Liquid fuel production from waste plastics by pyrolysis process and evaluation of its fuel properties

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Abstract - Waste plastics have produced very serious environmental challenges due to their enormous quantities and problems involved in their disposal. The most attractive technique of chemical feedstock recycling process is pyrolysis. The oil is obtained by the pyrolysis process from the waste plastics can be utilized as an alternative fuel. Waste Plastic Oil (WPO) and diesel are compared the properties of the fuel such as calorific value, density, water content, kinematic viscosity, flash point, ash content and charcoal have been determined as per ASTM standards. WPO has high viscosity of 3.25 cSt compared with diesel 2.10 cSt. The water content of the remaining oil phase was measured as 0.05 wt. % in WPO and 0.12 wt. % in diesel. The WPO has satisfactory heating value is 43MJ/kg and for diesel is 42.5MJ/kg. Higher value of moisture content present in the Charcoal, results in lower calorific value of charcoal.

Key words - waste plastics, waste plastics oil, char coal, properties of waste plastics.

I. INTRODUCTION

Plastics is one of the greatest innovations in the millennium. It is the fact that plastics is light in weight, it is not rust or decay, inferior cost, reusable and conserves natural resources. Economic growth, changing consumption and production patterns results in the rapid increase in the generation of waste plastics. The waste management system consists of the entire span of activities related to handling, treating, disposing or recycling the waste materials. General classification of wastes is difficult to some of the most general sources of wastes are domestic wastes, biomedical wastes, hazardous wastes, construction wastes, biodegradable wastes, commercial wastes, industrial solid wastes, non-biodegradable wastes, ashes and animal wastes.**[1].** Solid waste management, most of the plastic waste is either collected properly or disposed in an suitable manner to avoid its counter impacts on the state of affairs and public health.

Waste plastics are causing litter everywhere, even choking the sewage system. As plastic waste virtually does not degrade, it occupied the land space for several years after disposal. There are various methods for disposal of municipal and industrial waste, i.e. incineration, landfill, material recycling and chemical recovery. Land filling is not a suitable choice for disposing wastes and incinerator creates some pollutants to the air. Therefore, recycling and recovering are the best method to minimize the environmental impacts. Because of the existing after effects of the waste plastics, these materials transformed into an alternate fuel with the aid of conversion processes like thermal cracking and catalytic pyrolysis cracking methods.**[2,3].**

Plastics are composed primarily of hydrocarbons, but also contain additives such as antioxidants, colorants and other stabilizers.**[4].** Waste plastics cracked catalytically and thermally with or without presence of catalysts in a reactor in the temperature range 400-550°C to obtain suitable liquid fuels.**[5,6].** Many differences were observed between yields and composition of products which decreases with increasing in temperature. Thermal and catalytic oxidative decomposition is a capable technique to degrade plastic waste. **[7].** Decomposition of waste plastics is to derived gas, oil and wax in terms of the temperature, time and amount of catalyst. **[8,9].** Plastic waste was produced the highest liquid fraction. The presence of catalyst increased the gaseous fraction and reduced the liquid fraction.**[10].**

II. MATERIALS

Pyrolysis is a thermal degradation process in the absence of oxygen, performed to obtain WPO by using as a catalyst. **[11].** The experimental layout & setup of the pyrolysis process is shown in **Figure 1**. Different sizes and shapes of waste plastics were collected and crushed with a shredder for ease of handling the process. Finely crushed waste plastics were fed into a reactor chamber. The heating coil placed around the burning chamber is heated and

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maintained at a temperature range of 320-500^{0}C for 3-4 hours duration.**[12].**

