Extraction of Hdpe Pyrolysis Oil

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***Abstract*:- Plastic waste (PW) is an issue related to the environmental pollution. Even after adopting several recycling methods, considerable amount of PW is getting accumulated on earth and in seas and oceans. Thus, endangering the land and marine life. The best way to reduce PWs is to convert them into some useful products. Thermal pyrolysis is one of the best methods that transforms PWs. In the process, PWs are heated in the absence of oxygen to a particular range of temperature, that releases combustible gas vapours. The gas vapour when cooled suddenly, transforms into wax and plastic oil. In this research, a reactor unit was fabricated, thermocouple and pressure gauges were fixed to note down the temperature and pressure. 5 kg of High Density Polyethene (HDPE) plastic waste was transferred into the reactor and heated up to 450 ºC. The temperature was maintained for about 20 minutes. Half inch copper coil type heat exchanger for condensing the gas vapour. However, at 450 ºC only wax was obtained as the output. The conversion efficiency of the PWs into wax was around 79%. Further, the output wax was distilled till the temperature reached 250 ºC. The property of the distilled oil was tested, and the output was tabulated. It was noted that around 2.2 litres of oil was extracted from 5 kg of PWs.**

Keywords: Plastic Waste, Plastic Oil, HDPE, Wax, Heat Exchanger, Reactor, Pyrolysis

1. INTRODUCTION

The use of plastic materials in contemporary life has become more pervasive and impossible to ignore, which leads to an annual increase in plastic production across all industries[1], [2], which also experiences advancement and innovation. Advantages of plastic materials include its low weight, transparency, strength, and affordable production method. Used plastic will be released into the environment, eventually ending up in the ocean or a landfill. According to research, Indonesia is the second-largest producer of plastic garbage that ends up in the ocean behind China, with 187.2 million tonnes produced [3]. Large polymeric molecules make up plastic, which frequently resembles lengthy chains formed of an almost limitless number of interconnecting connections. Although there are many natural polymers, including silk and rubber, they have not been linked to environmental pollution since they degrade quickly in the environment. Today, however, the typical consumer interacts on a daily basis with a wide range of plastic materials that have been created specifically to thwart natural decay processes. These materials, which are primarily derived from petroleum and can be moulded, cast, spun, or applied as a coating, come in a variety of shapes and sizes [4]. In order to overcome the issue of plastic wastes disposal in the environment several measures have already been taken up worldwide. However, due to growing population and its direct impact on production and consumption of plastic wastes have not been able to come out with any one concrete solution that can solve this issue. Among the several solutions, pyrolysis is one such process that has gained wide recognition.

Pyrolysis is the thermal breakdown of a solid (or liquid) into smaller volatile molecules without the presence of oxygen or other oxidants. Pyrolysis is a required step in the combustion of most solid fuels. Pyrolysis of a given material can result in a wide range of thermal degradation products known as pyrolysis products. It is critical to remember that pyrolysis is a chemical reaction rather than a phase change. It is more accurately referred to as a thermal degradation process since it happens under heat and reduces bigger molecules into smaller ones. Many factors impact pyrolysis, including substrate type, the presence of oxygen or other compounds, the rate of temperature rise, and the temperatures attained. [5]. Plastics that have been combined, deteriorated, or contaminated can all be transformed by pyrolysis. Polypropylene (PP), Low Density Polyethylene (LDPE), and High-Density Polyethylene are the ideal polymers to use in order to acquire high-quality fuel and run safely (HDPE). Pyrolysis even accepts modest amounts of PET, PS, and PC plastics [6]. A simplified waste plastic pyrolysis process explanation and description is shown in Fig. 1.

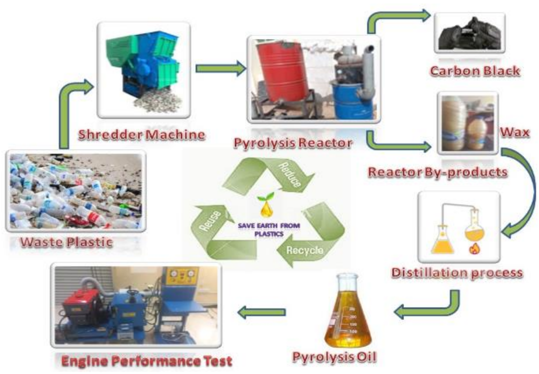

Figure 1: Simplified plastic pyrolysis process description

- Plastic wastes are collected from the identified locations.
- Plastics are shredded into smaller particles.
- Feed waste plastic materials into reactor and heat the reactor. When the temperature reaches 450°C, there will be oil gas and wax generating gradually.

