

**HIGH DENSITY POLYETHYLENE (HDPE-2) AND POLYSTYRENE (PS-6) WASTE
PLASTIC MIXTURE TURNS INTO VALUABLE FUEL ENERGY**

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Abstract

Disposal of waste plastic is a serious concern in USA. Waste plastic generated from different cities and towns is a part of municipal solid waste. It is a matter of concern that disposal of waste plastic is causing many problems such as leaching impact on land and ground water, choking of drains, making land infertile, indiscriminate burning causes environmental hazards etc. Waste plastics being non-biodegradable it can remain as a long period of landfill. Over 48 million tons of synthetic polymer material is produced in the United States every year. Plastic are made from limited resources such as petroleum. When waste plastic come in contact with light and starts photo degrading, it starts releasing harmful such as carbon, chlorine and sulfur causing the soil around them to decay, contributing many complications for cultivation. Waste plastics also end up in the ocean, where it becomes small particles due to the reaction caused by the sun ray and salt from the ocean. Million of ocean habitants die from consuming these small plastic particles when they mistake them for food. To solve this problem countries are resorting to dumping the waste plastics, which requires a lot of effort and money yet they are only able to recycle a fraction of waste plastics. This developed a new technology which will remove these waste plastics form landfill and ocean and convert them into useful liquid fuels. The fuels show high potential for commercialization due to the fact, its influence to the environment.

Keywords: waste plastics, fuel, energy, polystyrene, high density polyethylene, thermal, environmental,

1. INTRODUCTION

Polymers are becoming a necessity in modern life in many Western countries. Their discovery and subsequent utilization means that by the mid 1960s total world consumption of thermoplastics alone was 13 million tonnes [1]. With an increasing number of applications being found for these materials, today the demand for the main commodity thermoplastics is more than 70 million tonnes [1]. Although a significant amount of the thermoplastics are utilized in products with a long life span, the majority are used in short term applications such as packaging. Thus, the quantity of thermoplastics found in waste is increasing correspondingly. Plastic waste can originate from a multitude of sources. The major areas of waste creation are from the distribution industries representing 21.7% of all plastic waste [2] and municipal solid waste (MSW) which accounts for 60.4% [2]. Municipal solid waste is being targeted as an issue for improvement. However, the nature of MSW is very complex, making its treatment difficult. Other forms of waste are easier to handle, because of their uniformity and can be treated as they are created by, for example. Feeding back into the production process. Currently 80% of MSW goes to landfill, 10% is recycled and 10% is incinerated in the USA [3]. However, landfill is becoming an increasingly expensive option. Not only are suitable sites less available close to the point of waste generation. Leading to a rise in transportation costs, but costs of disposal are set to become

even more inflated. A landfill tax of per tonne has been introduced by the UK Government which becomes effective this year [4]. It is hoped that this will reduce the amount of waste going into landfill and in conjunction with this aim; the Government in the UK has set targets for waste recovery. The aim is to recycle 25% of all household waste by the year 2000 [5] and to reclaim for energy recovery 40% of waste by 2005 [4]. Treatment of homogeneous materials available in large quantities such as paper, glass and metal has been shown to be viable via materials recycling. These can also be separated from MSW for material recycling. The plastic fraction of MSW found in Europe represents approximately 7% by weight. In Germany 80% of all packaging waste, including plastics, must be separated from other waste [1] and 6% is to be recycled as material. However, viable markets for certain recycled plastics are only available at rates of 10-15% plastic recycling [6] due to its inferior quality when compared to virgin polymers. So, if enough industrial and domestic waste is to be utilized so as to meet new recycling targets then not only will contaminated and mixed plastics have to be dealt with but also alternatives to landfill and materials recycling will have to be found. Incineration currently handles approximately 10 % of waste produced in Europe [3] to give energy via electricity generation. District heating or combined heat and power schemes. However, incineration units emit dioxins, furans, acids gases and heavy metals which can cause damage to the environment and to health. Limits of emissions have been set so as to reduce any hazardous compounds. However this means new clean-up systems will have to be incorporated into many existing plants. Dramatically increasing their operating costs. Thermolysis native process to incineration and materials recycling. This approach of hydrocarbon processing has been investigated properly. Process presently interest increased. If applications for the products formed are found, then perhaps it could potential route for chemical or fuel production. To study this potential a mixture of plastics was thermolysis produce gases, oils and chars which were collected and subsequently analyzed.

