Experimental Investigation of Performance & Emission characteristics of Plastic Fuel Blends on DICI Engine

Shivani C. Deshmukh [1], Rushikesh N. Patil[2]
[1]Dept of Mechanical Engineering
[2]Assistant Professor, Dept of Mechanical Engineering
[1, 2] Deogiri Institute of Engineering and Management Studies,Aurangabad.

Abstract- *The world's annual production of plastic materials has been steadily increasing at a rate of nearly 5% over the past 20yrs due to economic growth and the change of consumption and production patterns. Recovery and recycling, however, remain insufficient, and millions of tons of plastics end up in landfills and oceans each year. Waste plastic is causing problem to the environment. India Consumes Approximately 16.5 Million tones plastic every year. Project deals with the extraction of OIL/DIESEL from the waste plastics and testing of fuel with its performance and emission characteristics without any changes in Internal Combustion Engine. Pyrolysis process becomes an option of waste-to-energy technology to deliver bio-fuel to replace fossil fuel. Addition of waste plastic fuel up to 20% with diesel shows an increase in break thermal efficiency when compare to diesel fuel. It provides increased efficiency while the specific fuel consumption characteristics show a decreasing value when compare to diesel and hence shows good fuel characteristics. B20 shows the better performance characteristics.*

Keywords- Plastic Waste, Plastic Fuel, LDPE, Pyrolysis, Performance characteristics, Emission Characteristics.

I. INTRODUCTION

Due to the fossil fuel crisis in past decade, mankind has to focus on developing the alternate energy sources such as biomass, hydropower, geothermal energy, wind energy, solar energy, and nuclear energy. The developing of alternative-fuel technologies are investigated to deliver the replacement of fossil fuel. The focused technologies are bio-ethanol, bio-diesel lipid derived bio-fuel, waste oil recycling, pyrolysis, gasification, dimethyl ether, and biogas. On the other hand, appropriate waste management strategy is another important aspect of sustainable development since waste problem is concerned in every city.

Plastic have been essential material and their applications in industrial field are continuously increasing. Plastic production and consumption is increasing day by day at faster rates with increase of human population, rapid economic growth, and change in life style. The global plastic production was estimated around 350 million tons per year and continuously increasing every year. The world's annual production of plastic materials has been steadily increasing at a rate of nearly 5% over the past 20yrs due to economic growth and the change of consumption and production patterns. Recovery and recycling, however, remain insufficient, and millions of tons of plastics end up in landfills and oceans each year. Waste plastic is causing problem to the environment. India consumes Approximately 16.5 Million tones plastic every year. Plastic is non-biodegradable that remains as a hazardous material for more than centuries. Recycling of waste plastics is expected to become the most effective way of regenerating and utilizing. Plastic pyrolysis has great potential to convert plastic waste into oil to achieve maximum economics and environmental benefits.

Pic 1: Plastic Products

Different Methods are used for plastic waste Management

1. Ocean Dumping
2. Sanitary Landfills
3. Open Dumping
4. Recycling-Pyrolysis.

II. LITERATURE REVIEW

B. PHANISANKAR, et.al [2020] Studied about the certain intention of the analyzing and fetch further the catalytic conversion of waste and standard plastic into liquid hydrocarbon fuel. A number of industrial methods are used for this experimentation, like pyrolysis, catalytic pyrolysis, Hydrocracking, Thermal Cracking etc. through which Catalytic Cracking is the best suitable method found, because the temperature required for this process is less than pyrolysis process. (22°C-390°C). Another result found as coil condenser was an excellent helper in hydrocarbon vapors condensation.

R. SINGH, et.al [2020] They have concluded that, pyrolysis of mixed plastic waste at 450°C produces a high-quality fuel having physical properties similar to conventional fuels like diesel and petrol represents an excellent alternative to be used as fuel in diesel engines. The utilization of crude PPO with diesel blends up to 50% can be utilized in diesel engines with a minor loss in efficiency and with a small increase in exhaust emission when compared to 100% diesel fuel characteristics.

N. Ahmad. et.al [2020] they have converted polystyrene waste plastic into liquid fuel using thermal liquefaction process in the presence of ethanol as a solvent. Furthermore, GC-MS analysis identified the presence of aromatics, alkenes, and alkyls compounds in the oil making it potential fuel source. The liquefaction of polystyrene was also performed using water as a solvent under same operation conditions for comparative study. Similarly, the pyrolysis of polystyrene was also conducted at 500°C for comparative study showed that liquefaction process and the use of ethanol as a solvent is more feasible for the production of better quality and quantity of Oil.

