



Polystyrene (PS) waste plastic conversion into aviation /kerosene category of fuel by using fractional column distillation process

Moinuddin Sarker, Mohammad Mamunor Rashid, Muhammad Sadikur Rahman, Mohammed Molla

Natural State Research, Inc. Department of Research and Development, 37 Brown House Road (2nd Floor), Stamford, CT 06902, USA.

Abstract

Environmental degradation and depleting fuel reserves are matters of great concern around the global. Solid waste plastic is currently receiving renewed interest for fuel generation. Waste plastic to fuel is suitable for compression ignition engines and more attention is focused in the world because of its potential to generate large-scale employment and relatively low environmental degradation. A post-commercial PS polymer waste was thermal degradation and fractional distillation without catalysts using a steel reactor operating thermally at ambient pressure under fume hood without vacuum system. Two types of temperature profile was used for this experiment such as PS waste plastic liquefaction purposed temperature used 100-400 °C and fractional column distillation temperature was used 180-305 °C for collection kerosene or aviation grade fuel. Produced fuel was analyzed by using gas chromatography and mass spectrometer and fuel hydrocarbon range showed into GC/MS analysis is C₆ to C₁₆.

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Keywords: Polystyrene; Waste plastic; Fuel; Aviation; Kerosene; Fractional distillation.

1. Introduction

The last 30 years have witnessed an explosive growth of the plastic industry. The production of synthetic polymers represented by polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) worldwide has increased more than 100 times in the last three decades. These plastics are widely used in many important day to day applications such as clothing, household appliances and in automotive products and aerospace. While we enjoy the conveniences that plastics can provide, the treatment of waste plastics becomes an unavoidable and imminent issue. In this regard, it can be safely stated that we are in urgent need and effective ways to recycle waste plastics. Recently new ways of environmentally-friendly waste plastic recycling have been of interest, and among them, the use of waste plastics as a supplemental fuel with coal in the steel making industry has attracted interest [1, 2].

Plastics are non-biodegradable polymers mostly containing carbon, hydrogen and few other elements. According to a nationwide survey conducted in India in the year 2000 approximately 6000 tonnes of plastic wastes were generated every day, and only 60% of it was recycled. In India alone, the demand for plastics is about 8 million tonnes per year. More than 10,000 metric tonnes/ day are produced in India and balance is imported from other countries. Most of the plastics are recycled and sometimes it is not done so due to lack of sufficient market value. Of the waste plastics not recycled about 43% is

polyethylene and most of them is in the form of containers and packaging materials. The extent of conversion of plastics or plastic derived waxes into light engine fuels can be increased by the application of stable hydro cracking catalysts. Similar to petroleum derived cracking products, the fractions from plastics processing contain appreciable quantities of aromatics and unsaturated hydrocarbons [3].

High temperature pyrolysis and cracking of waste thermoplastic polymers, such as polyolefines, polyethylene (PE), polypropylene (PP) and polystyrene (PS), are well-known and environmentally accepted methods of their utilisation. This group of processes embraces both thermal pyrolysis and cracking, catalytic cracking and hydrocracking in the presence of hydrogen. Pyrolysis is the typical chemical recycling process, enabling production of monomers, mainly ethylene, propene and butene from waste plastics. In case of cracking processes, their main products are fuels fractions, gaseous hydrocarbons and liquid mixtures of hydrocarbons boiling in the range of temperatures $\sim 35\text{--}360\text{ }^{\circ}\text{C}$ (gasoline and light gas oils) as well as the solid carbon residues, similar to coke. Numerous papers present the results of application of various acidic catalysts, such as silica–alumina, zeolites (HY, HZSM-5, mordenite) or alkaline compounds such as ZnO, CaO and K₂O [4-7]. An interesting method of polymers utilization is cracking, similar to the visbreaking of vacuum residue [8] or catalytic cracking of vacuum gas oil (VGO) in the presence of various zeolites containing cracking catalysts [9, 10]. A pilot level method of recycling waste plastic disposal in India produces waste plastic oil of 25,000 l/day [11].

2. Material and method

2.1 Materials

Transparent color drinking glass of polystyrene waste plastic collected from local city grocery store and local city chain store Wal-Mart. PS waste plastic comes with other foreign materials and PS waste plastic and other foreign materials separated manually. Then PS waste plastic washed with soap and water to removed foreign materials such as food particle, tea, coffee and sand etc. Collected waste plastic cut into small pieces manually with scissor for reactor setup.