2. EXPERIMENTAL PROCESS

2.1. RAW SAMPLE COLLECTION

We collected waste high density polyethylene (HDPE) from donut delight store at located Stamford city, CT and polystyrene (PS) waste plastic we collected from Norwalk city, CT wall mart store. HDPE waste plastic was milk white color container and PS waste plastic was red color drinking glass. After collection of waste plastic we were washing with liquid detergent and dry with room air. Waste plastic cut into small piece for grinding and we used grinder machine for 2-3 mm size. 2-3 mm size waste plastic we was put into reactor for fuel production purpose.

2.2. RAW SAMPLE PREPARATION

Grounded both types of waste plastic we analysis by using Gas Chromatography and Mass Spectrometer (GC/MS), Elemental Analyzer (EA-2400), Thermogravimetric Analyzer (TGA Pyris-1) and Fourier Transformed Inferred Spectroscopy (FT-IR spectrum 100). Raw sample analysis for compound structure, carbon, hydrogen, nitrogen percentage, onset temperature and conversion percentage, functional group and wave band energy measuring from both types of waste plastic. GC/MS analysis purpose we used CDS Pyroprobe for hard waste plastic transferred into GC column as a gaseous format.

2.3. PROCESS DESCRIPTION

Grounded waste plastic to fuel production process we applied thermal cracking process. In laboratory scale process performed in presence of oxygen, room atmosphere and under Labconco fume hood. For experimental purpose 300 gm of waste plastic sample used. Both waste plastic are same ratio from total sample. Reactor temperature range used from room temperature to 430 °C and standard condenser unit setup with water circulator system for condensation purposed. Waste plastic to fuel production process temperature is monitored by temperature monitor watlow system. Waste plastic

heat start at room temperature and temperature raised up to 15 minute later at 10 °C wise. When heat apply with waste plastic starts to melt, melts to liquid slurry, liquid slurry to vapor at when temperature are gradually increased. Vapor travel through condenser unit with water circulator system condenser inside surface and vapor interaction at the end we are collecting liquid fuel. Water circulator temperature we used 20 °C. No extra chemical and we did not use any kind of catalyst. After fuel production finish fuel purification purposed we used RCI fuel purifier like as hydro cyclone system remove all kind of fuel sediment and water portion. During waste plastic to fuel production period some portion of light gas are generate its call natural gas. This natural gas carbon chain number C₁ to C₄. This nature gas we pass through liquid alkali solution removing contamination and we can reuse this gas for heating source of waste plastic to fuel production purposed. Solid black coal we are getting after fuel production source of 4%. This solid black coal has higher Btu value. Produced fuel density is 0.79 g. /ml. Fuel production yield percentage is 92% and light natural gas yield percentage is 4%. Produced fuel color is light yellow. Whole experiment electricity input for one gallon of fuel production 13 kWh.

