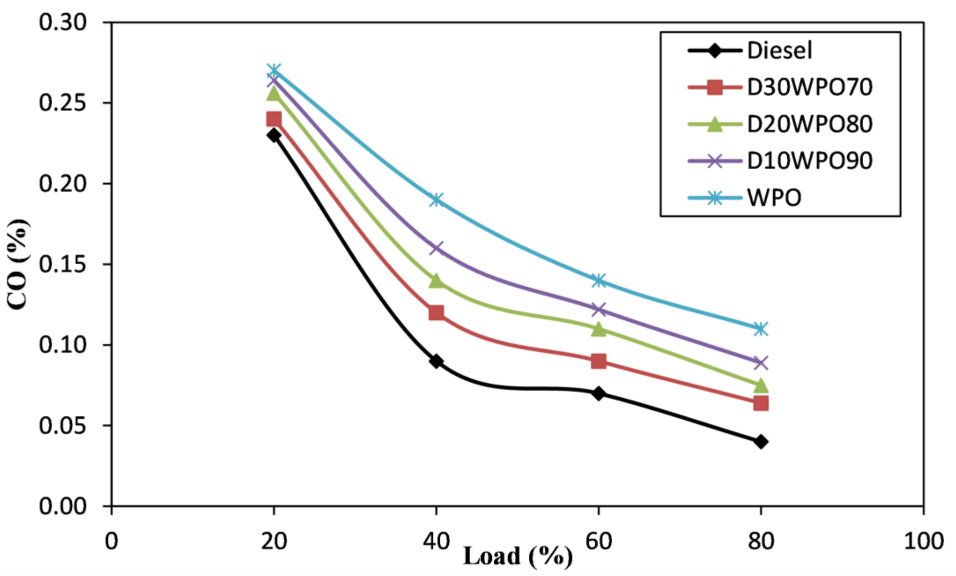

Figure 9: Variations of CO with load

Variations of carbon monoxide with respect to load for diesel and WPO-diesel blends are shown in the figure 9. Formation of Carbon monoxide emissions is mainly due to insufficient oxygen content, poor air entrainment and improper combustion. Variations of carbon monoxide with respect to load for diesel and WPO-diesel blends are shown in the figure. At 80% load CO emissions such as 0.04%, 0.064%, 0.075%, 0.089% and 0.11% is perceivedfor diesel, D30WPO70, D20WPO80, D10WPO90 and WPO respectively. From the figure it is observed that CO emissions for WPO, WPO-diesel blends are higher when contrasted with diesel, this is attributed to impoverished mixture preparation in the combustion chamber. At lower engine loads CO emissions are high as the load on the engine increments, the combustion temperatures increases and aids in oxidation of CO into Carbon-dioxide (CO_2) this is an another reason for diminishment of CO emissions [13&18].

Oxides of Nitrogen Emission

Figure 10 depicts the variation of Oxides of Nitrogen (NO_x) with respect to load for diesel and WPO-diesel blends. . It is perceived that the NO_x emission for neat WPO is higher thandiesel throughout the engine loading.

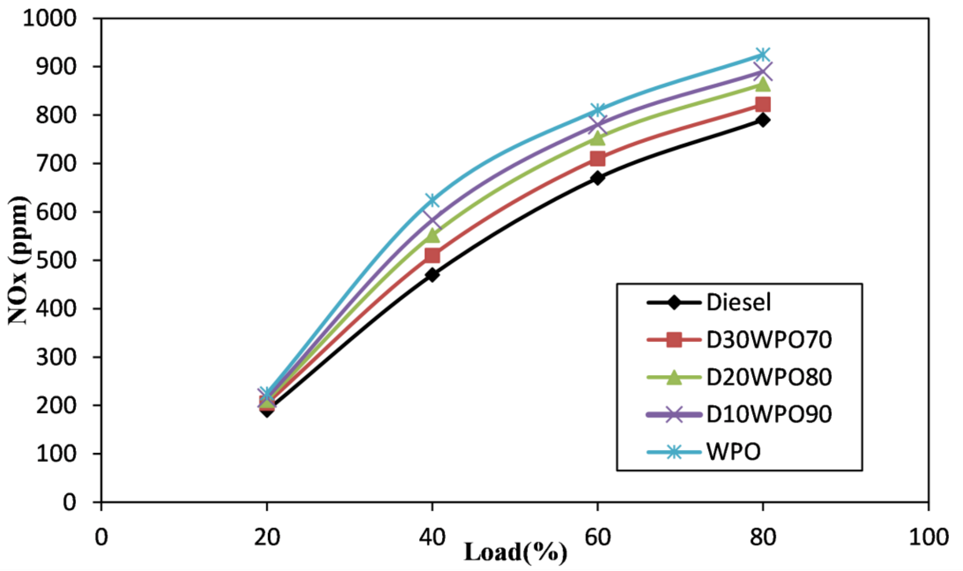

Figure 10: Variations of NOx with load

At 80% load, the NO_x emissions such as 790 PPM, 822 PPM, 864 PPM, 890 PPM and 925 PPM is perceived for diesel, D30WPO70, D20WPO80, D10WPO90 and WPO respectively, this is because at higher engine loads increment in the cylinder temperatures are noticed and in addition to this availability of oxygen percentage in WPO and WPO blends leads tothe increment in NO_x emissions when contrasted with diesel. Prolonged ignition delay of WPO and WPO blends promotes premixed combustion and this is another reason for escalated NO_x emissions when correlated with diesel [19].

Conclusions

From the last decade, research was done with WPO and WPO-Diesel blends on single cylinder diesel engines and Variable ratio compression ratios engines. However the Waste Plastic oil (WPO) blending percentages with diesel fuel was limited to (10%, 20% 30%) by volume. In this investigation an attempt is made by blending 70%, 80%, 90% WPO with diesel fuel and 100% neat WPO is used as fuel in four stroke four cylinder CRDI engine and the following conclusions are drawn from the results and discussions.

1. Engine operation was found smooth and steady throughout the experimental investigation by using 100% WPO as fuel.
2. Higher in-cylinder pressures and heat release rates are noticed for WPO when contrasted with diesel. This may be attributed to high viscosity and lower cetane number of WPO, which leads to poor atomization and spraying of fuel at the time of combustion.
3. Prolonged ignition delay is perceived for WPO blends when compared with neat diesel, this is because of lower cetane index of WPO blends.
4. Curtail in BTE is noticed for all WPO-Diesel blends, when contrasted with neat diesel. Maximum diminishment of 24.5% is perceived for pure WPO when compared with diesel.
5. BSFC got escalated with almost all the blends when compared with diesel, a bump in values of viscosity for the blends is major reason for heightening of BSFC values.
6. All WPO-diesel Blends presented higher NOx emissions when contrasted to diesel, this may be attributed to the high viscosity of WPO and prolonged ignition delay period, which leads to hike in cylinder pressure and heat release rates for WPO which results in increment in NOx emissions.

From observations, it is concluded that WPO can be used as a fuel in diesel engine without any engine modifications. Reduction in performance and combustion characteristics is observed for WPO and WPO-diesel blends when compared with neat diesel. however further investigations can be carried out by using alcohol additives, cetane improvers for enhancing the performance characterises of CRDI Engine.

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