2.2 Experimental process

Polystyrene waste plastic to aviation or kerosene grade fuel production process thermal degradation and fractional distillation process was applied. Two step temperatures was used for fractional fuel production process. One step for PS waste plastic to liquefaction and another step for aviation or kerosene grade fuel collection. 316 grade stainless steel reactor was used for this experiment and waste plastic was use for the experiment only 750 gm. Experiment was performed without any kind of catalyst and experiment was perfumed under labconco fume hood and experiment was fully closed system and without vacuum system. Small pieces PS waste plastic put into reactor chamber and reactor covered with fractional distillation column tower and setup was proper tighten. For PS liquefaction temperature was setup 100-400 $^{\circ}\text{C}$ and temperature controlled by Watlow controller. Start temperature was 100 $^{\circ}\text{C}$ and finished temperature was 400 $^{\circ}\text{C}$. Temperature was increased gradually 15 $^{\circ}\text{C}$ every 15 minutes afterward. Fractional distillation column temperature 180-305 $^{\circ}\text{C}$ was used for aviation or kerosene grade fuel collection (Figure 1). PS waste plastic has benzene group compounds and long chain hydrocarbon compounds and PS plastic additives percentage level high. This plastic melting temperature 260 $^{\circ}\text{C}$ but our experiment start temperature was 100 $^{\circ}\text{C}$ and when temperature increased gradually step by step we noticed that some vapor start to come out. First PS waste plastic start to melt and then turn into liquid slurry then liquid slurry turn into vapor at the end vapor turn into condensation to liquid. When liquefaction temperature range from 100 $^{\circ}\text{C}$ to 260 $^{\circ}\text{C}$ crossed then we saw vapor start to come out constantly and turn into liquid grade fuel. Fractional distillation column was performed as grading with different temperature profile. From this experiment we collected five grade fuels but our main goal was aviation or kerosene grade fuel collection. Experiment purposed electricity consumption was 5.40 kWh. Also during production period we collected some light fraction natural gas like methane, ethane, propane and butane either alkane or alkene group gas. Light fraction gas was cleaned by alkali wash and transfer into Teflon bag by using small pump. This light gas could be use as PS waste plastic to kerosene or aviation grade fuel production. Collected kerosene or aviation grade fuel cleaned by using RCI purification technology provided device. RCI purification technology device can removed water portion and fuel sediment from liquid fuel. Produced fuel density is 0.89 g/ml. In mass balance calculation percentage showed from this experiment kerosene or aviation grade fuel 23% and rest of 77% percentage are other grade fuels, light fraction natural gas and solid black residue.