3. RESULTS AND DISCUSSION

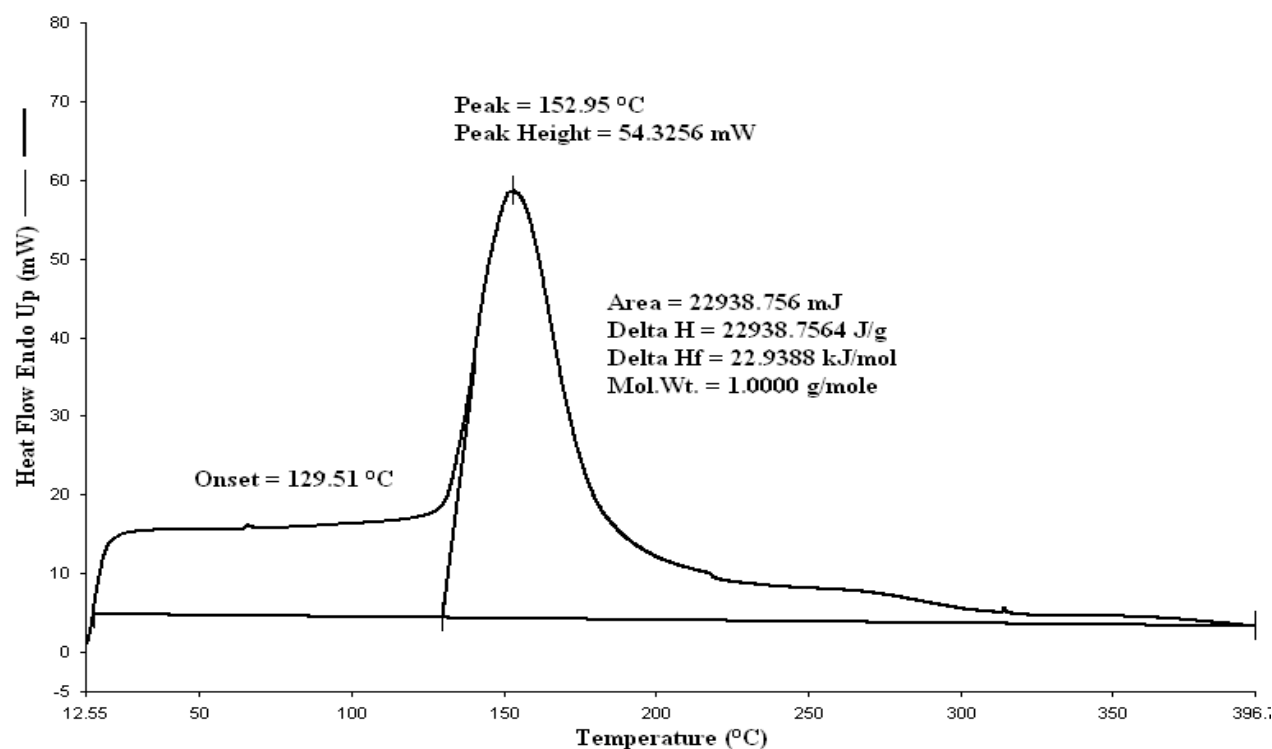


Fig. 1: DSC Graph of Produce Fuel

Differential Scanning Calorimeter (DSC) analysis produced fuel result showing fig.1. DSC (Perkin Elmer) analysis purposed we used carrier gas as Nitrogen (N₂) 20 ml per minutes. Temperature profile setup for fuel analysis 10 °C to up to 400 °C and temperature ramping rate 5°C per minute. Sample used 50 micro liter and aluminum pan used for sample holding. After sample run we saw the fuel graph onset temperature 129.51 °C. Height peak temperature is 152.95 °C and heat flow Endo up 54.3256 mW. Fuel vaporization enthalpy delta H is 22938.7564 J/g.