S. Tulashiea, et.al[2019] they proven that the pyrolysis technology can be used in converting the mixture waste plastics into an alternative energy source. It was observed that the oil contained more of aliphatic compounds, which is good for fuel in motor engines. Moreover, the fuel after characterization was observed to be in the diesel fuel range. The pyrolysis of plastic waste studied here presents an efficient, clean and very effective means of removing plastic debris that are left in the environment over the last several decades. The benefit of pyrolysis of mixture of plastic waste (recovery of energy and reduction of environmental problems) though will exist only as long as the waste plastics last it will surely provide a strong platform for us to build on a sustainable, clean and green future.

V. Mangesh, et.al [2019]they were adopted Experimental methods to find the suitability of PSW pyrolysis oil for conversion to diesel. The selected waste plastics for pyrolysis are HDPE, LDPE, PP, and styrene as these four materials 65% of the plastics in use. PPO had physicochemical properties closer to diesel values. PPO blended with diesel showed higher peal pressure and HRR (Heat Release Rate) than diesel. The CO, NOx and HC emissions of blended oil were significantly higher than pure diesel.

T. Anup, et.al [2014] they have performedthe experimentation on both the C.I & S.I Engine and concluded that petrol Engine was able to run with 100% waste plastic oil. Engine fuelled with waste plastic pyrolysis oil exhibits higher thermal efficiency up to 50% of the rated power for petrol engine. Engine fuelled with waste pyrolysis oil exhibits higher thermal efficiency up to 75% of the rated power for diesel engine. The NOx emission in waste plastic oil varies from 55ppm to 91 ppm for petrol grade fuel of plastic oil, and for diesel grade fuel of plastic varies from 192ppm to 1268ppm, CO emission increased by 5% in waste plastic oil compared to diesel operation.

C. Cleetus, et.al [2014] concluded that petroleum based fuel has been produced from waste plastic (polythene). In the performance analysis in engine, even though the plastic oil shows inferior results as compared to diesel, the lower blends percentage oils shows results close with that of diesel (B10, B20, and B 30). This makes it a strong competitor in the area of alternate fuels. Also the blend B20 has low CO emissions than for diesel. However, the NOx emissions are higher for B20.

M. Mani, et.al [2010] concluded that, WPO (Waste Pyrolysis oil) exhibits a higher cylinder peak pressure compared to diesel because of evaporation of WPO inside the cylinder by absorbing heat from the combustion chamber. The heat release rate with WPO is higher compared to Diesel due to better combustion. With an increase in percentage of WPO, NOx increases due to higher heat release rate and combustion temperature. Hydrocarbon is higher for WPO due to higher quantity of fuel admission. Smoke for WPO increases by about 35%, 40% throughout the load spectrum compared to diesel. Engine with WPO result in better performance than blend of WPO and diesel.

III. PROBLEM STATEMENT AND OBJECTIVES

3.1: Problem Statement

Sources of diesel are limited available and emission coming out by burning of diesel is affecting negatively on environment. Hence, it is necessary to search for an alternative fuel which can be used in available Internal Combustion Engine without any major modification.

3.2: Objectives

1. To prepare fuel from plastic waste.
2. To prepare blends of plastic fuel with diesel.
3. To check experimentally performance and emissionof diesel engine running on fuel prepared from plastic waste.
4. To compare performance and emissionparameters of plastic fuel blend with diesel fuel.

IV. METHODOLOGY

4.1: Pyrolysis Process

The conversion of oil from plastic has dual benefits. First, the oil produced can be used as a fuel for domestic purposes and also in vehicles and industries when further refined. Secondly the various types of pollution caused due to waste plastics can be minimized. Plastic in the first place is manufactured from natural gas specifically from ethane which is a constituent of natural gas. Therefore the waste plastic can be converted back into it. The pyrolysis is a simple process in which the organic matter is subjected to higher temperature about 300ºC to 500ºC in order to promote thermal cracking of the organic matter so as to obtain the end products in the form of – liquid, char and gas in absence of oxygen. Pyrolysis is a thermo chemical decomposition of organic matter at high temperature in absence of oxygen. The standard Pyrolysis process is as shown in Fig. Pyrolysisoffersagreathopeingeneratingfueloils,whichareheavil ypricednow.Thisreduces the economic burden on developing countries.