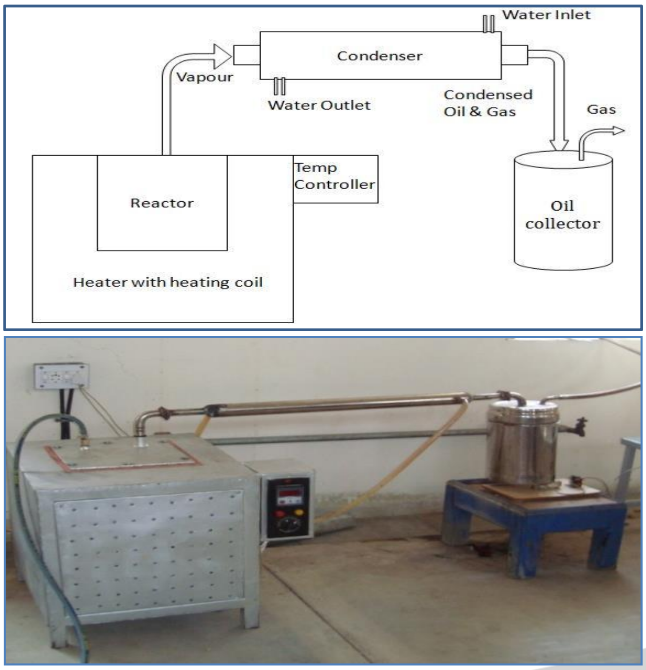

Figure 1 Experimental layout and setup of pyrolysis process

At this high temperature, waste plastic becomes vaporized and passes through the condenser devices. Due to the cold water present in the condenser, latent heat transfer occurs by condensing the waste plastic vapour. **[13].** The condensed waste plastic vapour is then stored in the oil collector in the form of plastic oil. From the pyrolysis treatment the following output products were collected: WPO - 75% to 90%, Gas - 5% to 20% and Residual coke - 5% to 10%. **[14].**

III. RESULT AND DISCUSSIONS

The physical and chemical properties of the WPO and diesel oil including the Gross calorific value, Cetane index, density, water content, kinematic viscosity, flash point and ash content is as shown in the **Table 1**.

Gross calorific value

The Gross Calorific Value of the fuel determined in accordance with IS 1448, P25 calorimeter used. In this experiment, weighted oil samples are placed in a combustion bomb calorimeter and ignited by heating wires in oxygen enriched environment. The system automatically logs the temperature increase in the combustion bomb and calculates the temperature increasing rate and gross heating value of the weighed sample. The WPO and diesel have satisfactory heating values for fuel oils are 43 MJ/kg and 42.5 MJ/kg respectively. Brake thermal efficiency entirely depends upon calorific value of the fuel.

Table 1 properties of diesel and WPO

Sl.No	Properties	Protocol	Diesel	WPO
1.	Density(kg/m^3)	IS 1448, P 16	860	835
2.	Kinematic viscosity (cSt)	ASTM D 445	2.10	3.25
3.	Gross calorific value (MJ/kg)	IS 1448, P25	42.5	43
4.	Flash point ^{0}C	IS1448, P20	50	41
5.	Fire point ^{0}C		56	49
6.	Cloud point ^{0}C	ASTM D 97	-6	+ 6
7.	Cetane number	IS 1448, P9	50	48
8.	Water content (%)	ASTM D 95	0.05	0.12
9.	Sulphur content (%)	ASTM D 5433	0.25	0.20
10.	Ash content (%)	ASTM D5347	0.01	0.012

Cetane index

The Cetane index (CCI) of the oils was calculated in accordance with IS1448, P8 by using the oil densities at 15^{0}C. Both pyrolysis oils show a greatly reduced CCI compared with diesel and biodiesel. The main reason for this is that pyrolysis oils have significant aromatics content and for the same carbon number aromatics have the lowest cetane number, followed by naphthenes and paraffins. Diesel CCI is higher, indicates that will combust more rapidly in the engine and also could be less harmful emissions from the exhaust compared to WPO. **[15.16].**

Density

The density of the oils was measured by an IS1448, P16 densitometer. Liquid samples are injected into a measuring cell and the device calculates the liquid density by measuring the light reflection from the liquid surface. It can be seen that of the WPO density is lower than conventional diesel are 835 and 860 respectively. Fuel density is straightly related to the performance of the engine, the injection system works primarily on a volume basis. However, an increase in fuel density leads to an advance in fuel injection timing and a greater spray cone angle as well as reduced fuel spray penetration in the cylinder.**[17].** This may result in a poorer combustion and unstable engine operation.

