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Experimental investigation of emission parameters of diesel engine fueled with various plastic pyrolysis oils

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Abstract

Plastic has various advantages and is becoming more ubiquitous by the year, yet recycling and disposal remain challenges for the world. We conduct tests in this study to evaluate the appropriateness of various Plastic Pyrolysis Oils (PPOs) made from Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), and Polypropylene (PP) for diesel engine fuel. Determine which type of plastic pyrolysis oil would function best as an alternative fuel in an experimental investigation. The elemental composition of pyrolysis oil generated from LDPE, HDPE, and PP to diesel was assessed, tabulated, and compared in this study. This study examines emission characteristics (Nitrogen Oxide (NO_X), Hydro Carbon (HC), and Carbon Monoxide (CO)) for Diesel, LDPE, HDPE and PP in CI engines using different injection pressure, compression ratio, and load in a specific configuration. In the result of experimental work the CO emission range for diesel and LDPE is exceeded only during overload situations or when the engine load is 100%. The average NO_X emission is lowest when PP is used in comparison to other fuels, and the highest NO_X emission occurs when LDPE is utilised as a fuel. Increased fumigation rates may be to blame for the rising hydrocarbon content of plastic oil. Unburned hydrocarbon levels are lower at lighter loads due to increased oxygen availability. The use of this whole pyrolysis oil results in a significant decrease in Nitrogen Oxide (NO_X), Hydro Carbon (HC), and Carbon Monoxide (CO) exhaust emissions. With the help of this current study. one can solve plastic waste disposal problem and also find any unknown fuel (PPOs) that can be used as an alternative fuel for CI engine or not.

Keywords: Pyrolysis Process, Diesel Engine, Exhaust emissions (Nitrogen Oxide (NO_X), Hydro Carbon (HC), and Carbon Monoxide (CO)), Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), and Polypropylene (PP)

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1. Introduction

In our society, it is common practice to toss away food in plastic bags. Animals searching for food get the food in plastic bags and they consume food with plastic that is not digestible, and the storage of this plastic in their stomach leads to the development of cancer's cell in their bodies. The majority of plastic garbage ends up in landfills, where it forms a layer in the soil, due to plastic layer preventing rainwater from reaching the required depth and crops from receiving sufficient nutrients from the soil. Storage of petroleum product is limited and as per the current usage; it will become empty in nearest future, so required to find alternative option of petroleum products. Inter molecular structure of plastic material having long chain of carbon and hydrogen and during the combustion of carbon can get energy. And in the current work with the help of pyrolysis process fuel generated from different types of waste plastic and used in Diesel engine and tested for performance and emission of the engine. With using waste plastic fuel in engine, can reduce the waste plastic goes into land filling, to save the life of animal by awareness in society and also satisfy the scarcity of petroleum product.

Plastics are regularly used in both home and business settings all over the world. Plastics have the benefit of being easy to produce, lightweight, and cost-effective (Andrady and Neat, 2009). Plastics have grown more acceptable for usage that requires competitively greater strength and thermal stability as a result of polymer technology development (Preston, 1981). While Europe consumed 50 million tonnes of plastic in 2016, only 27.3 million tonnes of post-consumer waste were collected under the stated plan (Hopewell et. al, 2009). According to the data, just around half of the plastics used have been collected as garbage. Effective recycling can help everyone get closer to that 100% target. Reduced consumption, reuse, recycling plastics, and energy recovery are listed in decreasing order of environmental safety, with landfill being the least safe option (Friedberger et. al, 2016). Innovative plastic recycling has been made feasible by a range of cutting-edge innovations, such as chemically recyclable polymers. Huang and Guan et al. reported manufacturing waxes and liquid fuels from several types of polyethylene materials (diesel) under relatively simple conditions (Huang et. al, 2016).