The capital cost required to invest on pyrolysis plant is low compared to other technologies. So, this technology may bean initiative to solve fuel crisis and the problem due to disposal of plastics.

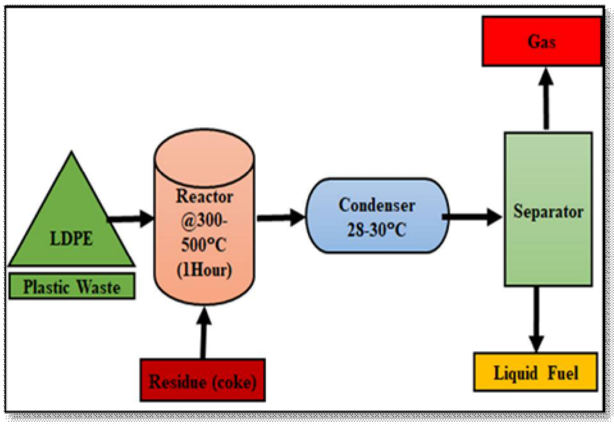
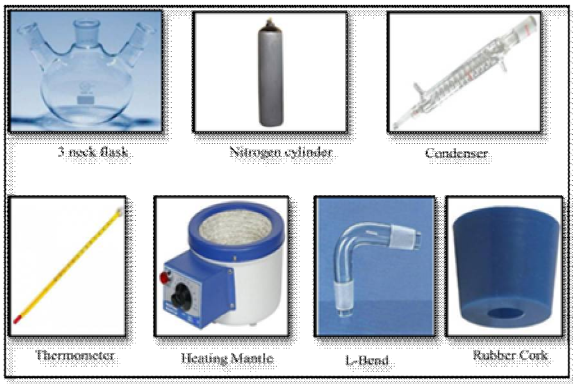


Fig 1: Block diagram of pyrolysis process

4.2: Fuel Extraction

The process was carried out in Laboratory on small scale. The equipment required for this process are **Heating Mantle** to heat the waste plastic continuously, **Three neck flask** for pour the waste plastic which need to heated, **Condenser** for converting the vapors into liquid. Condenser used for the process is of Shell & Tube type of condenser**.** **Thermometer** is used to measure the temperature in the flask. Thermometer is connected to the one neck of the flask. **Nitrogen gas** is used at the start of process to remove the oxygen from the flask. Another use of nitrogen gas is it helps the vapors to push out and comes into the condenser for condensation. **L-bend** is used to connect one neck of flask to the condenser. **Rubber cork** is used to close the flask with all the neck. The process for converting waste plastic into fuel is given below:

1. First the plastic wastes (L.D.P.E type of waste) are feed in three neck glass flask. The one neck is connected to condenser with L-bend, another neck is connected to nitrogen cylinder & third neck is connected to rubber cork with thermometer. This flask is enclosed because to create inert atmosphere. The inert atmosphere is created to avoid the burning of plastic due to presence of oxygen. Oxygen helps to anybody for burning; to avoid this, the contact of oxygen should be extracted from the flask.This is done by the supply of nitrogen which forces the oxygen out the flask and theinert atmosphere condition is achieved. Supply of nitrogen is at a rate of 5 lit/Min. for 5 minutes.



Pic.2: Components used for Fuel Extraction Process

2. Flask is kept on heating mantle. The sufficient temperature is set on heating mantlethat is 70°C at the start, then gradually the temperature of heating mantle increases. The wastes are melted at 115 to 120°C. After One hour, the temperature increases about 200°C and formation of vapor starts, boiling of vapors takes place at 300°C.

3. At the temperature of 350°C, These vapors are entering in the condenser. Condenser condenses these vapors &converts it into liquid state which is the final product of the process, known as fuelfromplasticwaste. The conversion of total waste into fuel requires 2to 3 hours.