- The oil gas then enters condensing system / heat exchanger and turns into wax and is collected in the collection tank.
- Wax is then subjected to distillation process to obtain the plastic oil.
- The gas which can't be liquefied will be designed to go back to combustion system. It can be recycled to heat the reactor as fuel.
- The oil will then be subjected to specific tests, which will be dealt as a part of the future work.

In the current work, the raw materials utilised were HDPE type plastic with Density (ρ) = 0.93–0.97 g/cc [7] and Crystalline melting temperature (TM) = 131 °C [8]. Normally, plastic bottle cap are made of HDPE plastics and these wastes were collected from the college canteen waste bins at University of Technology and Applied Sciences - Salalah, Oman. The mineral water cap bottle size of 28 mm were shredded using a shredder machine as shown in the Fig. 1. Also, the study employed a conventional type of reactor, made of carbon steel. The reactor heating process reaches a maximum temperature of 450 ºC, in a space that has been isolated to reduce the heat emanating from the system. This reactor can work either as a thermal or catalytic pyrolysis process.

2. REACTOR DESIGN AND FABRICATION

2.1 Reactor Design

- An empty commercial LPG gas cylinder was modified to work as a reactor as seen from Fig. 1
- The Diameter of the reactor = 0.35 m
- Height of the reactor = 0.90 m
- Total internal volume of reactor = $\frac{\pi}{4} \times 0.35^2 \times 0.9 = 0.087 m^3$ = 87 litres

Thus, the total volume of the reactor was 87 litres of liquid fuel. One end of the reactor is open for feeding the plastics and another end was closed with a 4" valve to remove residue. The final design parameters are indicated below:

- The internal volume of the reactor is 0.087 m^3.
- Internal diameter of straight part of reactor, D= 330 mm
- Intensity of internal pressure developing at the pyrolysis temperature of 450°C is 8.5 bar
- Number of cylinder cover bolts = 8.
- The wall thickness of the reactor tank was in accordance with the standard that is available on the market.
- The flange of the cylinder was made of low-carbon steel with a permissible stress of 62 MPa at a temperature of 430 °C.

2.2 Fabrication

The furnace / reactor for heating the waste plastics was fabricated to accommodate (a) compressed air (b) LPG. When the compressed air passed with high velocity, low pressure developed, and the atmospheric air introduced will help to burn LPG. During slow heating, only LPG was used. When high rate of heating was required, both LPG and Diesel were used. A schematic diagram of the furnace and the inlet for compressed air and LPG is as shown in Fig 2(a) and (b). In the furnace LPG and diesel fuels were used with compressed air. Regarding condenser design a half an inch copper coil type heat exchanger with total length of 7 m was used to condense the output vapour. This coil type heat exchanger was immersed in an 88 cm height and 57 cm diameter water drum with the total volume of 225 litres. Fig. 2(c) illustrates the schematic diagram of the condenser unit. The fabricated setup is shown in Fig. 2(d).

