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Production of Oil from Waste Plastics and Polythene using Pyrolysis and its Utilization in Compression Ignition (C.I.) Engine

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Abstract

Objectives: Utilization of waste effectively and efficiently is one the major concern in today's world. The depleting natural resources (like fossil fuels) add further to this concern. If we continue to use and exploit fossil fuels at the existing rate, then after another 150 years or so they would be no longer available for our use. Therefore, it is the duty of present generation to use fossil fuels judiciously so that something is left for the generations to come. The need of the hour is to adopt some measures which can help to manage wastes and at the same time to create some alternate fuels out of the waste only to conserve the precious fossil fuels. Thus pyrolysis these days is catching everybody's attention due to its potential to utilize variety of waste feedstock's to generate combustible products and may prove to be potential technology for society in the times to come. **Methods/ Statistical Analysis:** The process known as "Pyrolysis" which can be a possible solution for conversion of waste to fuel. In pyrolysis wastes like plastic, polythene, tyres and biomass etc. can be used as feedstock's, using heat in absence of air are converted to fuel oil, chemicals and gas. In the present work pyrolysis is used for converting waste plastic into fuel oil termed as pyrolytic oil. A semi batch type pyrolysis reactor was used to carry out pyrolysis. The pyrolysis was carried out at 3500C.The vapours of the waste plastic and polythene generated during pyrolysis were condensed using condensing unit into oil. The pyrolytic oil obtained was filtered using multiple pass filter paper. The following test fuels were developed: blends (5%, 10%, 15% and 20% by volume) of this oil with diesel were prepared and they were compared with 100% diesel. Performance parameters such as, Thermal Efficiency, Specific Fuel Consumption and Torque were measured. These performance parameters were measured at different loads at 1500rotations per minute (r.p.m).Now this derived oil was further checked for emissions like Nitrogen Oxide (NO), Carbon Monoxide (CO), Hydro Carbon(HC) etc. on Gas Analyser. Findings: Properties like calorific value, kinematic viscosity and density were measured and compared with diesel. The calorific value of pyrolytic oil was about 39.769 MJ/kg. Viscosity of the pyrolytic oil was checked with Redwood Viscometer and was 0.0038 stokes at 600C. The density of the derived fuel was 780 kg/m3. The results clearly indicated that these three properties were comparable with other conventional fuel oils especially diesel. Therefore, this derived pyrolytic oil was further used for carrying out investigations on compression ignition engine for checking its performance parameters. The results clearly indicated that indicated thermal efficiency and Brake thermal efficiency obtained with 20% blend was more in comparison with 100% diesel. The value of torque at different loads came out almost similar for different blends and 100% diesel. The results were clearly in favour of pyrolytic oil. The value of NO emissions were higher in comparison to 100% diesel but the emission levels of CO, HC, and CO2 were found lower.

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than 100% diesel. The absorption coefficient of this oil was checked on Smoke meter and compared with 100% diesel. It was observed that absorption coefficient with 20% blend was much lower as compared to 100% diesel. From the research work it is established that pyrolytic oil can serve as a good alternate fuel as compared to diesel because of its performance and less emissions. From investigations it is seen that various factors like calorific value, density, viscosity etc. obtained with this oil are comparable with other fuel oils especially diesel. Results obtained with different blends (5%, 10%, 15% and 20%) of pyrolytic oil with diesel have shown that the various performance parameters like indicated thermal efficiency, brake thermal efficiency, torque etc. are more or less at par with diesel fuel. **Application/ Improvement:**With some suitable alterations in the reactor the efficiency and yield can still be improved keeping economic viability into consideration at the same time

Keywords: Alternative Fuel, Pyrolysis, Waste Plastics, Waste Polythene

1. Introduction

Generation of power from waste and search for alternate fuels would be a great asset for the humanity as it will lead to conservation of precious fossil fuels. C.I. Engine performance with alternate fuels like Bakain Methyl Ester[1], Methyl Ester of Jatropha[2] etc. has been successfully carried out with satisfactory results. Along with engine performance close monitoring over emissions is also essential. The emission levels have been found lesser with some blends such as Refined Sunflower oil[3]. Modifications such as timed turbulence in C.I. engine has led to Fuel economy and lesser emissions as well[4]. Improvement in engine design and methods to obtain maximum efficiency through alternate fuels is the need of the hour. Analysis for improvement of power from the engines are also going on at the same time[5]. Even improvement in different alloys at microstructural level is helping this cause[6]. Continuing in this series Pyrolysis has been identified as the best fit for this purpose. Pyrolysis basically a thermo-chemical process is being used as a technology to manage wastes like plastic, tyres, biomass etc. and at the same time utilizing its products to conserve fossil fuels. The technique of recycling waste plastic and polythenes through pyrolysis started some 20 years back. Recycling of waste plastic and polythenes has become very important as they are non-biodegradable and pose a threat to our environment. The different types of plastics used are Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Low-density polyethylene (LDPE), Polyvinyl chloride (PVC),Polypropylene (PP) and Polystyrene (PS). Among six main plastics, low density polythene (LDPE) is used in various field such as grocery bags, water hoses, garbage cans, film, containers etc[7].LDPE consists of more branches which make it weaker in intermolecular force, and as a result it has less hardness and tensile strength. LDPE is ductile as compared to HDPE as it has side branching and a less crystalline structurewhich allows it to be moulded easily. It is resistant to water, and thus can be usedin manufacturing of plastic bags, foils etc. In contrast HDPE has less branching and thus has a higher strength[8]. Due to its good strength, HDPE is used in making oil containers, bottles, toys and more. It is the third largest plastic type found in solid waste category. PVC is an exceptional plastic. PVC is resistant to fire and is thus used in making electrical insulations. Some other applications of PVC include packaging, credit cards, shoes, frames for windows, artificial leather, etc. PS is a long chain of hydrocarbon attached with phenyl group. It is resistant to heat and is light and durable. It is used in manufacturing of toys, electronic and medical items. PP has a higher melting point and is more hard and rigid thus making it suitable for plastic industry. 24.3% waste is generated by PP in plastic wastes category.