Our study intends to turn solid plastic garbage into PPO for diesel engines and make it useful. Pyrolysis at 400°C to 900°C or catalytic pyrolysis can be used to achieve effective pyrolysis. According to Sorumetal's kinetic studies, the energy of dissociation in a single C-C bond is 347 KJ/mol, but 611 KJ/mol in a double C=C bond (Sørum et. al, 2001) For our research, we examined some of the most commonly used plastics, such as HDPE, LDPE, and PP, which account for 65% of worldwide resin demand (Kahraman et. al, 2017). Ali Kharam and colleagues investigated the emissions and performance of a 4-stroke, single-cylinder, water-cooled, direct-injection CI engine. Bio ethanol was shown to increase the BSFC of binary mix fuels by 30.6%. Volumetric efficiency is increased by 3.7%. When compared to diesel fuel, a fuel with a high bioethanol concentration reduced CO and NO emissions by 80% and 31.3%, respectively (Attar et. al, 2016). According to Peyyala et al., the BSFC of B10 is larger than B20 when load circumstances increase (Peyyala et al, 2013). According to a research by Xue et al., reducing PM, CO, and HC emissions from diesel engines resulted in a modest loss of power, an increase in fuel consumption, and NOx emissions that were greater than diesel. Cumali Ilklç et al. discovered that B5, B20, and B50 fuels outperform diesel fuel by 2.2%, 6.3%, and 11.2%, respectively (Ilkılıç et. al, 2011) Madi'c and Radovanovi'c employed Taguchi's DOE technique to optimise an ANN trained model using the Levenberg-Marquardt algorithm. The prediction accuracy of the Taguchi optimised ANN model was good (Madi'c et. al, 2011). Kazancoglu et al. proposed using Taguchi's technique in combination with BPNN in a wire cut electron discharge machining process to reduce surface roughness. The expected values were quite close to the trial values (Kazancoglu et al, 2002).

Moosavi et al. investigated the influence of various factors on the realisation of wavelet-ANFIS and wavelet-ANN hybrid models. Every model contains numerous layers; Taguchi's technique (Moosavi et al, 2017) was used to determine the best structures prototype. Drilling characteristics of 2nd generation hybrid composites were explored by Adalarasan and coworkers. To optimise the drilling parameters, a Taguchi-based response surface technique with an L18 orthogonal array was applied (Adalarasan et. al, 2011). Khoualdia et al. proposed an ANN-based monitoring and verification system for gear-bearing combination failure prediction. Grey-Taguchi technique and Taguchi standard orthogonal array were used as multi-objective optimisation approaches to get the best ANN model design (Khoualdia et al, 2012). Padhi et al. created sophisticated components (FDM) using fused deposition modelling. Taguchi's technique using ANN to evaluate the accuracy for the dimensions of FDM-fabricated components under various operating conditions. The predicted values from the models matched the experimental data (Padhi et. al, 2017).

Sahare et al. enhanced the end milling technique for Al2024-T4 work piece material. Input process parameters were cutting fluid flow rate, cutting speed, feed per tooth, and depth of cut. The response parameters were material removal rates, surface roughness, and cutting force. The findings demonstrated that ANN combined with Taguchi's method was appropriate for amending (Sahare et. al, 2018). Patel and Bhatt employed Taguchi's design of experiments approach to determine the parameter's optimal set of ANN trained using feed forward back-propagation. To demonstrate the approach's execution, a prediction model of a similar stress for a car chassis is employed. After the network has been trained, the optimal values of the ANN parameters are derived based on the performance statistics. When the Taguchi approach is employed to optimise the parameters, the ANN outperforms random parameter values (Patel and Bhatt, 2018).

Simplex-lattice design optimization to assess the impact of blending pentanol and biodiesel made from neem oil into pure diesel with a volume percentage of 70%. Their result shows that most of the engine performance was significantly improved by adding pentanol to the diesel-Neem biodiesel (Sulaiman et al. 2021). fibre reinforcement composition of 38.3 wt% and fibre reinforcement length of 3 mm produced the optimum Epoxy-Deleb palm fibre composite with tensile modulus of 260.365 MPa, the tensile strength of 12.485 MPa, the flexural strength of 25.704 MPa, impact energy of 0.882 J, and water absorption of 0.369%. Deleb palm fibre have effect on the physio-mechanical properties of the Epoxy-Delab fibre composite (Iliyasu et al. 2022). The analysis proposed an optimal solution of 75 wt% zeolite 4A and 25 wt% zeolite 13X, which gave a desirability of 0.944 (Sowunmi et al. 2022). The ANOVA result showed that, at a confidence interval of 5%, the effects of the fiber characteristics on the physio-mechanical properties of the composites were particularly notable for tensile strength and a decrease in water absorption (Oyedeji et al. 2022). Any unknown fuel can be analyzed if used as an alternative fuel or not with the help of chromatography technique. From the literature review it can be concluded that comparison of different types of PPOs with Diesel fuel in the CI Engine for performance and emission characteristics reported less.