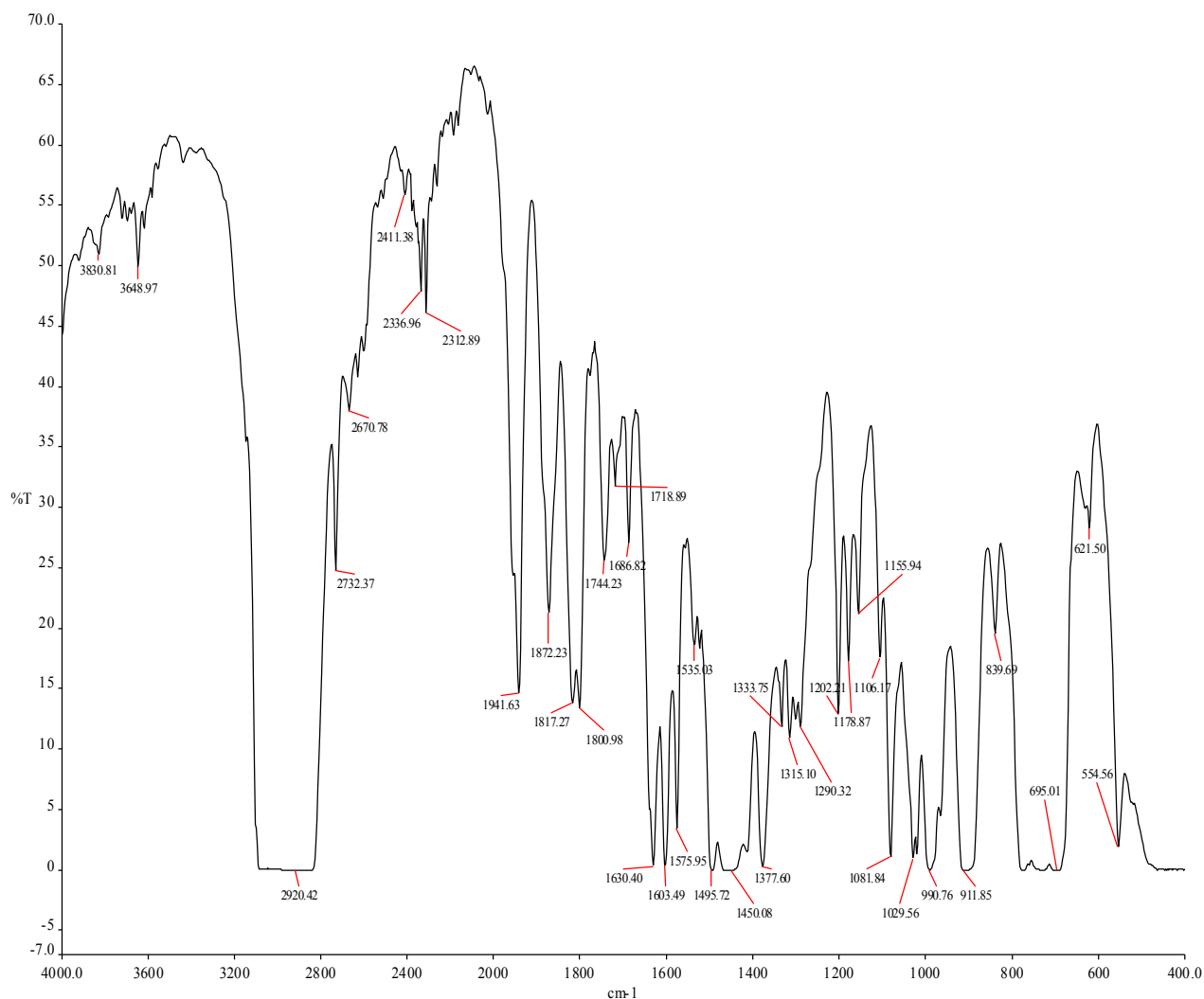


Fig. 2: FT-IR Spectrum of Produced Fuel

Table1: FT-IR Spectrum Functional Group List

Number of Wave	Wave Number (cm ⁻¹)	Functional Group	Number of Wave	Wave Number (cm ⁻¹)	Functional Group
1	2920.42	C-CH ₃	10	1630.40	Conjugated
2	2732.37	C-CH ₃	11	1603.49	Conjugated
3	2670.78	C-CH ₃	12	1450.08	CH ₃
4	1872.23	Non-Conjugated	13	1377.60	CH ₃
5	1817.27	Non-Conjugated	14	1029.56	Acetates
6	1800.98	Non-Conjugated	15	990.76	Secondary Cyclic Alcohol
7	1744.23	Non-Conjugated	16	911.85	-CH=CH ₂
8	1718.89	Non-Conjugated	17	695.01	-CH=CH- (cis)
9	1686.82	Conjugated			