From the research carried out by various researchers and after carefully observing the various properties of conventional fuels in comparison to plastic derived oil it is established that plastic derived oil can be used as an alternate fuel to suffice our needs. Under pyrolysis conditions, plastic wastes can be decomposed into three fractions: gas, liquid and solid residue[9]. The liquid products are usually composed of higher boiling point hydrocarbons**.** In order to obtain useful gasoline-range hydrocarbons from the pyrolytic oil, fractional distillation is preferred for product separation. More valuable chemical raw materials including benzene, toluene and other condensed aromatic hydrocarbons may be obtained by refining the pyrolytic oil. Studies conducted on waste plastic pyrolytic oil have suggested that this oil can be used as a substituent to both petrol and diesel[10].Petrol engine could be run with 100% waste plastic oil and even the thermal efficiencies are higher in comparison to Petrol and Diesel. Different types of plastics require different temperatures for cracking down and to convert into oil. The yield of the different waste plastics are 1.17% for the pyrolysis of low density polyethylene ,15% from the pyrolysis of polystyrene ,and 13.88% from the pyrolysis of high density polyethylene[11]. For recovery of larger amount of oil from waste plastics addition of suitable catalyst is required. The catalyst influences not only the structure of the products, but also their yield[12]. Hydrocarbon molecules from the basic materials are split under the impact of catalyst inside the reactor in 70–240 °C. It was observed that the yield was better in the case of individual plastic material as opposed to mixed feed in all cases except polypropylene under non-catalyzed vacuum process. The impact of temperature on product yield and the composition was studied under pyrolysis[13]. Pyrolysis was performed at temperatures between 500 and 700°C. The yield of products obtained was totally different. 9.79 and 88.76% gas and for other it was 18.44 and 57.11% of oil. From the tests conducted it was established that as temperature increased the aromatic compounds in the oil also increased. The molecular weight also gets affected. The feedstock types strongly affect the product yields and the quality of liquid and solid products[14]. HDPE waste produces the highest liquid fraction. However, the heavy oil fraction is still high in the oil from HDPE waste pyrolysis with natural zeolite catalyst can produce higher liquid product.

Without any changes in the engine the pyrolytic oil generated from waste plastic can be used as an alternate fuel[15].

Table 1. Properties of different plastic pyrolysed oil

Property (Physical)	Plastic Type						Standard Value (Commercial)	
	PET	**HDPE**	**PVC**	**LDPE**	**PP**	**PS**	**Petrol**	**Diesel**
Calorific Value	28.2	40.5	21.1	39.5	40.8	43.0	42.5	43.0
Viscosity	N.A	5.08	6.36	5.56	4.09	1.4	1.17	1.9-4.1
Density	0.90	0.89	0.84	0.78	0.86	0.85	0.780	1.9-4.1
Pour Point	N.A	-5	N.A	N.A	-9	-67	-	6
Flash Point	N.A	48	40	41	30	26.1	42	52

[Source: Sharuddin et al.][17]

1.1 Effect of Various Factors on Pyrolysis

From the research it has been established that the most influencing factors affecting pyrolysis of plastics are:

The chemical composition of feed[16]:
The structure and chemical composition of the plastic used in pyrolysis directly influence the products of pyrolysis.

Heating rates and temperature:
The most important feature during pyrolysis is the temperature, with increase in temperature the polymer is cracked but not every type of polymer can be cracked with increase in temperature. The thermal breaking temperature of C-C bonds is constant for a given type of plastic, its exact value is determined by temperature sensors located at different position of reactor.

Reactor type:
Type of reactor used in pyrolysis greatly influences the process. The types of reactors used for conducting pyrolysis are Batch Type, Semi-Batch Type and Continuous Type of Reactor.

1.2 Advantages of Pyrolysis are

- Reduction in volume of waste (<50–90%),
- All the three types of fuel like solid, liquid and gas can be produced,
- The fuel obtained can be stored and transported easily.
- The problems related with environment are greatly reduced,
- Energy can be derived from renewable sources like municipal solid waste or sewage sludge,
- It involves low capital cost

2. Design of the Pyrolysis Reactor

For carrying out this project work Semi-Batch kind of reactor was used. In this kind of reactor the feedstock is added initially before the start of pyrolysis process and the products are removed continuously once they are generated.