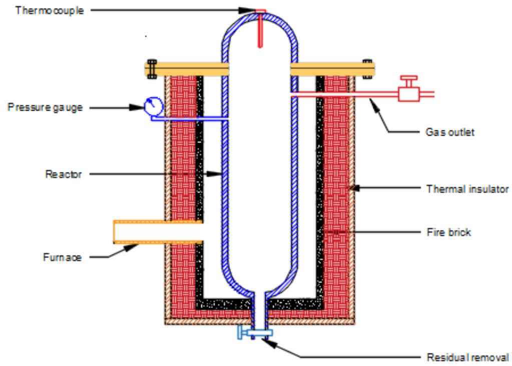

Fig. 2(a) A schematic diagram of the furnace

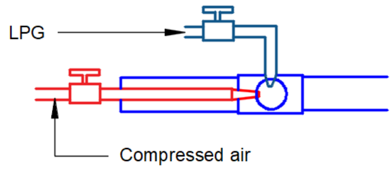

Figure 2(b) inlet for compressed air and LPG

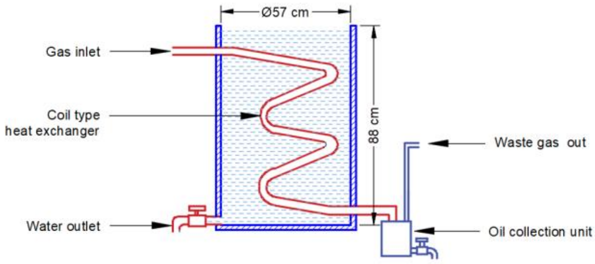

Figure 2(d) A schematic diagram of the condenser unit

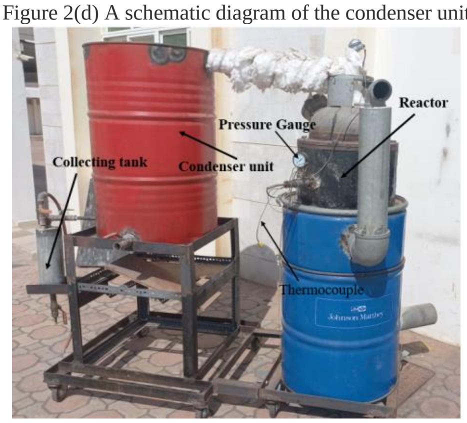

Figure 2(c) Fabricated Set-up of the pyrolysis reactor

3. RESULTS AND DISCUSSIONS

The experiment was conducted with HDPE plastics and yield of liquid (wax) output was measured at different temperature ranges with different heating rates. The generation of gas happens at 150ºC, but it cannot be cooled as only little quantity of gas is produced. However, when the temperature reached 350 ºC, large amount of gas starts to come out. At this time temperature was maintained between 350 - 375 ºC for 20 minutes. The output was collected for each 25 ºC temperature range with 20 minutes-maintained temperature. The valve was opened, and the semisolid-wax (Naphtha) was collected. Once the valve was opened, the pressure and temperature drops suddenly. The collected output was weighed and stored. Then again it was heated to the next range of temperature (376 - 400 ºC) and the output was collected after 20 minutes. Likewise, the output was collected in the range of 401 – 425 ºC and 426 - 450 ºC. The quantity of output was measured and tabulated as shown in Tables 1 and 2.

It was noted that the maximum yield was in the range of 400 - 425°C. Observations also revealed that 65 % to 70 % of oil was extracted in this temperature range. The temperature was kept constant for 30 minutes in these ranges. When the wax is expelled, the temperature decreased sharply. The volume of wax output, heating range is shown in Table 1. Also, Table 2 depicts quantity of wax output at different temperature ranges. Fig. 3(a) indicates the oil yield percentage increases with the heating rate. Fig. 3(b) illustrates with the increase in temperature and heating rate the output (the amount of wax collected) also increases

Table 1: Temperature range and the volume of wax output

Sl. No.	Temperature Range	Wax Output (kg)		
		4 Deg. C/min	6 Deg. C/min	8 Deg. C/min
1	351-375	0	0.114	0.316
2	376-400	0.37	0.687	1.343
3	401-425	2.405	2.964	3.318
4	426-450	3.7	3.8	3.95

Table 2: Heating rate verses wax output

Mass of HDPE feedstock (kg)	Heating rate (deg. C/min)	Output Percentage (%)	Output Mass (kg)	Volume of wax/Oil =(mass/ mass density) (litres)
5	4	74	3.7	3.98
	6	76	3.8	4.09
	8	79	3.95	4.25

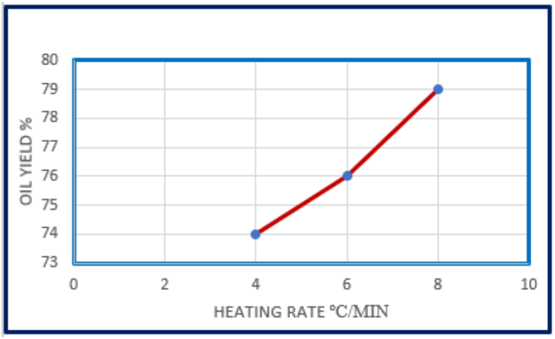

Figure 3(a) Oil Yield Percentage Vs. Heating Rate

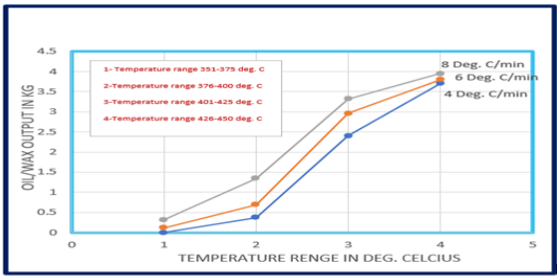

Figure 3(b) Wax output Vs Temperature Range

For 5 kg of HDPE feed stock the wax output was 3.95 kg at heating rate of 8 Deg. C/min whereas the output is 3.70 kg at heating rate of 4 Deg. C/min. Thus, the conversion of 79% and 74 % correspondingly. Since the heating mode was controlled manually, it was difficult to maintain a particular temperature. Due to the use of conventional furnace the maximum heating rate that could be achieved was only 8 Deg. C/min.