Pic.3: Laboratory Setup for Fuel Extraction

Pic.4: Plastic Fuel

4. Now, collected fuel is further tested in the Kulkarni laboratory, Pune to know the parameters such as Calorific Value, Density, Viscosity, Flash and Fire Point. The values for those properties given below:

Table No 1: Properties of Plastic Fuel

Sr. No.	Parameters	Unit	Plastic Fuel	Diesel
1.	Gross Calorific Value	Kcal/kg	11698	10897
2.	Flash Point	°C	23	72
3.	Fire Point	°C	27	82
4.	Density 1) @15°C 2) @25°C	gm/cc gm/cc	0.7917 0.7863	0.8375 0.9155
5.	Viscosity 1) @15°C 2) @40°C	cst cst	2.432 2.162	3.05 2.61

4.3: Experimental Setup

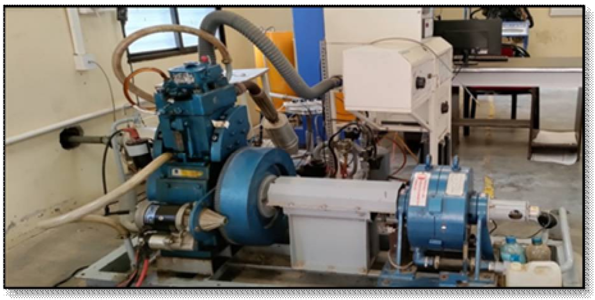
The plastic fuel needs to be tested in an engine to specifically check the use of the fuel and its strength. For this process at some small level experimentation was carried out on a Variable Compression diesel engine by using a blend of plastic fuel and diesel. The specifications of engine are as follows.

Specifications:

Power:-3.50 KW
Speed:-1500 rpm
No of Cylinder: - Single Cylinder

The blend of plastic could lead a safe test. This blend test was taken in an IC engine Lab of **Dr. Babasaheb Ambedkar Marathwada University, Aurangabad.** The engine is a Single Cylinder four-stroke water Cooled diesel engine. First of all, the test was taken on the diesel fuel to check the various points of a diesel fuel to compare with the blend. There were two supplies to the engine by which the diesel was injected into the cylinder. The first supply was by a fuel tank fixed at a point and another supply was given by a vertical glass tube. Both of the supplies were regulated by two switches. The fuel tank was used to continually supply the fuel to make the engine run continuously.

The vertical tube was having the marking on it to measure the amount of fuel consumed by engine within a certain time period. The engine output shaft was connected to a flywheel which was having a loading system. The Load sensor senses the load on the engine and shows it on the digital meter, Sensor measure load in kilograms. Temperature of different Thermostat is also shows at various points. All this values are calculated and shows with a graph on the computer screen attached to the engine having Engine soft Software. The exhaust system was connected to a pipe. We can test the emissions made by fuel by connecting the pipe to the 3 gas analyzer machine. After starting the engine, we took the first test on the diesel, by gradually varying a load from No load, 25%, 50%, 75% and 100% load. The blends were made B10, B20, B30 and B40 the same process repeated for these four blends and also measure the emissions for the every blend at the same time.



Pic.5: Experimental Setup

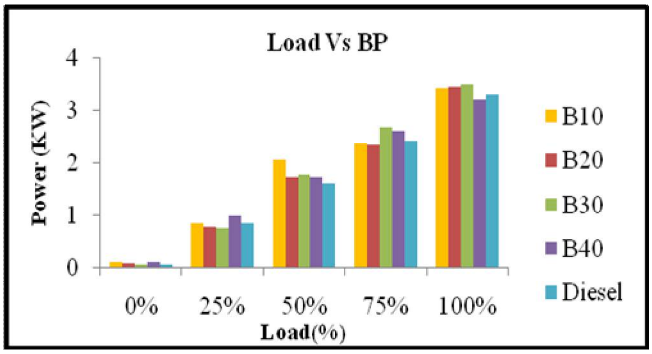
V. RESULT AND DISCUSSION

5.1: Performance Analysis

5.1.1: Load Vs. Break Power

The power developed by an engine at the output shaft is called Break Power and is therefore the capacity of the engine. The power developed in the combustion chambers of the engine is greater than the delivered power because of friction and other mechanical losses. From the graph1, it is observed that brake power increases with respect to load for all test fuels. This may be due to more amount of fuel taking part in combustion process increases which leads to increase in brake power. B20 shows the maximum brake power of all load conditions among all test fuels. For further blends decrease in brake power compare to B20 is observe this may due to presence of more plastic fuel in the remaining blend compare to B20 which may leads partial incomplete combustion

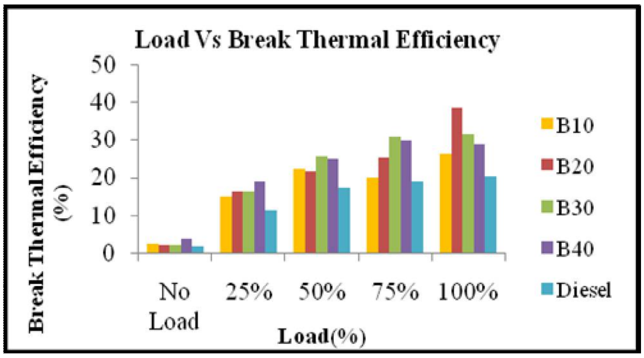
.