The Pyrolysis set up consists of two main parts i.e. the reactor and the condensing unit. The reactor has an inner cylinder and an outer cylinder which are made concen-

Table 2. Comparison of calorific values of various plastics with conventional fuels

S.No.	Fuel	Calorific Value (MJ/kg)
1.	Methane	53
2.	Gasoline	46
3.	Diesel	43
4.	Coal	30
5.	Polyethylene	43
6.	Mixed Plastics	30-40
7.	Municipal solid wastes	10

[Source:Panda A.K. et al. .][18]

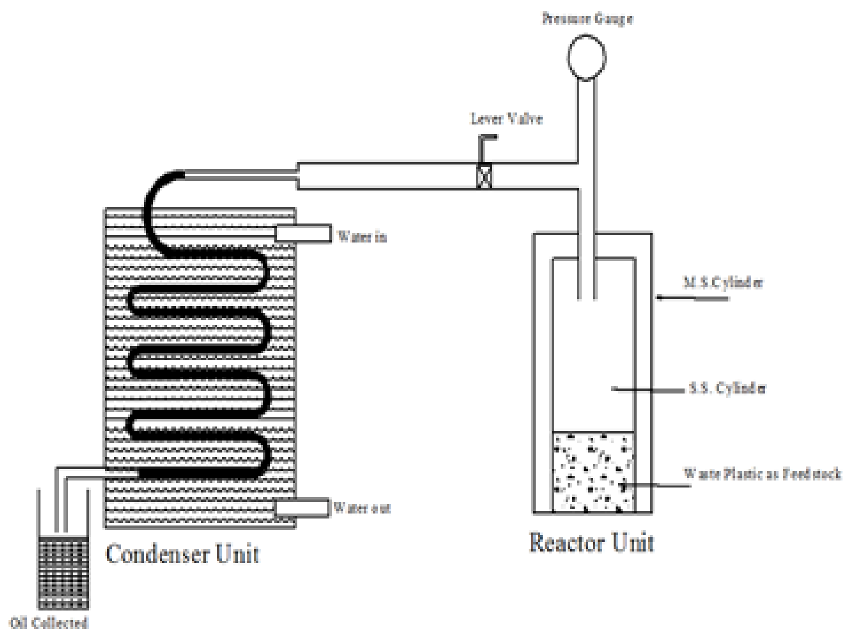

Figure 1. Reactor for carrying out Pyrolysis.

Table 3. Dimensions of the reactor

Height of reactor	400mm
Diameter of outer cylinder	203mm
Diameter of inner cylinder	127mm
Diameter of base plate	203mm
Thickness of base plate	2.032mm
Thickness of inner (ss) cylinder	1.219mm
Thickness of outer (ms) cylinder	1.219mm
Diameter of gas outlet pipe	12.7mm

Figure 2. Actual picture of Pyrolysis reactor with its Condensing unit.

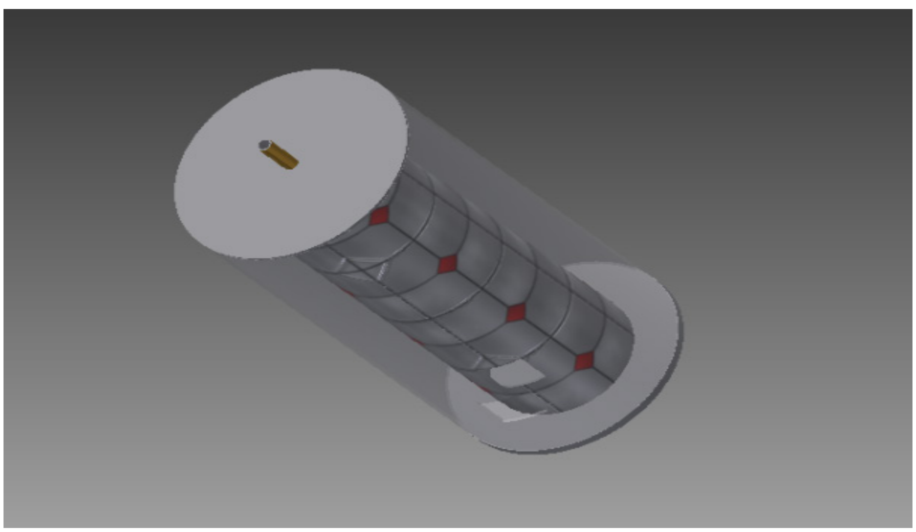

Figure 3. 3-D view of Reactor unit.

tric on a base plate. Pyrolysis reactor is mainly made up of three materials namely mild steel, stainless steel and iron. Glass wool and Asbestos ropes are used as insulating mediums so as to reduce heat losses due conduction and convection.

2.1 Other Equipment used to Carry out Pyrolysis

Apart from the main pyrolysis reactor the other equipment that are required to carry out this process are burner, LPG gas cylinder and sensors and gauges.

2.1.1 Burner

The burner used in pyrolysis process is high pressure burners, which have the ability to throw flames with high pressure, it located direct under the reactor with a stand mounted on it.

2.1.2 LPG Gas Cylinder

Liquefied petroleum gas cylinder is used because it does not create any pollution while burning of gas, it has high octane rating which allows it to mix better with air and to burn more completely then does gasoline, generating less carbon. LPG is cheap when we compare it with other power producing fuels so that the overall efficiency of plant increases.

2.1.3 Sensors and Gauges

There are various sensors and gauges used to determine temperature and pressure inside the reactor. The pressure gauge is mounted on top of reactor where gas outlet takes place and for temperature there is a sensor, wherever temperature you want to measure just touch the nib of sensor on that particular region and it will give you the estimated value of temperature.