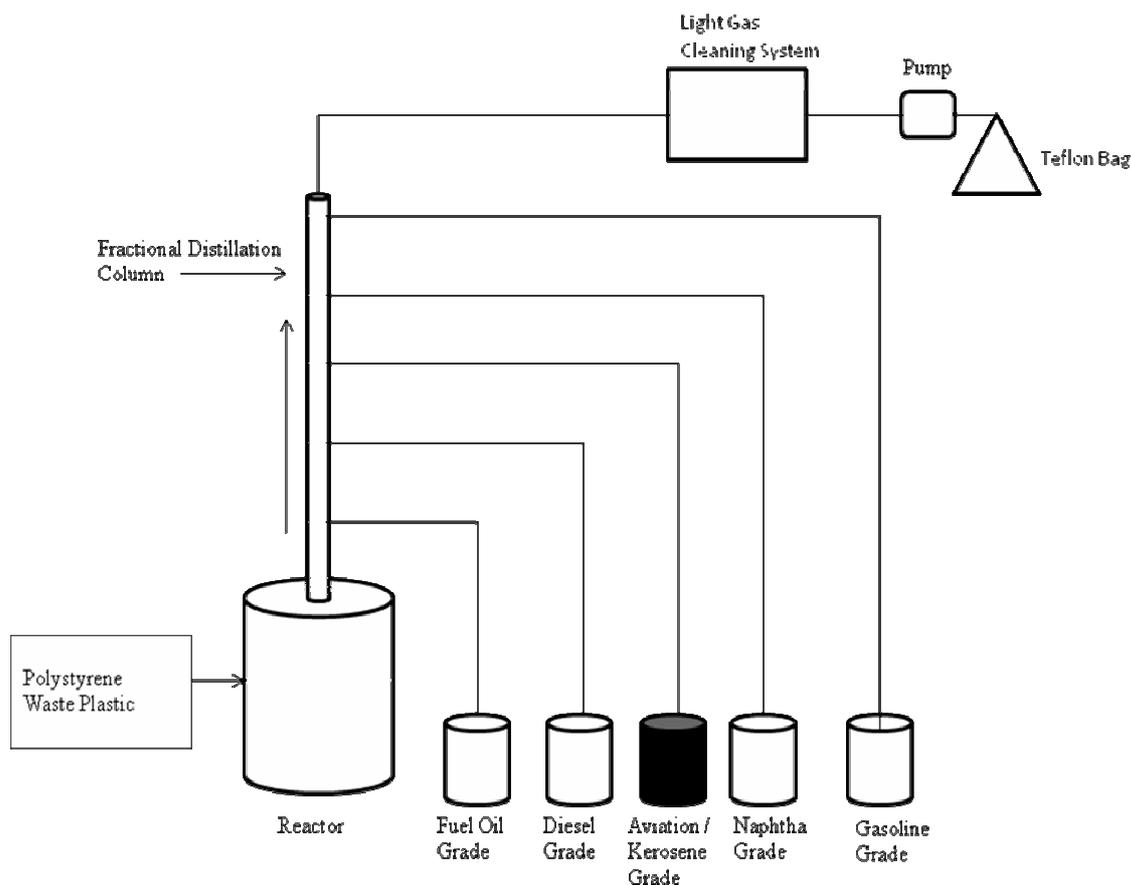


Figure 1. PS waste plastic fuel to aviation grade fuel production process

3. Results and discussion

3.1 Analytical technique

Perkin Elmer GC/MS was used for liquid fuel analysis purposed. GC/MS model number is clarus 500. Capillary column and helium gas use for liquid sample analysis. Capillary column specification is Elite-5MS, L=30 meter, mmID=0.25, um df=0.5, maximum temperature =350 °C, cat. # N9316284 and Serial # 846805. Perkin Elmer FT-IR spectrum 100 was use for fuel analysis purposed and NaCl cell used for liquid sample holder and scan number used 32 and resolution 4 cm^{-1} . At the end we used Perkin Elmer Differential Scanning Calorimeter for liquid fuel enthalpy value determination and temperature used for DSC 0-400 °C and rate was 20°C/min. and carrier gas was nitrogen at 20 ml/ min.

3.2 Liquid product analysis

From GC-MS analysis of PS waste plastic to aviation or kerosene grade fuel (Figure 2 and Table 1) in accordance with the various retention times and trace masses different types of hydrocarbon compound and benzene derivatives compounds are appeared in the analysis result index. Many compounds are emerged on the analysis carbon range C_6 to C_{16} . Based on the retention time and trace mass following hydrocarbon compounds as follows such as at the initial phase of the analysis at retention time 3.27 and trace mass 78, compound is Benzene (C_6H_6), retention time 4.85 and trace mass 91, compound is Toluene (C_7H_8), retention time 6.46 and trace mass 91, compound is Ethyl benzene (C_8H_{10}), retention time 7.03 and trace mass 51, compound is 1,3,5,7-Cyclooctatetraene (C_8H_8), retention time 7.06 and trace mass 77, compound is 1,3,5,7-Cyclooctatetraene (C_8H_8), retention time 7.54 and trace mass 105, compound is Benzene,1-ethyl-2-methyl- (C_9H_{12}), retention time 7.89 and trace mass 117, compound is Benzene,2-propenyl- (C_9H_{10}), retention time 8.03 and trace mass 91, compound name is Benzene,propyl-, (C_9H_{12}), retention time 8.19 and trace mass 77, compound is Benzaldehyde ($\text{C}_7\text{H}_6\text{O}$), retention time 8.59 and trace mass 78, compound is α -Methylstyrene (C_9H_{10}), retention time 8.70 and trace mass 117, compound is Benzene-2-Propenyl- (C_9H_{10}), retention time 8.75 and trace mass 43, compound is 1,4-Diphenyl-1-pentanone ($\text{C}_{17}\text{H}_{18}\text{O}$), retention time 9.00 and trace mass and trace mass 105, compound is