2. Pyrolysis process and experimental methodology

Pyrolysis Process
The Pyrolysis setup is shown in Figure 1.

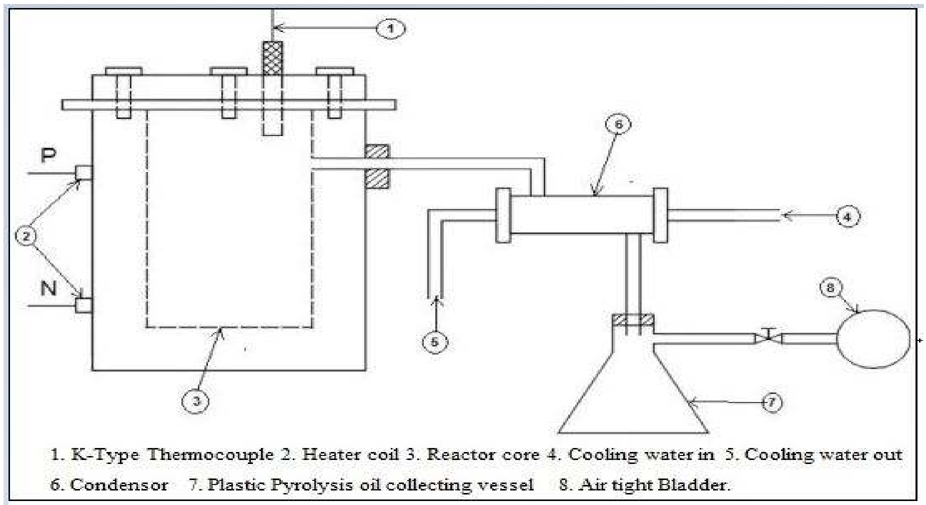

Figure 1: Pyrolysis process setup

Different types of plastic waste used as a raw material in the pyrolysis process to produce waste plastic pyrolysis oil. Pyrolysis is a process of temperature decomposition of organic material in the absence of oxygen. Closed container selected inside that waste plastic filled then heat given from the bottom of container, vapour of plastic waste cooled inside the condenser at the bottom of condenser plastic pyrolysis oil collected in a bottle (Figure 2).