2.2 Testing of Pyrolytic fuel on Compression Ignition (C.I.) Engine

In the beginning tests were performed on the engine using diesel as fuel for obtaining base results. After that some different blends of waste plastic and polythene oil were made and were tested on the engine. Blends of waste plastic- polythene oil was made with Diesel. The blends are of 5%, 10%, 15%, 20% in one litre of diesel. The engine was started using diesel only and was made to run for 15 minutes before recording observations. After engine conditions stabilized and reached to steady state, the base line data was taken. Load was varied by0Kg, 4Kg, 8Kg, 12Kg and 16Kg at constant speed of 1500rpm.Gaseous emissions like CO, HC, CO_2, O_2, NO were measured using gas analyser with absorption coefficient also calculated using smoke meter.

The engine known as VCR (Variable Compression Research) engine is a special engine made for research purpose. All the tests were carried out on this engine. All the data from the research engine for different loads and blends have been noted at steady state of the engine. The Figure of the engine is shown

Figure 4. Variable Compression Research Engine.

2.3 Production of Pyrolytic Oil

Initially the project was started by extracting pyrolytic oil from bio-mass and for this purpose different variety of Indian wood like pine, deodar etc. were used. After the production of pyrolytic oil it was not found fit for carrying out the whole thesis because of the following reasons:

- The heating value (calorific value) of the oil obtained was very less (around 11 MJ/kg).

Figure 5. Waste Plastic and Polythene as feed stock.

Figure 6. Pyrolytic Oil.

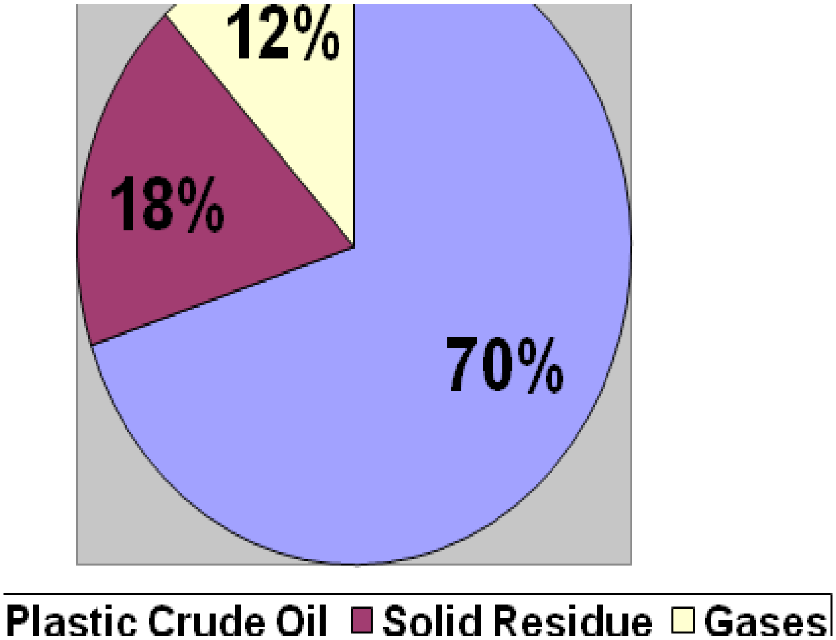

Figure 7. Percentage wise yield of Pyrolysis from Plastic Waste.

- This oil had low oxidation stability.
- The oil started to gum out after it had been kept for some hours.
- The yield obtained was very low because of the presence of extra moisture and ash content.

Therefore an alternate for this was found and pyrolysis on waste plastic and polythene was undertaken as the project work. The feedstock was handpicked from the dumping site taking suitable precautions and care.

2.4 Economics of Fuel Production

For production of pyrolytic oil almost 1 kg of L.P.G. was spent in about 40-50 minutes. The cost of 1 kg of L.P.G. is around Rs.40. Therefore the cost of generating 1 litre of pyrolytic oil is around Rs.40. The main cost being for the usage of L.P.G. (Liquefied Petroleum Gas) whereas the feedstock was freely available. This production cost can further be brought down by overall optimization of the pyrolytic plant. Reduction in losses will account to further reduction in overall production price of the pyrolytic oil.

3. Results and Discussion

3.1 Comparison of properties of pyrolyticoil (Derived from Experimentation) with Diesel

Table 4. Comparison of Properties between Waste Plastic and Polythene Oil and Diesel

S.No.	Parameter	Diesel 100%	Wppo 5	Wppo 10	Wppo 15	Wppo 20
1.	Brake Thermal Efficiency	23.95	24.75	23.81	23.86	24.91
2.	Torque	12.57	12.63	12.62	12.66	12.76
3.	B.S.F.C	0.26	0.25	0.26	0.25	0.24
4.	NO concentration	1172.4	1190.4	1200.6	1148.4	1210
5.	CO concentration	0.07	0.08	0.06	0.07	0.06
6.	HC concentration	139	126	131	120.2	115
7.	CO_2 concentration	4.76	4.68	4.66	4.5	4.39
8.	Absorption Coefficient	0.32	0.27	0.32	0.23	0.31

3.2 Tabulation of Results for Diesel and different blends

The tabulation of the overall results for 100% Diesel and the blends of pyrolytic oil is shown below in the table.