Graph 1: Variation of Break Power with Load

5.1.2: Load Vs. Break Thermal Efficiency

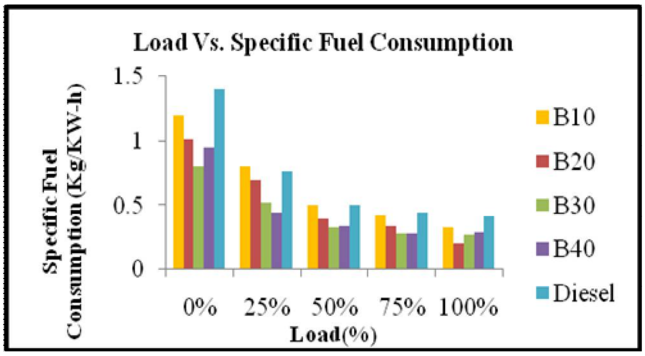
The variation of brake thermal efficiency with load for Plastic fuel blends is shown in graph 2. It was observed that, increase in engine load, the heat generated in the cylinder increases which result in increased thermal efficiency.Increased temperature in exhaust also results in lower BTE due to the lower conversion of heat into energy. From the graph it is observed that B20 shows the higher Break Thermal Efficiency at higher load (38.57%) compared to other blends. It is due to the increased load results in higher conversion and less heat loss which results in increase in BTE. Higher Calorific value will also results in increase in break power increase the BTE.



Graph 2: Variation of Break Thermal Efficiency with Load

5.1.3: Load Vs. Specific Fuel Consumption

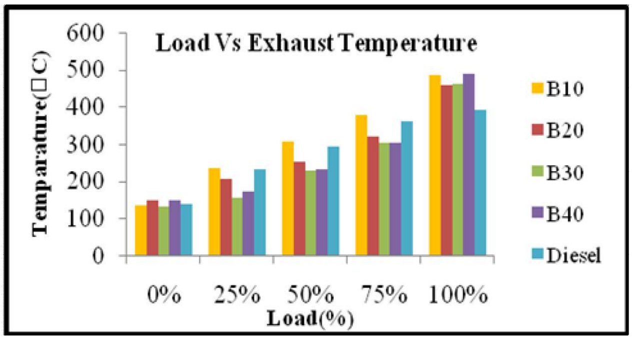
With an increase in the load, the SFC for different blend is represented in Graph.3. It was observed that with an increase in load the SFC reduces comparatively. For Diesel the SFC at zero load is higher (0.14 kg/kw-h) while at full load value decreases (0.42 kg/kw-h). In the case of blends, B20 shows the minimum value of SFC at full load condition (0.2 Kg/Kw-h) and higher at zero load (1.02 Kg/Kw-h).. At higher engine speed the fuel combustion is improved due to improved mixing of fuel and air. Better mixing and high-in-cylinder temperature also promote the combustion process providing low specific fuel consumption. In case of blends, the reduced SFC has mostly observed due to lower heating value, and higher viscosity of the fuel.



Graph 3: Variation of Specific Fuel Consumption with Load

5.1.4: Load Vs. Exhaust Temperature

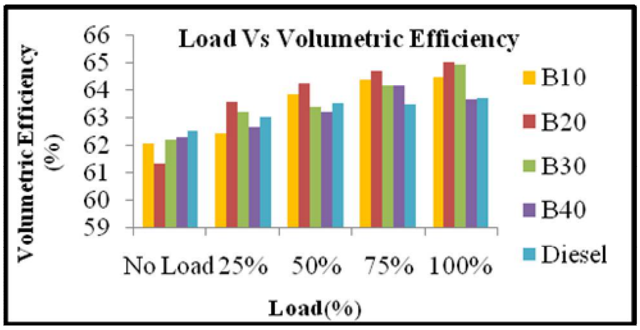
Graph 4 represents the exhaust temperature variation at different loads for different blends and diesel. For diesel exhaust temperature changes from 139.04°C at zero load to 391.4°C at full load while for 40% blend, the temperature was 147.04°C at zero load to 490.28°Cat full load. It is found that increase inplastic fuel blend increase the exhaust temperature. Delayed combustion in the cylinder results in low heat transfer which results in increase in exhaust temperature.