FT-IR spectrum 100 (Perkin Elmer) used for produced fuel analysis. Sodium Chloride (NaCl) cell is used for sample holding. NaCl cell thickness is 0.05 mm. Spectrum display range 4000-400 cm^{-1} ; scan number 32, resolution 4 cm^{-1} . From FT-IR spectrum analysis we found some functional group wave number high range to low range see fig.2 and table 1. FT-IR Spectrum-100 analysis of HDPE-2 and PS-6 fuel in favor of wave number several types of functional groups are appeared. In accordance with wave number 2920.42 cm^{-1} , 2732.37 cm^{-1} and 2670.78 cm^{-1} compound is C-CH₃ and wave number 1872.23 cm^{-1} , 1817.27 cm^{-1} , functional compound is Non-Conjugated and wave number 1686.66 cm^{-1} compound is Conjugated. Then wave number 1450.08 cm^{-1} , 1377.60 cm^{-1} functional group is CH₃, wave number 1029.56 cm^{-1} , functional group is Acetates, wave number 990.76 cm^{-1} functional group is Secondary Cyclic Alcohol, wave number 911.85 cm^{-1} , compound is -CH=CH₂, and ultimately wave number 695.01 cm^{-1} , compound is -CH=CH-(trans). Energy value are calculated, using formula is Energy= $h\nu$, where h =plank constant, ν =frequency of photon and $\nu=cW$, therefore, $E=hcW$, where C =the speed of light (3×10^{10} cm/sec), W =wave number in cm^{-1} . According to equation high wave number light has more energy than low wave number light such as wave number 2920.42 cm^{-1} (C-CH₃), energy, $E=6.11 \times 10^{-20}$ J, wave number 2911.01 cm^{-1} (C-CH₃) energy, $E=5.78 \times 10^{-20}$ J, wave number 1872.23 cm^{-1} (Non-Conjugated) energy, $E=3.61 \times 10^{-20}$ J and ultimately wave number 911.85 cm^{-1} (-CH=CH₂) energy, $E=1.80 \times 10^{-20}$ J. Euclidean Search Hit List: 0.517 F91080 TRICHLOROACETONITRILE, 0.474 F37460 2,5-DIHYDROXYACETOPHENONE, 0.417 F65155 2-METHOXYPHENYLACETONITRILE, 0.393 F65470 3-METHYLACETOPHENONE, 0.300 F65156 3-METHOXYPHENYLACETONITRILE, 0.272 F64700 2-METHOXYACETOPHENONE, 0.254 F89970 P-TOLYLACETONITRILE, 0.250 F22850 4-CHLOROACETOPHENONE, 0.247 F54150 2-HYDROXYACETOPHENONE, 0.247 F24110 ETHYL 4-CHLORO-2-CYANOACETOACETATE (Perkin Elmer FT-IR tutorial library).