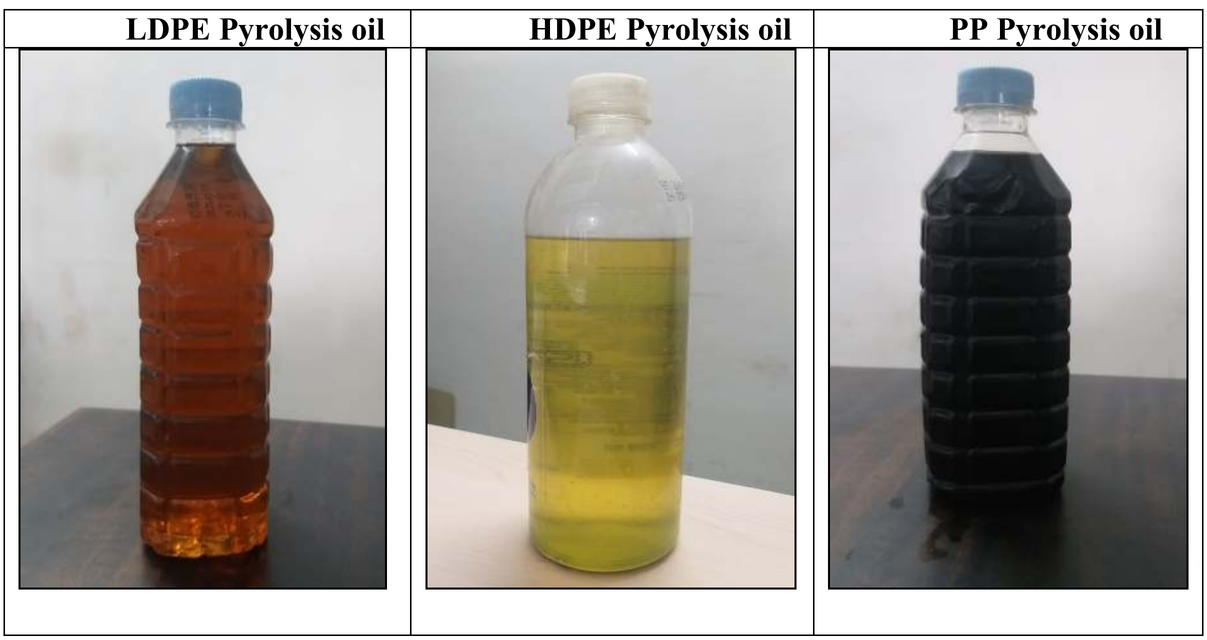

Figure 2. Pyrolysis oil used in experiment.

The pyrolysis process is used to create pyrolysis oil from plastic trash. In the absence of oxygen, it is the thermo chemical breakdown of an organic material. Plastic waste may be pyrolyzed to make fuel for internal combustion engines. This method of disposal is hygienic, environmentally friendly, and efficient. With the help of plastic Pyrolysis process fuel produced and tested in engine for emission characteristics. The structure of macromolecular polymers is broken down into smaller molecules and, on occasion, monomer units during the plastic pyrolysis process. Many process parameters, such as residence time, temperature, the presence of a catalyst, and others, can impact how these molecules degrade in the future. Both a catalyst and one that does not are used in the pyrolysis reaction. Thermal and catalytic pyrolysis will occur. Plastic trash is continuously treated in a pyrolysis chamber.

Cracking happens when polymer chains are broken down into smaller molecular weight compounds at high temperatures with minimal oxygen. There are three distinct cracking processes that have been reported: hydro cracking, thermal cracking, and catalytic cracking. In order to produce gasoline-based items, At moderate temperatures and pressures, hydro cracking of polymer waste typically comprises a stirring batch autoclave reaction with hydrogen over a catalyst. Pyrolysis, also known as thermal cracking, is a process of degrading polymeric materials by heating them to temperatures between 500°C and 800°C in the absence of oxygen. A literature research was conducted to learn about the various ways used to convert waste plastics into fuel across the world. Distilling crude oil can provide a variety of products, including diesel, petrol and kerosene. This technique may convert any HDPE waste plastic into various fuel grades. Reading through these various research articles reveals that a variety of pyrolysis processes have been used to properly analyse and turn plastic garbage into sustainable fuels. Following a thorough review of the literature, the parameters to be used were established based on engine parameters and accessibility. Table 1 shows the parameters and level of the experiment.

Table 1: Parameters for optimization

Parameters	**Level1**	**Level2**	**Level3**	**Level4**
Type of fuel	1(Diesel)	2(LDPE)	3(HDPE)	4(PP)
CR	15	16	17	18
IP	180	200	220	240
Load (%)	0	33	66	100

In the current study compression ratio, injection pressure, load on engine and PPOs with different level taken for the experimental work. The compression ratio has a significant impact on engine power, fuel economy, emission, and other performances of internal combustion engines. Basic engine theory states that a higher compression ratio produces higher torque and horsepower. One way of having different compression ratio is by changing piston head shape. the increase of injection pressure results to fast combustion, a serious reduction of soot especially at part load and low engine speeds but at the same time to a considerable increase of NO emissions. It is the force which resists the power produced by the engine. Every engine is designed for particular load called as rated load or maximum load at particular speed. Whenever the load on engine increases, the engine speed decreases. To compensate this loss in engine speed, more fuel is supplied to the engine.

3. Experimental Methodology

The steps in the process are as follows-

- Gathering waste plastic from scrap
- Setting up the pyrolysis apparatus.
- Extraction of fuel from waste plastic.
- CI engine performance tests with this extracted fuel
- Comparison of the carbon properties of the extracted fuel with those of diesel using Taguchi Method analysis.

The standard Design of the experiment was chosen after the parameters were chosen. The same test was run for each of the four fuels separately. The common experimental design used to compare performance and emission parameters is shown in **Table 2**.