Graph 4: Variation of Exhaust Temperature with Load

5.1.5: Load Vs. Volumetric Efficiency

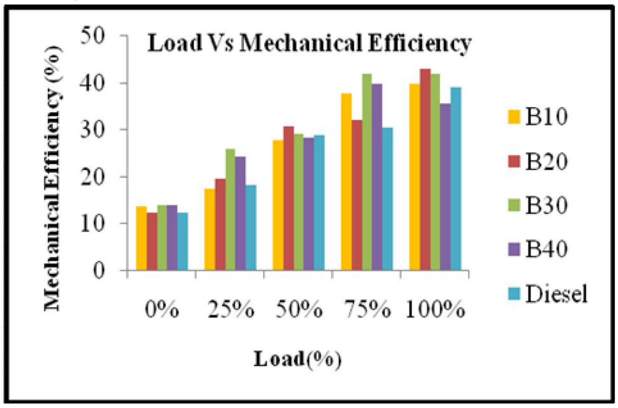
From graph 5 it is observed that, the volumetric efficiency increases with increase in the load. Diesel shows higher volumetric efficiency (6373%) at high load while blend B20 shows the higher volumetric efficiency (65.05%) among all other prepared blends at higher load. It is due to less plastic fuel content compared to other blend in B20.



Graph 5: Variation of Volumetric Efficiency with Load

5.1.6: Load Vs. Mechanical Efficiency

From Graph 6, it is observed that, with an increase in the load, mechanical efficiency increases at certain load condition and then decreases. Diesel shows the higher mechanical efficiency (38.99%) at full load and then decreases at high load. In case of blends, B20 shows higher mechanical efficiency (43.11%) at full load.

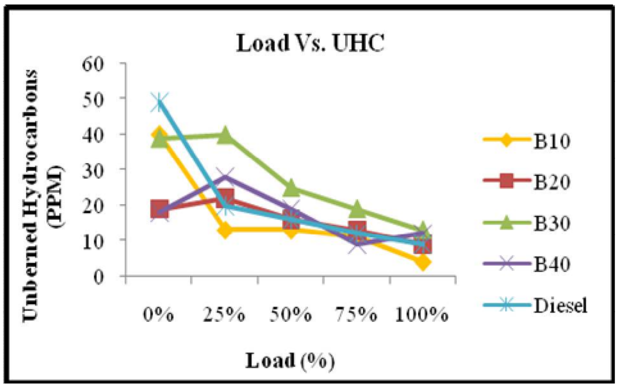


Graph 6: Variation of Mechanical Efficiency with Load

5.2: Emission Analysis

5.2.1: Load Vs. Unburned Hydrocarbons

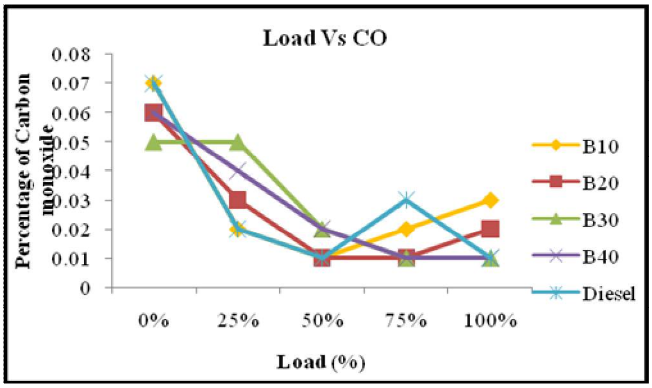
The variation of UHC emission with increasing load for diesel and plastic fuel blends is represented in the graph 7. For diesel, the value of UHC decreases from zero load to high load. For blend, it also shows the Value of UHC decreases from zero load to high load, But increase with increase in the percentage of plastic fuel. The increase in the amount of plastic fuel emission increases due to incomplete combustion and un-reacted hydrocarbons. There are 2 main reason reported for higher UHC emissions with plastic blend. First, the fuel (Plastic fuel blend) does not propagate more rooted into the combustion chamber resulting in the congregation along the cylinder wall. The second reason is non-reactive unsaturated hydrocarbons which do not break during the combustion process and gets emitted with the exhaust.