As load increases break thermal efficiency increases for diesel as well as blends of waste polythene oil. The brake thermal efficiency of waste plastic and polythene oil (wppo20) is more as compared to other proportions of blends and 100% diesel, the increment in brake thermal

Table 5. Overall results for 100% Diesel and pyrolytic oil blends

Properties	Diesel	Waste plastic and polythene oil
Calorific Value (kJ/kg)	44800	39769.017
Kinematic Viscosity (Centistokes)	1-4.11	3.8
Density at 30^0C (in g/cm^3)	0.79	0.78
Flash point (in ^{0}C)	52-96	100
Fire Point (in ^{0}C)	62-106	110
Auto ignition (in ^{0}C)	210	228

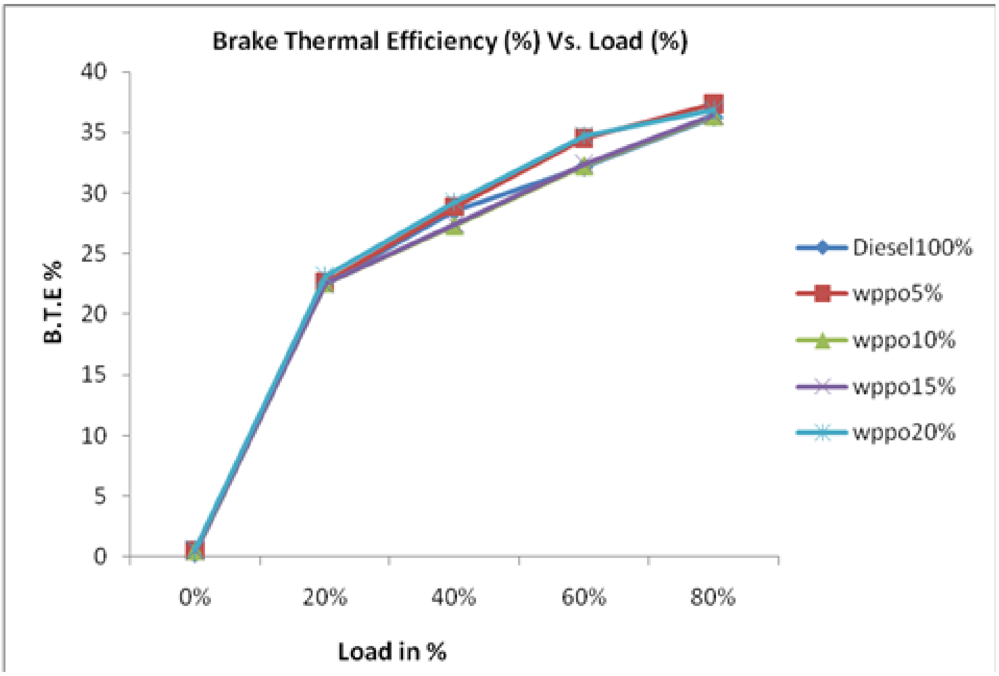

Figure 8. Brake Thermal Efficiency vs. Load.

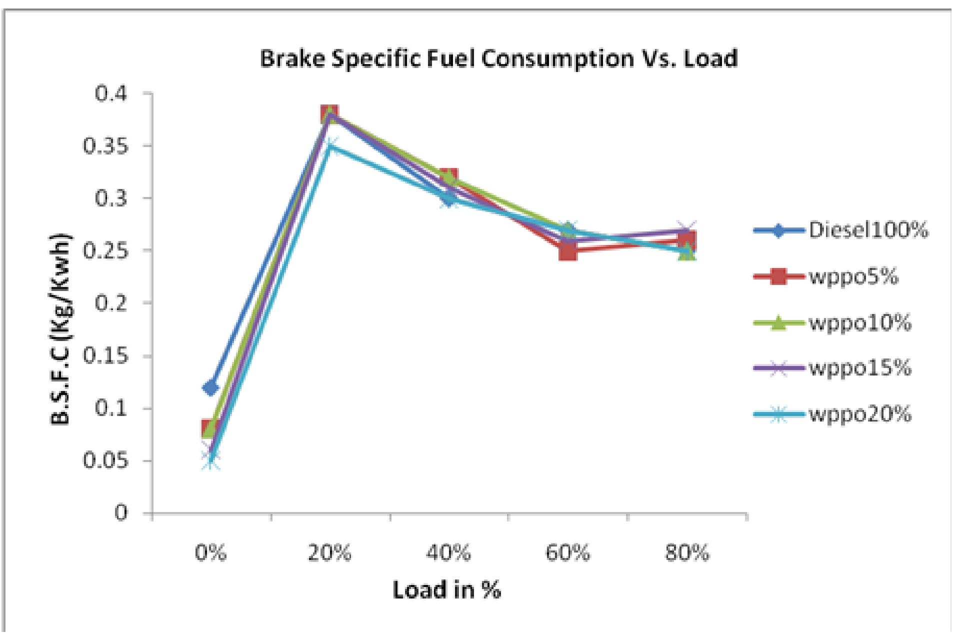

Figure 9. Brake Specific Fuel Consumption vs. Load.

efficiency is due to better combustion because of good amount of calorific value and less viscosity of waste plastic and polythene oil.