Now, since a good percentage of plastic was converted in to wax, the wax was further subjected to the distillation process. At heating rate of 8 ºC, 79 % conversion was obtained as already studied before. The output achieved was 3.95 kg on wt. basis. For distillation, 500 ml of wax was heated. A counter flow heat exchanger was used to cool the vapour output. Exactly, at 50 ºC, vapour started to come out. At 55 ºC, first drop of oil was collected in the flask. The distillation unit was heated at the rate of 2 Deg. C/min with the help of the LPG fuel. Up to 120 ºC, the vapour output and oil collection was less. After 120 ºC, the vaporization was more, and oil output also increased. Then after 180 ºC, the vaporization decelerated and only less amount of fuel was collected up to 250 ºC. Distillation process was repeated to ensure repeatability under the same condition, and same amount of oil was collected. It was observed that only about 10% of oil was collected in the range of 50 ºC to 120 ºC and 75% of oil was collected in the range of 121-180 ºC. Around 15 % oil was collected in the temperature range of 181 - 250 ºC. Thus, from 500 ml of wax, a total of 260 ml of oil was collected which indicates a conversion rate of 52%. In that, 26 ml of oil was collected in the temperature range 50 - 120 ºC, 195 ml of oil in the temperature range of 121 - 180 ºC and 39 ml in the range of 181 - 250 ºC. After 250 ºC, the conversion rate was very slow, and thus was neglected. The same can be understood with the help of Fig. 4

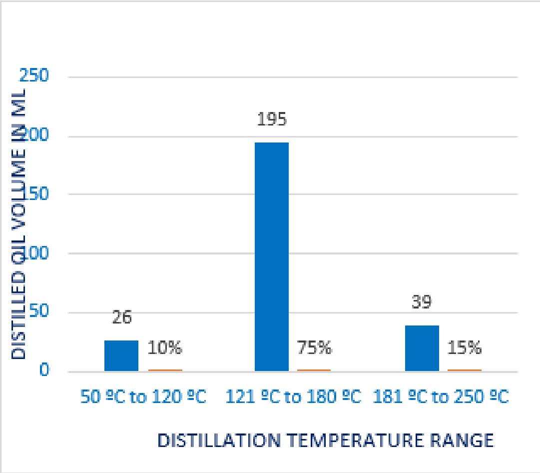

Figure 4 Distilled Oil Output Vs. Temperature

Further, the obtained distilled fuel was tested under standard testing conditions and the values are tabulated as shown in Table 3.

Sl.No.	PARAMETER	TEST METHOD	UNIT	SAMPLE A (50 °C to 120 °C)	SAMPLE B (121 °C to 250 °C)	GASOLINE	DIESEL
1	Density @15 °C	ASTM D1298-12b	g/cm^3	0.7463	0.7837	0.715-0.780	0.820-0.845
2	Specific gravity @15 °C	ASTM D1298-12b	-	0.747	0.7844	0.715-0.780	0.82-0.845
3	Viscosity @ 40°C - kinetic Viscosity	ASTM D396-21	mm^2/S	0.5905	1.4076	0.6	2-4.5
4	Viscosity @ 40°C - Dynamic Viscosity	ASTM D396-21	MPa.s	0.4269	1.0767	0.6	1.44
5	Flash Point	ASTM D93-20	°C	22	30	-45	62
6	Calorific value	(Bomb Calorimeter)	kJ/kg	39500	42250	45800	45000
7	Residue after Combustion	ASTM D482-19	%	0.025	0.0405	-	-

From the result, it can be concluded that, the **sample A** has the property close to gasoline and **sample B** close towards diesel.

Conclusion

- With the increase in the heating rate the output of wax collected also increases. From 5kg of PWs around 3.95 kg of wax was obtained.
- From 3.95 kg of wax around 2.2 litres of oil was obtained or in other words, 2.2 litre of oil was extracted from 5 kg of PWs.
- The conversion percentage was less due to the difficulty in maintaining constant temperature in conventional furnace. However, literatures indicate that with the use electric furnace and catalysts like zeolite, the yield and quality of pyro-oil can be improved, and these studies shall be taken as a part of future work.
- The pyrolysis oil extracted from HDPE can be blended with conventional fuels and used in Spark ignition and Compression ignition Engines to study the Performance and Emission characteristics of the engines.

ACKNOWLEDGEMENT

The authors would like to thank The Research Council - Oman for fully funding the work described in this publication through the TRC Reg no: BFP/RGP/EBR/20/519. A special thanks is also extended to the University of Technology and Applied Sciences – Salalah (UTAS).

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