Graph 7: Variation of Unburned Hydrocarbons with Load

5.2.2: Load Vs. Carbon Monoxide

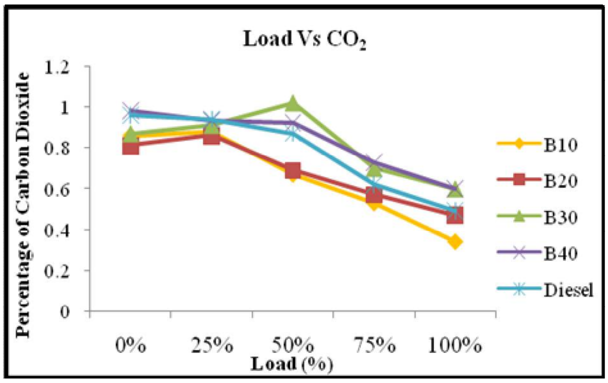
Combustion of hydrocarbons produces CO as an intermediate compound which forms due to incomplete combustion. Air fuel ration relative to stoichiometric proportions is the major component in the production of CO. The result shows that the plastic fuel blends produces more CO as compared to diesel fuel. The reason for the increase in CO concentration is high fuel consumption at higher loads. Also it was reported that the increase CO emission is due to low in-cylinder temperature during to combustion. It was observed that diesel produces maximum CO emission at low load condition. For an increased proportion of plastic fuel blend, the increase in emission was observed. Plastic fuel blend contains a high amount of oxygenated compound which results in increases CO emission



Graph 8: Variation of Carbon Monoxide with Load

5.2.3: Load Vs. Carbon Dioxide

Complete oxidation of fuel results in higher heat release and high CO_2 formation. From the environmental aspects, the CO_2 emission has to be reduced which adds to the greenhouse effect. Figure represents the emission of CO_2 with variation in load for diesel and plastic fuel blends. It was observed that CO_2 emission is lower in case of plastic fuel blend B20 is lower due to insufficient combustion while diesel produced an increase CO_2 emission due to increased combustion. At lower loads high availability of oxygen causes complete combustion resulting in high emission while at increased load low oxygen content causes insufficient combustion resulting in low CO_2 emission.



Graph 9: Variation of Carbon Monoxide with Load

VI. CONCLUSION

The utilization of plastic waste for the conversion into fuel oil via pyrolysis is available method with the high amount and superior quality. The utilization of waste plastic fuel with diesel in different proportions was tested in a diesel engine, and the results are reported as follows:

1. Pyrolysis of LDPE plastic waste at above 400°C produces a high quality fuel having physical properties similar to conventional fuel like diesel. A waste plastic fuel is excellent alternative to be used as fuel in diesel engine without any modification in available internal combustion engine.
2. Addition of waste plastic fuel up to 20% with diesel shows an increase in break thermal efficiency when compared to diesel fuel. It provides increased efficiency while the specific fuel consumption characteristics show a decreasing value when compare to diesel and hence shows good fuel characteristics.
3. At full load condition, UHC and CO_2 emissions are low in case of plastic fuel blend when compared to diesel. CO shows comparatively same value as of diesel.

VII. ACKNOWLEDGMENT

Authors are thankful to Director, DIEMS, Aurangabad and Director-DDUKK, Aurangabad for their support to carry out this research work. The authors acknowledge DDUKK, Automobile Division, for allowing conducting experiments on Engine Testing Setup. The authors acknowledge the use of the facility created by Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, for the analysis of Fuel blend samples.

REFERENCES

[1] B.Phanisankar, N.VasudevaRao, J.Manikanta, " Conversion of waste plastic to fuel products", Materials Today, Vol.33,part 8,2020,pp 5190-5195.

[2] K. Vershinina, P.Strizhak V. Dorokhov, D. Romanov, "Combustion and emission behavior of different waste blends in a laboratory furnace", Fuel, Vol.285, 2020,pp 1-10.

[3] N. Ahmad, N. Ahmad, I. Maafa, U. Ahmed, P. Akhter, N. Shehzad, U. Amjad, M. Hussan, " Thermal conversion of polystyrene plastic waste to liquid fuel via ethanolysis",Fuel,Vol.279, 2020, pp118498-118508.

[4] K. Kumar Jha,T. Kannan, "Alternate fuel preparation in low cost from waste plastic: A review", Materials Today: Proceedings, 2020, pp1-2.