Water content

The water content of the bio-oils was determined using a Mettler Toledo V30 Compact Volumetric Karl Fischer (KF) titrator in accordance with ASTM D95. The water content of the remaining oil phase was measured as 0.05 wt. % in WPO and 0.12 wt. % in diesel. This could be considered as reasonable exist since it does not greatly reduce the oil heating values and does not lead to a further significant

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phase separation problem during oil storage. Furthermore, modest water content in the oils can reduce the combustion temperature in the cylinders and thereby reduce NOx emission.

Viscosity

Kinematic viscosity, which is the resistance to flow of a fluid under gravity, was measured in accordance with ASTM D 445 with a Cannon–Fenske Routine glass capillary viscometer. During the test, fixed volume of oil samples are passed through the capillary of the viscometer under gravity at 40^{0}C. The sample travelling time is recorded. The kinematic viscosity is then the product of the viscometer calibration constant and the measured flow time. WPO has a very high value of 3.25 cSt compared with conventional diesel 2.10 cSt. Viscosity is beneficial in lubricating the fuel supply system and thus decreasing mechanical wear, however on the other hand it worsens the flow characteristics of the oil and its atomization quality which can cause incomplete combustion and engine power loss.

Flash point

Flash point was determined in accordance with IS1448, P20 by a Closed Cup apparatus. A test flame is directed to the pre-set location where the vaporized oil may be released at specified temperature intervals until the flash is detected and have flash points, 41^{0}C for WPO oil and 50^{0}C for diesel. They may therefore be considered to have a high safety level in transportation and storage.

Ash content

Ash content of the oil was determined in accordance with ASTM D 5347. The carbonaceous solid samples produced from the Carbon Residue test were combusted in a muffle furnace at 775^{0}C. The remaining ash was cooled at room temperature and weighed and then expressed as a mass percentage of the original oil sample. Ash content of the oils was measured as 0.012 wt. % for WPO and 0.01 wt. % for diesel.

WPO - Charcoal

Charcoal is a bi product obtained by the pyrolysis process from waste plastics and it consists of carbon, ash, water and other volatile elements in the charcoal. The properties of Charcoal such as moisture, Ash, volatile matter, fixed carbon and Gross Calorific value are as shown in the **Table.2.** The higher value of moisture content existing in the charcoal results in bring down the calorific value.**[18].**

Table 2. Properties of Charcoal of Waste Plastics.

Parameters	Units	Results	Methods
Moisture	%	4.35	IS : 1350 P – I 1984
Ash	%	62.98	IS : 1350 P – I 1984
Volatile matter	%	20.59	IS : 1350 P – I 1984
Fixed carbon	%	12.08	IS : 1350 P – I 1984
Gross calorific value	kJ/kg	7037.48	IS : 1350 P – II 1970

IV. CONCLUSION

Investigations the fuel properties of WPO and diesel carried out to assess the potential for using WPO as an effective alternate fuel for diesel engines. The following conclusions could be raddled from the present study.

- WPO has higher heating values is 43 MJ/kg and compared to diesel is 42.5 MJ/kg. Flash and fire point is earlier compared to diesel. Flash point temperature have 41^{0}C for WPO and 50^{0}C for diesel.
- WPO of density and water content are lower than that of diesel fuel are 835 kg/m^3 & 0.05 wt % and 860 kg/m^3 & 0.12 wt.% respectively. WPO has significant aromatics content so that Pyrolysis oil shows a normally reduced Cetane number compared with diesel.
- Viscosity of WPO has a high value of 3.25 cSt compared with diesel 2.10 cSt. It increases the lubricating of fuel supply system and thus decreasing mechanical wear.
- Ash content of the oils was measured as 0.012 wt. % for WPO and 0.01 wt. % for diesel and the higher value of moisture content present in the Charcoal, results in lower calorific value of charcoal.

REFERENCES

[1] Ayhan Demirbas 2011, 'Waste management, waste resource facilities and waste conversion processes', Energy Conversion and Management, vol. 52, pp. 1280-1287.