The value of Brake Specific Fuel Consumption is almost similar for 100% Diesel and the other blends

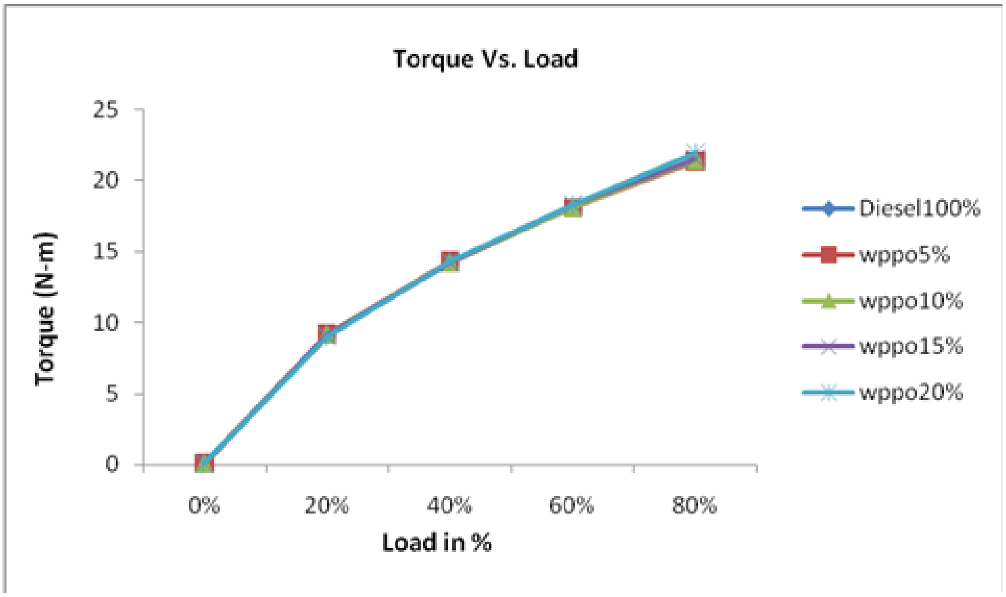

Figure 10. Torque vs. Load.

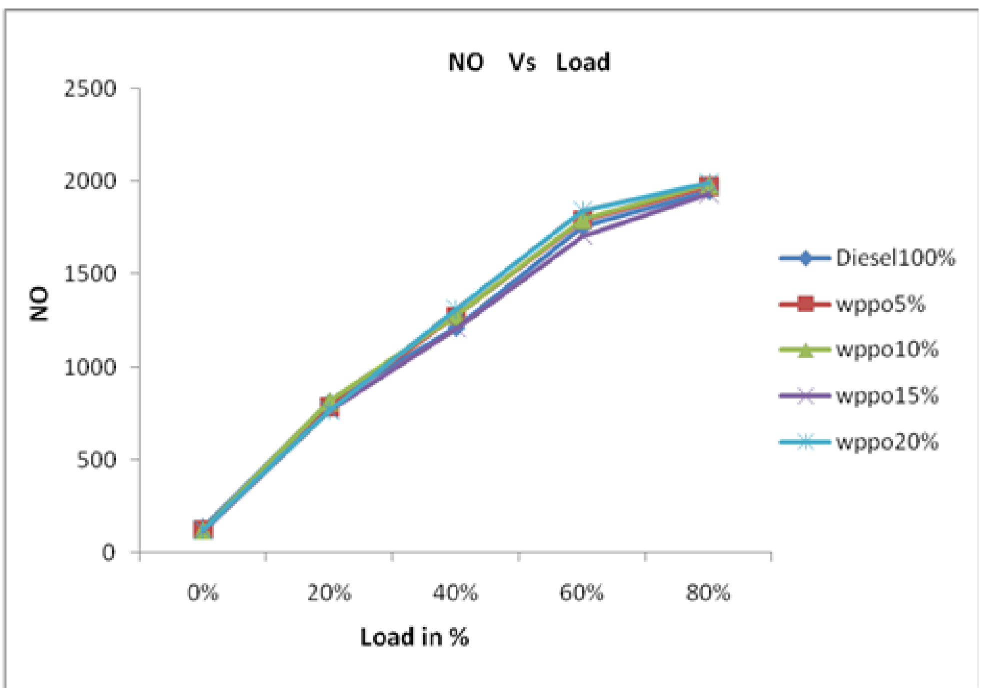

Figure 11. NO vs. Load.

From the graph torque is slightly more for Wppo 20 blend as compared to 100% diesel and other blends of waste plastic and polythene oil in the CI engine.

NO tends to increase with load. As the load increases the temperature also increases which in turn increases the NO emission. It is observed that NO emission increases with increase in load, when 100% diesel and Wppo20 are compared NO is relatively higher in Wppo20.