Table 2: Standard Design of experiment

Sr No.	Type of Fuel	Compression Ratio	Injection Pressure (Bar)	Load (%)
1		15	180	0
2	Diesel,	16	200	33
3		17	220	66
4	LDPE,	18	240	100
5		15	180	33
6	HDPE,	16	200	66
7		17	220	100
8	PP	18	240	0
9		15	180	66
10		16	200	100

Table 2 (cont'd): Standard Design of experiment

Sr No.	Type of Fuel	Compression Ratio	Injection Pressure (Bar)	Load (%)
11		17	220	0
12	Diesel,	18	240	33
13	LDPE,	15	180	100
14	HDPE,	16	200	0
15	PP	17	220	33
16		18	240	66

Table 3. Fuel Properties Table.

Sample/ Properties	**Acid Value**	**Specific Gravity**	**Density**	**LCV**	**HCV**	**Flash Point**	**Fire Point**	**Viscosity@ 40^0C**	**Dynamic Viscosity@ 40^0C**
Unit	**(mg of KOH)/ gm of oil**	**-**	**kg/m^3**	**Calorie/ $(gm-^0c)$**	**Calorie/ $(gm-^0c)$**	**^0C**	**^0C**	**cSt**	**Cp**
ASTM Standard	D6751	D287	D287	D48009	D4809	D9358T	D9358T	D445	D445
Diesel	0.6	0.83	830	10034	10619	53	56	2.09	1.73
LDPE PO	-	0.765	765	10530	11116	35	41	2.22	1.69
HDPE PO	-	0.79	790	9714	10300	31	37	1.86	1.47
PP PO	-	0.736	736	9901	10487	24	31	1.64	1.21

The diesel fuel and plastic pyrolysis fuel with their properties are as shown in Table 3.

Table 4 Test engine specification.

Particular	**Specification**
Engine type	Single Cylinder, 4-stroke, Water cooled Engine
Bore and Stoke	87.5 mm by 110 mm
Rated Power	3.5 kW at 1500 rpm
CR Range	12:1 to 18:1
Injection Variation	0-25 degree BTDC
Dynamometer	Eddy Current Type, Water Cooled With Unit Load
Calorimeter	Pipe In Pipe Type
Temperature Sensor	RTD Type PT100 And Thermocouple
Load sensor	Load Cell, Type Strain Gauge, Range 0-50 kg
Rotameter	Engine Cooling 40-400 LPH, Calorimeter 25-250 LPH

Specification of the water cooled diesel engine contain in Table 4 on which experimental work performed with diesel and different types of plastic pyrolysis oil. Experimental setup is designed with different compression ratio and injection pressure. Figure 3 indicated the photographic view to change the compression ratio and injection pressure.

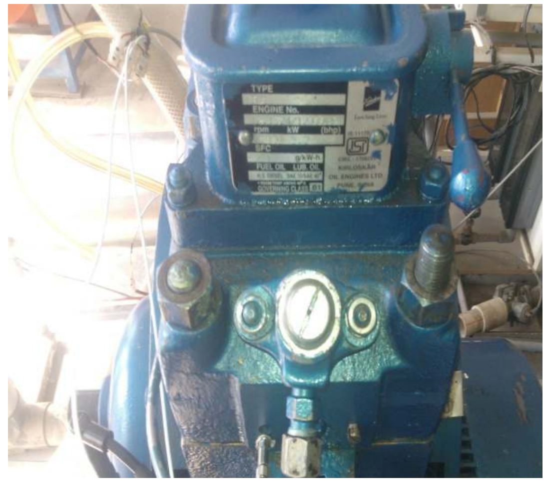

Figure 3. Changing in Compression Ratio and Injection Pressure.

4. Results and Discussion

Following the experiment with all four fuels—Diesel, HDPE, LDPE, and PP—a full graphical and tabular comparison was performed. First, several elements such as brake thermal energy, fuel consumption, volumetric efficiency, brake specific energy consumption, and so on were evaluated using engine and sensor data. A careful comparison of exhaust emissions was performed to determine whether or not there is a reduction in exhaust gases. In determining the exhaust emission of various emission characteristics, we used the most recent BS-VI emission range as our parameter. Table 5 depicts the emission range for several emission parameters throughout our experiment. In the current experimental work total 64 experiments required for one fuel. With the help of Taguchi Design of Experiment optimization technique can reduce the number of experiment to perform and it gives 16 experimental set of parameters for one fuel.