[2] Neha Patni, Pallav Shah, Shruti Agarwal, & Piyush Singhal 2013, 'Alternate Strategies for Conversion of Waste Plastic to Fuels', Renewable Energy, vol. 2013, pp. 1-7.

[3] Al-Salem, SM, Lettieri, P & Baeyens, J 2009, 'Recycling and recovery routes of plastic solid waste (PSW): A review', Waste Management, vol. 29, no. 10, pp. 2625-2643.

[4] Williams, PT & Williams, EA 1990, 'Interaction of plastics in mixed plastics pyrolysis', Energy and Fuels, vol. 13, pp. 188–196.

 DOI : 10.35291/2454-9150.2022.0123

[5] Achyut K Panda & Singh, RK 2013, 'Experimental Optimization of Process for the Thermo-catalytic Degradation of Waste Polypropylene to Liquid Fuel', Advances in Energy Engineering, vol. 1, no. 3, pp. 74-84.

[6] Yumiko Ishihara, Hidesaburo Nanbu, Tadashi lkemura & Tomoyuki Takesue 1990, 'Catalytic decomposition of polyethylene using a tubular flow reactor system', Fuel, vol. 69, no. 10, pp. 978-984.

[7] Adil Koc & Ali Y Bilgesu 2007, 'Catalytic and thermal oxidative pyrolysis of LDPE in a continuous reactor system', Journal of Analytical and Applied Pyrolysis, vol. 78, no. 1, pp. 7-13.

[8] Jasmine Shah, Rasul Jan, M & Zahid Hussain 2005, 'Catalytic pyrolysis of low-density polyethylene with lead sulfide into fuel oil', Polymer degradation stability, vol. 87, no. 2, pp. 329-333.

[9] Buekens, AG & Huang, H 1998, 'Catalytic plastics cracking for recovery of gasoline-range hydrocarbons from municipal plastic wastes', Resources, Conservation and Recycling, vol. 23, no. 3, pp. 163-181.

[10] Mochamad Syamsiro, Harwin Saptoadi, Tinton Norsujianto, Putri Noviasri, Shuo Cheng, Zainal Alimuddin & Kunio Yoshikawa 2014, 'Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors', Energy Procedia, vol. 47, pp. 180-188.

[11] Mani, M, Subash, C, Nagarajan, G 2009, 'Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil', Applied Thermal Engineering, vol. 29, pp. 2738–2744.

[12] Senthilkumar, P, Sankaranarayanan, G 2015, 'Production of waste polyethylene bags in to oil and studies performance, emission and combustion characteristics in DI diesel engine', International Journal of Humanities, Arts, Medicine and Sciences, vol. 3, pp. 149-158.

[13] Senthilkumar, P and Sankaranarayanan, G 2016, 'Effect of Jatropha methyl ester on waste plastic oil fueled DI diesel engine', Journal of the Energy Institute, vol.89, pp. 504-512.

[14] Senthilkumar, P and Sankaranarayanan, G 2016, 'Investigation on environmental factors of waste plastics into oil (WPO) and its emulsion to control the emission in DI diesel engine', Ecotoxicology and Environmental safety, vol.134, pp. 440–444.

[15] Senthilkumar, P 2018, 'Environmental effect of using diesel on waste plastic oil fueled in DI diesel engine', International Journal of Mechanical Engineering, vol. 7, no.3, pp.1-8.

[16] Mani, M, Nagarajan, G, Sampath, S 2007, 'Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine', Energy, vol. 36, pp. 212-219.

[17] Yamane, K, Ueta, A & Shimamoto, Y 2001, 'Influence of physical and chemical properties of biodiesel fuels on injection, combustion and exhaust emission characteristics in a direct injection compression ignition engine', In: The 5th international symposium on diagnostics and modelling of combustion in internal combustion engines, comodia 2001, Nagoya.

[18] Vongsaysana Sayakoummane & Achara Ussawarujikulchai 2009, 'Comparison of the Physical and Chemical Properties of Briquette and Wood Charcoal in Khammouane Province, Lao PDR, Environment and Natural Resources Journal, vol. 7, no. 1, pp. 12-24.

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