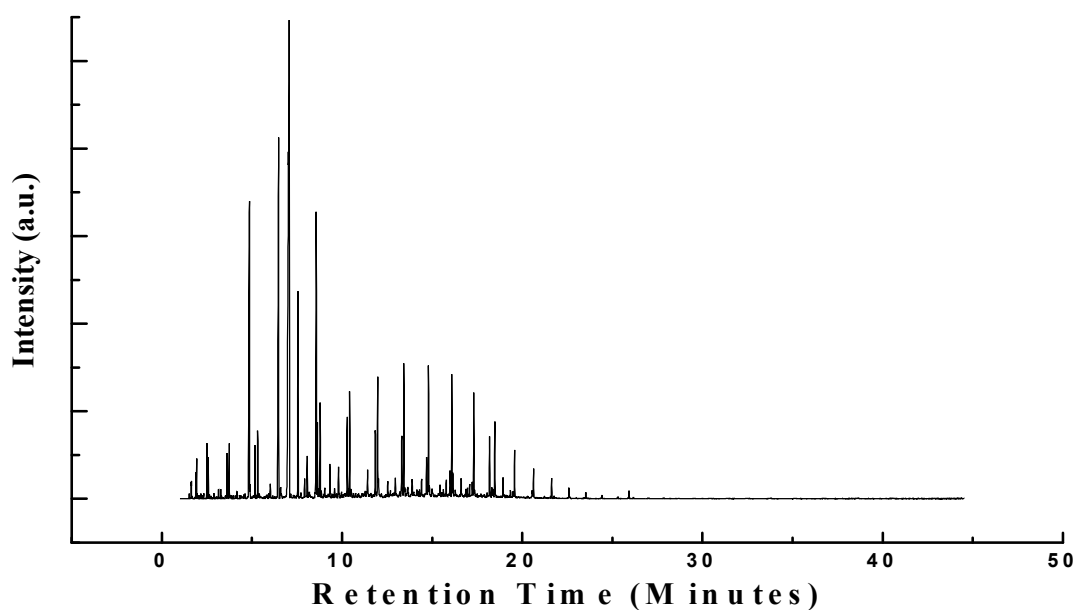


Fig. 3: GC/MS Chromatogram of Produced Fuel

Table 2: GC/MS Chromatogram Compound list of Produced Fuel

Number of Peak	Retention Time (M)	Trace Mass	Compound Name	Formula	Molecular Weight
1	1.64	43	Butane	C ₄ H ₁₀	58
2	1.89	42	Cyclopropane, ethyl-	C ₅ H ₁₀	70
3	1.93	43	Pentane	C ₅ H ₁₂	72
4	2.50	41	1-Hexene	C ₆ H ₁₂	84
5	2.58	41	Hexane	C ₆ H ₁₄	86
6	3.28	78	Benzene	C ₆ H ₆	78
7	3.62	41	1-Heptene	C ₇ H ₁₄	98
8	3.74	43	Heptane	C ₇ H ₁₆	100
9	4.17	83	Cyclohexane, methyl-	C ₇ H ₁₄	98
10	4.86	92	Toluene	C ₇ H ₈	92
11	5.17	41	1-Octene	C ₈ H ₁₆	112
12	5.32	43	Octane	C ₈ H ₁₈	114
13	6.02	43	2,4-Dimethyl-1-heptene	C ₉ H ₁₈	126
14	6.48	106	Ethylbenzene	C ₈ H ₁₀	106
15	7.07	103	1,3,7-Octatrien-5-yne	C ₈ H ₈	104
16	7.56	105	Benzene, 1-ethyl-2-methyl-	C ₉ H ₁₂	120
17	8.07	91	Benzene, propyl-	C ₉ H ₁₂	120
18	8.57	117	α-Methylstyrene	C ₉ H ₁₀	118
19	8.64	41	1-Decene	C ₁₀ H ₂₀	140
20	8.79	43	Decane	C ₁₀ H ₂₂	142
21	9.33	117	Benzene, 2-propenyl-	C ₉ H ₁₀	118
22	9.81	91	Benzene, butyl-	C ₁₀ H ₁₄	134
23	10.29	41	1-Undecene	C ₁₁ H ₂₂	154
24	10.43	57	Undecane	C ₁₁ H ₂₄	156
25	11.42	91	Benzene, pentyl-	C ₁₁ H ₁₆	148
26	11.84	41	1-Dodecene	C ₁₂ H ₂₄	168
27	11.98	57	Dodecane	C ₁₂ H ₂₆	170
28	12.53	117	Benzene, cyclopentyl-	C ₁₁ H ₁₄	146
29	12.96	91	Benzene, hexyl-	C ₁₂ H ₁₈	162
30	13.31	41	2-Tridecene, (E)-	C ₁₃ H ₂₆	182

31	13.43	57	Tridecane	C ₁₃ H ₂₈	184
32	13.89	142	Naphthalene, 2-methyl-	C ₁₁ H ₁₀	142
33	14.42	92	Benzene, heptyl-	C ₁₃ H ₂₀	176
34	14.69	41	1-Tetradecene	C ₁₄ H ₂₈	196
35	14.80	57	Tetradecane	C ₁₄ H ₃₀	198
36	15.99	41	1-Pentadecene	C ₁₅ H ₃₀	210
37	16.09	57	Pentadecane	C ₁₅ H ₃₂	212
38	17.22	41	1-Hexadecene	C ₁₆ H ₃₂	224
39	17.31	57	Hexadecane	C ₁₆ H ₃₄	226
40	18.19	92	Benzene, 1,1'-(1,3-propanediyl) bis-	C ₁₅ H ₁₆	196
41	18.39	55	8-Heptadecene	C ₁₇ H ₃₄	238
42	18.48	57	Heptadecane	C ₁₇ H ₃₆	240
43	18.93	91	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	C ₁₆ H ₁₆	208
44	19.57	57	Octadecane	C ₁₈ H ₃₈	254
45	20.55	203	Naphthalene, 1-phenyl-	C ₁₆ H ₁₂	204
46	20.63	57	Nonadecane	C ₁₉ H ₄₀	268
47	21.63	57	Eicosane	C ₂₀ H ₄₂	282
48	22.60	57	Heneicosane	C ₂₁ H ₄₄	296
49	23.53	57	Docosane	C ₂₂ H ₄₆	310
50	24.43	57	Tetracosane	C ₂₄ H ₅₀	338