Table 5: Emission Range of Different Emission Parameters

Emission parameter	Fuel	Emission Range during experiment	BS-VI emission Range	Remarks
CO (%vol)	1 (Diesel)	0.07-0.41	0.3	Only in overload, out of range
	2 (LDPE PO)	0.05-0.45		Only in overload, out of range
	3 (HDPE PO)	0.09-0.33		Only in overload, out of range
	4 (PP PO)	0.07-0.26		Within Range
NO_x (g/kWh)	1 (Diesel)	0.99-4.93	4.2	Only in overload, out of range
	2 (LDPE PO)	0.71-4.32		Only in overload, out of range
	3 (HDPE PO)	1.49-4.10		Within Range
	4 (PP PO)	0.86-4.04		Within Range
HC (ppm)	1 (Diesel)	15-52	200	Within Range
	2 (LDPE PO)	22-67		Within Range
	3 (HDPE PO)	36-90		Within Range
	4 (PP PO)	31-260		Only in low load, out of range

4.1 Analysis for CO emission

Figure 4 depicts the carbon monoxide (CO) emissions with load for diesel, LDPE, HDPE, and PP.Carbon monoxide (CO) is occasionally produced during the combustion process as a result of incomplete combustion. Inadequate air mixture preparation and a shortage of oxygen. The carbon monoxide level rises as the load rises. Diesel CO levels range from 0.07% at CR 18, IP 200, and 0% load to 0.41% at CR 18, IP 180, and 100% load. CO in LDPE ranges from 0.05% at CR 18, IP 200, and 0% load to 0.31% at CR 17, IP 200, and 100% load. CO ranges from 0.09% at CR 18, IP 200, and 0% load to 0.33% at CR 16, IP 240, and 0% load for HDPE, and from 0.07% at CR 17, IP 180, and 66% load to 0.26% at CR 17, IP 220, and 0% load for PP. The CO emission range for diesel and LDPE is exceeded only during overload situations or when the engine load is 100%. Carbon dioxide emissions are lower than those of diesel for almost all loads.

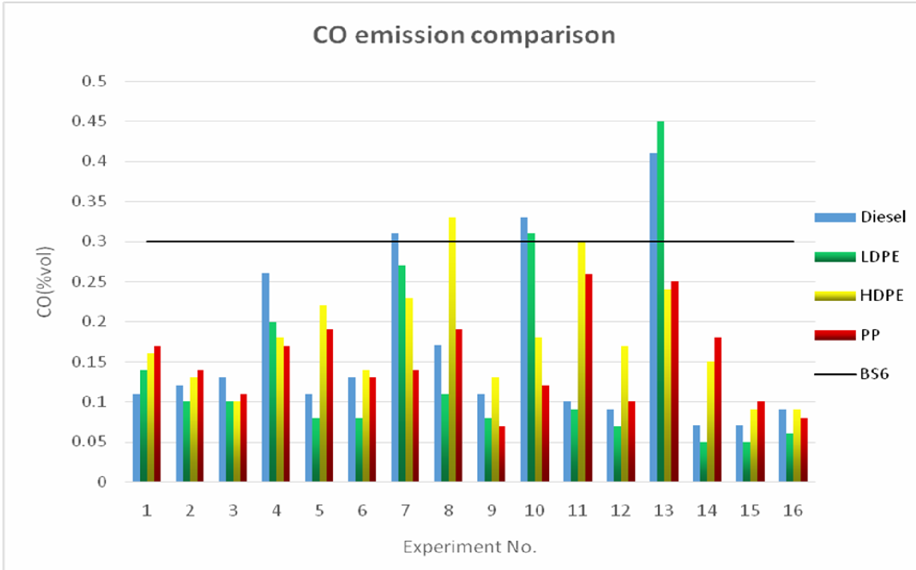

Figure 4: Emission comparison for CO

It has been discovered that HDPE contains chemicals with a higher carbon number than fuel. These higher carbon compounds require more oxygen to burn completely. A turbocharger's efficiency is much lower at part loads than it is at full loads. Because of the higher carbon number of the combined fuel, there is inadequate air for it. Also, from Figure 2, it can be determined that CO emission is lowest when LDPE is utilised at IP of 200 or 220, CR of 18, and Load% of 0 or 33. Furthermore, the largest CO emission occurs while utilising LDPE with an IP of 180 and at full load (100%). When LDPE is used as a fuel, the average CO emission is the lowest when compared to other fuels, while the highest CO emission occurs when HDPE is used as a fuel. When the CR is 18, the CO emission is the lowest for all fuels when compared to the average values of other lower CR.