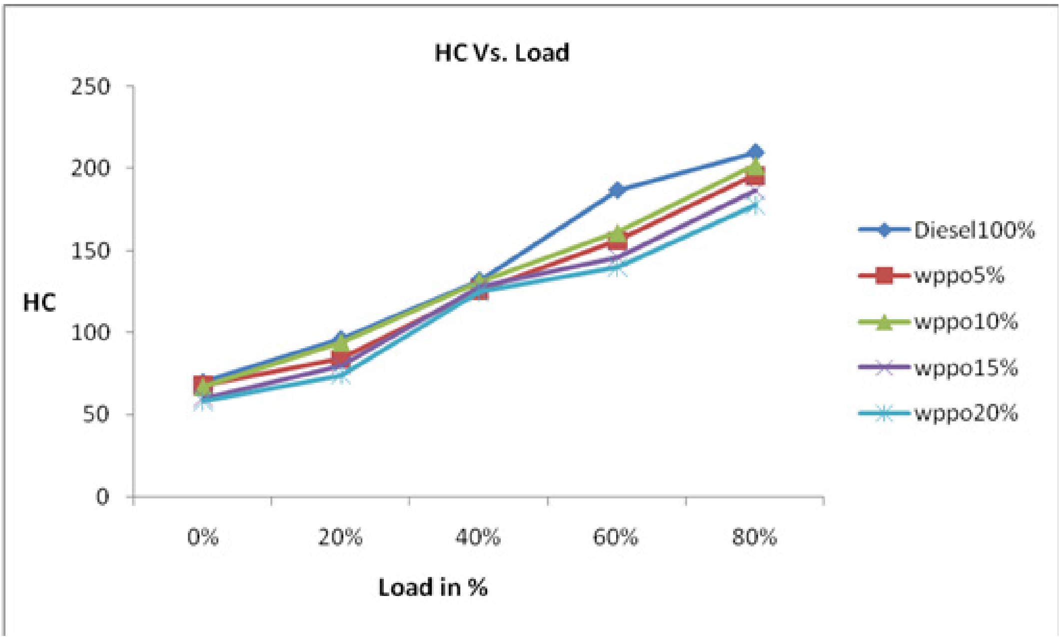

Figure 12. HC vs. Load.

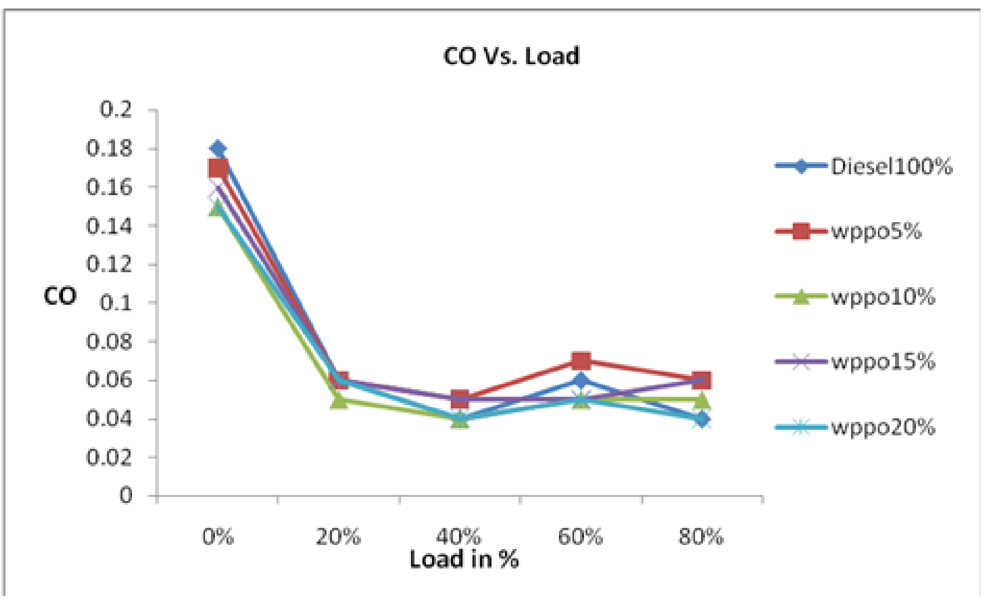

Figure 13. CO vs. Load.

HC level is found to be low for waste plastic and polythene oil compared to diesel. Unburnt hydrocarbon emissions are the direct result of incomplete combustion, thus HC level is increased with increase in loads, this is due to diffused combustion, increase in temperature and after burning phenomenon.

CO level decreases as the proportion of waste plastic and polythene oil in the blends increase. This is due to

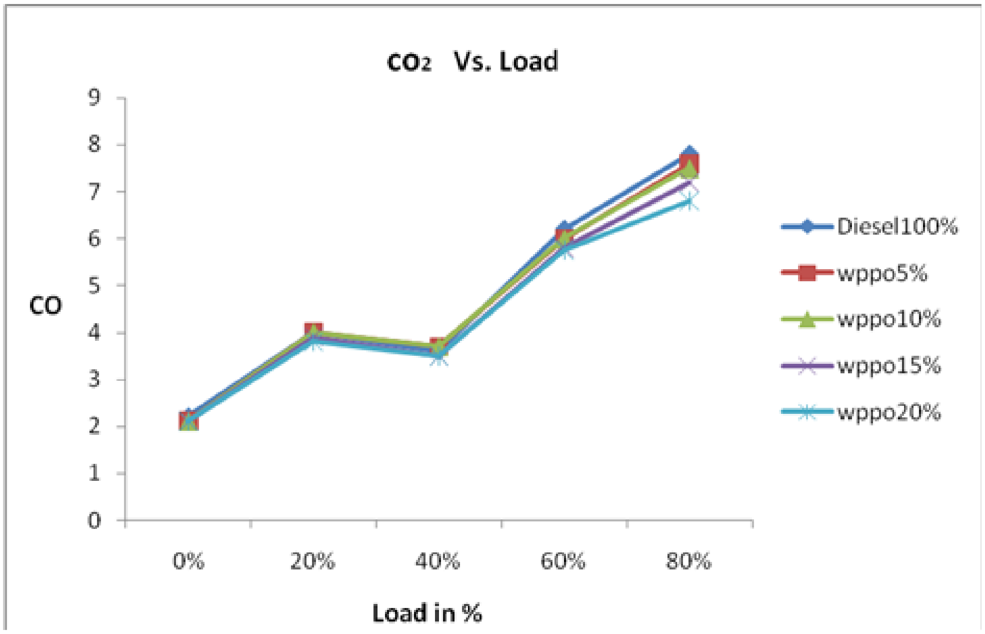

Figure 14. CO¬2 vs. Load.