Perkin Elmer Gas Chromatography and Mass Spectrometer used for produced fuel analysis. Helium gas is use for sample carrier. Elite capillary column is use for gas chromatography. Program setup for GC initial temperature is 40 °C and maximum temperature is 325 °C. From initial temperature to maximum temperature reach ramping rate per minute 10 °C. Initial temperatures hold 1 minute and final temperature hold for 15 minutes. Samples inject volume 0.5 µL and sample split flow 101.0 mL/min. MS program set up for mass detection 35.00-528.00 EI+. Data format centroid, scan time 0.25 sec and internal scan time 0.15 sec per scan. NIST library is use for chromatogram compound identification.

Fig.3 and table 2 are shown produced fuel GC/MS analysis results. From GC/MS analysis we found start compound Butane (C₄H₁₀) at retention time 1.64 minutes and molecular weight these compound 58. We used high density polyethylene and polystyrene for this experiment for that reason we got some aromatic compound also. Because polystyrene has benzene ring compound and high density polyethylene has straight chain hydrocarbon compound. Aromatic compound are present in this fuel such as Benzene (C₆H₆) at retention time 2.38 minutes appear. Toluene (C₇H₈) at retention time 4.86, Ethylbenzene (C₈H₁₀) at retention time 6.48 minutes, α-Methylstyrene (C₉H₁₀) at retention time 8.57

minutes appear. All aromatic compounds are shown chromatogram at low boiling point range. Aliphatic compounds start low boiling point to high boiling point C_4 to C_{24} . Aliphatic compounds have alkane, alkene and alkyl group compounds present in this fuel. Long chain hydrocarbon compounds are shown in this chromatogram at retention time 24.43 minute and long chain hydrocarbon compound name is Tetracosane ($C_{24}H_{50}$) and molecular weight is 338. This $C_{24}H_{50}$ compound boiling point is higher than other compounds.

4. CONCLUSION

Two valuable products are formed from the thermolysis of mixed plastic waste. These are gas and oil. Depending on the reaction conditions used the products have varying compositions and properties. At lower thermolysis temperatures a heavy wax is formed. This is comparable in its molecular weight range, boiling point and functional group composition to an atmospheric residue cut from crude oil; thus, thermal cracking could be carried out on the wax forming a gasoline type mixture of hydrocarbons. A lighter, mainly aliphatic wax is also a product of thermolysis at temperatures below $400\text{ }^{\circ}\text{C}$ which again could be commercially cracked to form gasoline. At higher temperatures, the oil formed is much more aromatic and has a lower boiling point of between 120 and $220\text{ }^{\circ}\text{C}$. It is similar to naphtha and could be cracked to form ethene. A hydrocarbon gas is produced at all temperatures with its concentration increasing at higher temperatures. The results therefore indicate that depending on the product type required the operating conditions can be changed accordingly. It can also be inferred that if the temperature was increased to higher than $450\text{ }^{\circ}\text{C}$ then due to increased secondary reactions, it is possible that the resultant oil would directly resemble gasoline without any further processing. It is therefore evident, that thermolysis of mixed plastic waste shows a huge potential not only in dealing with waste reduction but also in producing products which show a real ability to be adapted for chemical feedstock production.

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REFERENCES

- [1] Prospects for Plastics. Shell Briefing SC&C. Leaflet No. I, 1993.
- [2] APME, Plastics Recovery, in: Perspective: Plastics Consumption and Recovery in Western Europe 1989- 1991. Association of Plastics Manufacturers in Europe (APME), Brussels, 1991.
- [3] R.J. Rowatt, The plastic waste problem, *Chcmtech* 23 (1993) 56-60.
- [4] Making Waste Work, a Strategy for Sustainable Waste Management in England and Wales, HMSO, 1995.
- [5] M. Olgivie, Achieving the Government Target of 25% Recycling of Household Waste by 2000: Some Technical Choices. Presented to Institute of Local Government studies seminar on Recycling: Opportunities for Local Authorities, 4th March, 1991.
- [6] G. Mackey. A Review of Advances Recycling Technology, in: C.P, Rader et al. (Eds.), Plastics. Rubber and Paper Recycling-A Pragmatic Approach, ACS Symposium series, 609, 1995.