4.2 Analysis for NO_x emission

Nitrogen oxides are produced when nitrogen and oxygen combine at quite high temperatures. NOx emissions comprise a substantial quantity of NO. Figure 5 displays NOx production for diesel, LDPE, HDPE, and PP. The primary contributions to nitrogen oxide formation are the air-fuel (A/F) ratio and ambient temperature. When there is enough burning, the temperature rises and more free oxygen atoms interact with nitrogen, increasing the rate at which nitrogen oxide is created. The greater NOx in PPO mixes compared to diesel may be due to the fact that plastic oil contains oxygenated hydrocarbons, which aid proper combustion and, as a result, the formation of NOx in exhaust.

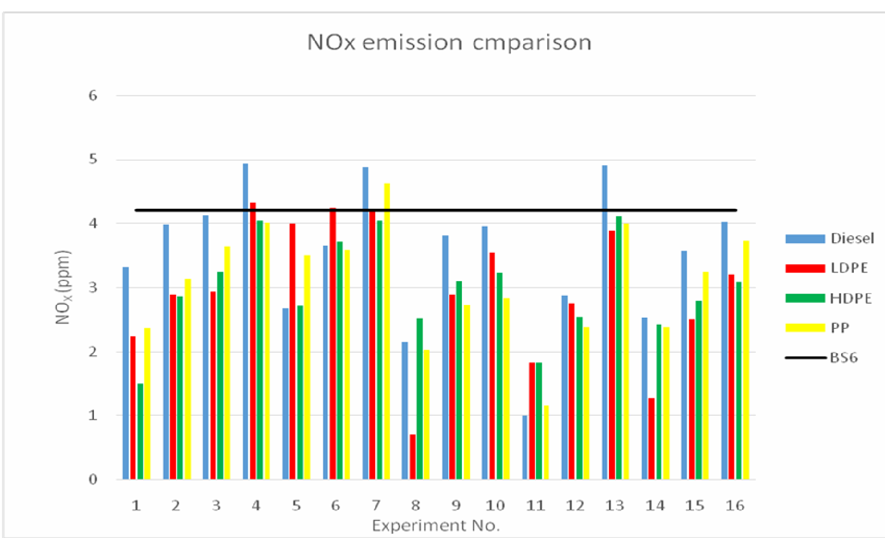

Figure 5: NO_x Emission comparison

Because the fuel is burned later, there is less oxygen available for combustion, resulting in lower NOx emissions. NOx emissions exceed the BS6 level mostly during overload circumstances. Figure 3 shows that NOx emissions are lowest when PP is utilised with an IP of 220, a CR of 17, and a load percentage of 0%. Furthermore, the maximum NOx emission occurs when utilising Diesel at IP of 240, CR of 18, and load of 66%. The average NOx emission is lowest when PP is used in comparison to other fuels, and the highest NOx emission occurs when LDPE is utilised as a fuel. NOx emissions are highest when any fuel is operated at a high CR of 18 with an IP of 240 and at full load.

4.3 Analysis for HC emission

Figure 4 depicts the HC emissions of the four fuels utilised in a chart format. Unburned HC is just the result of inadequately burnt fuel. "Hydrocarbon" refers to natural molecules in their gaseous state, whereas particulate matter is defined as solid hydrocarbons. Hydrocarbon emissions come from incomplete combustion of the Fuel-Air combination. Figure 6 shows that when PP is utilised as a fuel at CR 15, IP 180, and 0% load, the maximum amounts of HC emissions occur. Under the identical CR 18, IP 180, and 0% load circumstances, diesel fuel had the lowest emission values. Furthermore, PP releases the most hydrocarbons when compared to the other three fuels, whereas diesel fuel emits the least.