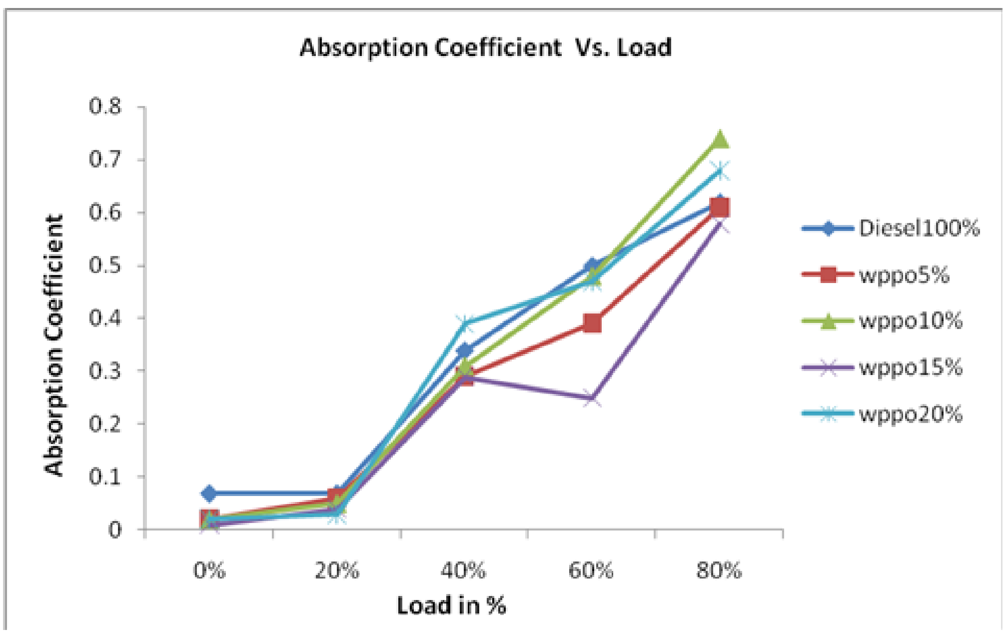

Figure 15. Absorption coefficientvs. Load.

the fact that engine is not optimized to run with diesel oil blends or waste plastic and polythene oil, so there is large possibility of rich fuel air mixture in the cylinder and the higher specific fuel consumption resulting in a lower CO level. CO level is comparatively less when compared to diesel.

CO_2 level is found to be low for waste polythene oil compared to diesel. This is due to diffused combustion; increase in temperature and after burning phenomenon.

The absorption coefficient of D100 as compared to blends of waste plastic and polythene oil is higher(except Wppo 10 and 20)

4. Discussion

The results obtained with Wppo 20% blend were better than 100% diesel. Efficiencies are better and the emissions are less. The C.I. engine was run satisfactorily with this blend.

Pyrolysis technology has been solving the problem of waste utilization effectively and efficiently. Pyrolytic oil can serve as a good alternate fuel as compared to diesel because of its performance and less emissions. With some suitable alterations in the reactor the efficiency and yield can still be improved keeping economic viability into consideration at the same time. Overall optimization needs to be done for achieving more economical and environment friendly methods. Some countries have already started using this technology commercially by offering pyrolytic oil blends as main fuel for the engines to run but this technology will take some time to come into full effect across the globe.

5. Conclusion

After carrying out tests on performance and emission of waste plastic- polythene oil, it can be concluded that this pyrolytic oil can serve as an alternate fuel as compared to diesel because of its performance and less emissions.

From experimental investigations the following conclusions can be drawn:

1. Diesel engine was able to run satisfactorily with 20% blend of pyrolytic oil.
2. Waste plastic-polythene oil shows higher brake thermal efficiency as compared to Diesel.
3. Torque delivered by pyrolytic oil blends at various loads is almost similar to that of Diesel.
4. CO emissions are comparatively lesser than diesel.
5. HC emission level is also found to be low in comparison with diesel.
6. NO emissions are almost similar in both the cases.
7. The absorption coefficient of pyrolytic oil is much lower as compared to diesel.

Thus it is found that wppo20 shows better performance compared to conventional diesel, wppo5, wppo10 and wppo15 as far as characteristics like brake thermal efficiency, indicated thermal efficiency, torque and the emission parameters are concerned. From this project we can say that wppo20 can be substituted for diesel fuel.

6. Future Scope

Pyrolytic oil has paved way for alternate fuel but it is not commonly used as fuel. There are very few Pyrolysis plants available in India and world. There is still lot of scope left in Pyrolysis.

- Research work can be conducted on unusual combination of raw material like for instance bio mass and polythenes or bio mass and plastics.
- Role of catalyst cannot be ignored in Pyrolysis. Modifications in catalyst may prove more beneficial for overall yield of the pyrolytic oil.
- Overall optimization of the process to achieve more economical and environment friendly method.
- Pyrolysis plant can be integrated with other systems and equipment for easy removal of oil and it's by products.

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