[5] D. Kulandaivela, I.G. Rahamathullahb, A.P. Sathiyagnanamc, K. Gopald, D. Damodharane, De Poures, Melvin Victorf "Effect of retarded injection timing and EGR on performance, combustion and emission characteristics of a CRDi diesel engine fueled with WHDPE oil/ diesel blends", Fuel, Elsevier Ltd., vol.278, 2020,pp1-12.

[6] Yong-HaoKuan, Fang-Hsien Wu, Guan-Bang Chen, Hsien-Tsung Lin, Ta-Hui Lin "Study of the combustion characteristics of sewage sludge pyrolysis oil, heavy fuel oil, and their blends", Energy, Vol.201, Elsevier Ltd., 2020, pp1-15.

[7] Amar Kumar Das, DulariHansdah, Alok Kumar Mohapatra, Achyut Kumar Panda, "Energy, exergy and emission analysis on a DI single cylinder diesel engine using pyrolytic waste plastic oil diesel blend", Journal of the Energy Institute, Vol. 93, 2020, pp 1624-1633.

[8] S. Kofi Tulashiea, E. Kofi Boadub, Samuel Dapaaha, "Plastic waste to fuel via pyrolysis: A key way to solving the severe plastic waste problem in Ghana", Thermal Science and Engineering Progress, Vol11, 2019, pp417-424.

[9] R. Singh, B. Ruj, A. Sadhukhan, P. Gupta, V. Tigga, "Waste plastic to pyrolytic oil and its utilization in CI engine: Performance analysis and combustion characteristics", Fuel, Vol.262, 2019, pp116539-116545.

[10] V.L. Mangesh, S. Padmanabhan, P. Tamizhdurai, S. Narayanan, A. Ramesh, "Combustion and emission analysis of hydrogenated waste polypropylene pyrolysis oil blended with diesel", Journal of Hazardous Materials,2019,pp 1-40.

[11] L. Quesada, M. Calero, M. Martin-lara, G. Blazquez, "Characterization of fuel produced by pyrolysis of plastic film obtained of municipal solid waste", Energy, Vol. 186,2019, pp115874-115881.

[12] V. Mangesh, S. Padmanabhan, P. Tamizhdurai, A. Ramesh, "Experimental investigation to identify the type of waste plastic pyrolysis oil suitable for conversion to diesel engine fuel" Journal of cleaner production ,Vol.246, 2019, pp1-28.

[13] Shashankpala, V Chintalaa, Amit Kumar Sharmab, Praveen Ghodkec, Sagar Kumara, Pramesh Kumara, "Effect of injection timing on performance and emission characteristics of single cylinder diesel engine running on blends of diesel and waste plastic fuels", Materials Today: Proceedings, Vol.17, 2019 PP209–215.

[14] HariramVenkatesan , SeralathanSivamani, KunalBhutoria, Harsh H. Vora, "Experimental study on combustion and performance characteristics in a DI CI engine fuelled with blends of waste plastic oil", Alexandria Engineering Journal, Vol. 57, 2018, PP 2257-2263.

[15] C.A. Rinaldini, E. Mattarelli a, T. Savioli, G. Cantore , M. Garbero , A. Bologna, "Performance, emission and combustion characteristics of a IDI engine running on waste plastic oil", Fuel, Vol.183, PP 292-303.

[16] Viswanath K. Kaimal, P. Vijayabalan, "An investigation on the effects of using DEE additive in a DI diesel engine fuelled with waste plastic oil", Fuel, Vol.180, 2016, PP 90-96.

[17] J. Devraj, Y. Robinson, P. Ganapathi, "Experimental investigation of performance, emission and combustion characteristics of waste plastic pyrolysis oil blendedwith diethyl ether used as fuel for diesel engine", Energy , Vol.85, 2015, PP 304-309.

[18] Viswanath K. Kaimal, P. Vijayabalan, "A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends", Energy Conservation and Management, Vol.105, 2015, PP 951-956.

[19] T. Anup, V. Watve, "Waste Plastic Pyrolysis Oil as Alternative For SI and CI Engines", International Journal of Innovative Research in Science, Engineering and Technology, Vol.3,issue 7, 2014, PP 14680-14687.

[20] C. Cleetus, S. Thomas, S. Varghese, "Synthesis of Petroleum-Based Fuel from Waste Plastics and Performance Analysis in a CI Engine," Journal of energy, 2013, pp1-10.

[21] M. Mani, G. Nagarajan, S. Sampath,"Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine", Energy, Vol.36, 2010, 212-219.