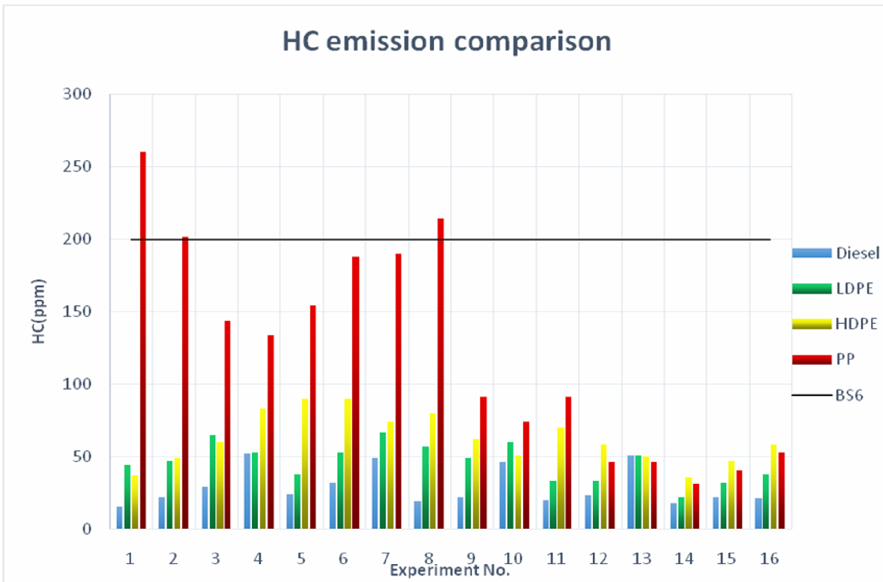

Figure 6: HC emission comparison

Increased fumigation rates may be to blame for the rising hydrocarbon content of plastic oil. HC emissions in exhaust are greatly enhanced due to the difficulties of combusting unsaturated double bond molecules and compounds with higher carbon numbers. Unburned hydrocarbon levels are lower at lighter loads due to increased oxygen availability, but higher at higher load ranges due to more fuel being admitted, resulting in higher hydrocarbon levels at low loads. As a result, the PP low load conditions occasionally cross the BS6 line. There are two possible theories for why plastic oils emit more HC than diesel. One is that gaseous hydrocarbons remain on the cylinder walls and go unburned because the fuel spray does not disperse evenly into the pyrolysis chamber. Another explanation is that pyrolysis oil contains unsaturated hydrocarbons that are unbreakable during burning.

5. Conclusion

Diesel fuel and waste plastic oils generated by catalytic pyrolysis of HDPE, LDPE, and PP were tested under varied loads to determine the influence of plastic pyrolysis oil on compression ignition engine performance and emission characteristics. The following findings were made:

- CO levels in diesel range from 0.07% to 0.41%, LDPE ranges from 0.05% to 0.31%, HDPE ranges from 0.09% to 0.33%, PP E ranges from 0.07% to 0.26% at CR 18, IP 200 0% load, CR 18, IP 180, 100% load respectively. The CO emission range for diesel and LDPE is exceeded only during overload situations or when the engine load is 100%.
- NO_X emissions are lowest when PP is utilised with an IP of 220, a CR of 17, and a load percentage of 0%. the maximum NO_X emission occurs when utilising Diesel at IP of 240, CR of 18, and load of 66%. The average NO_X emission is lowest when PP is used in comparison to other fuels, and the highest NO_X emission occurs when LDPE is utilised as a fuel.

- In PP maximum amounts of HC emissions occur. Diesel fuel had the lowest emission values. Increased fumigation rates may be to blame for the rising hydrocarbon content of plastic oil. Unburned hydrocarbon levels are lower at lighter loads due to increased oxygen availability.

With the current experiment technique can also find out any unknown fuel can be used as an alternative fuel or not. In the current work with the help of Pyrolysis process fuel generated from different types of waste plastic and used in Diesel engine and tested for emission of the engine. With using waste plastic fuel in engine, can reduce the waste plastic goes into land filling, to save the life of animal by awareness in society and also satisfy the scarcity of petroleum product

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