Benzene,(1-methylpropyl)-(C₉H₁₀), retention time 10.18 and trace mass 117, compound name is Benzene, (2-methyl-2-propenyl)- (C₁₀H₁₂), retention time 10.88 and trace mass 117, compound is Benzene, 1-butenyl-,(E)- (C₁₀H₁₂), retention time 11.79 and trace mass 41, compound is 3-Undecene, (E)-(C₁₁H₂₂), retention time 11.96 and trace mass 128, compound is Naphthalene (C₁₀H₈), retention time 12.91 and trace mass 91, compound is Benzene,hexyl-, (C₁₂H₁₈), retention time 13.93 and trace mass 117, compound is Benzene, cyclohexyl (C₁₂H₁₆), retention time 14.93 and trace mass 168, compound is Naphthalene, 1-(2-propenyl)-, (C₁₃H₁₂), retention time 15.39 and trace mass 167, compound is Diphenylmethane, (C₁₃H₁₂), retention time 16.55 and trace mass 167, compound is Benzene, 1,1'-ethylidenebis- (C₁₄H₂₄). Also at retention time 16.55 and trace mass 91, compound is Benzene, 1,1'-(1,2-ethanediy)bis- (C₁₄H₁₄), retention time 18.88 and trace mass 91, compound is Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-, (C₁₆H₁₆) etc. In the ultimate phase of the analysis index several compound are detected as according to their retention time and trace masses such as retention time 19.28 and trace mass 91, compound is Benzene, 1,1'-(1,4-butanediyl)bis-(C₁₆H₁₈), retention time 19.50 and trace mass 44, compound is Naphthalene, 1,2,3,4-tetrahydro-1-phenyl- (C₁₆H₁₆), and ultimately retention time 20.49 and retention time 204, compound is Naphthalene, 1-phenyl- (C₁₆H₁₆) respectively. In the analysis Naphthalene derivatives compounds are noticed because in polystyrene composition styrene compounds are constituents.

FT-IR analysis of PS waste plastic fuel aviation or kerosene grade fuel (Figure 3 and Table 2) according to their wave number and spectrum band following types of functional groups are appeared in the analysis. In the spectrum field we noticed that higher wave number are emerged in the initial phase and middle index of the spectrum and in higher wave number small and bulky both functional groups are available and in low wave number double bond and single bond functional groups are available such as methane group, cis and trans alkene etc. Hereafter wave number 3620.11 cm⁻¹, functional group is Free OH (Sharp) group, wave number 3442.85 cm⁻¹ functional group is, Intermolecular H bonds (broad), wave number 2963.36 cm⁻¹ and 2732.56 cm⁻¹ functional group is C-CH₃, wave number 2185.56 cm⁻¹ functional group is C=C=C-CH, wave number 1874.55 cm⁻¹, 1802.12 cm⁻¹, 1747.00 cm⁻¹, 1705.28 cm⁻¹, 1631.62 cm⁻¹ and 1687.86 cm⁻¹ functional group is Non-Conjugated, wave number 1376.22 cm⁻¹ functional group is CH₃, wave number 1028.47 cm⁻¹ functional group is Acetates, wave number 990.09 cm⁻¹ and 907.58 cm⁻¹ functional group is -CH=CH₂ and ultimately wave number 696.88 cm⁻¹ functional group is CH=CH-(cis) etc Energy values are calculated, using formula is $E=h\nu$, Where h =Planks Constant, $h=6.626 \times 10^{-34}$ J, ν = Frequency in Hertz (sec⁻¹), Where $\nu=c/\lambda$, c =Speed of light, where, $c=3 \times 10^{10}$ m/s, $W=1/\lambda$, where λ is wave length and W is wave number in cm⁻¹. Therefore the equation $E=h\nu$, can substitute by the following equation, $E=hcW$. According to their wave number several energy values are calculated such as for 2963.36 (cm⁻¹) calculated energy, $E=5.93 \times 10^{-20}$ J. Similarly, wave number 1874.55 (cm⁻¹) energy, $E=3.71 \times 10^{-20}$ J, wave number 1375.81 (cm⁻¹) energy, $E=2.73 \times 10^{-20}$ J and eventually wave number 907.58 (cm⁻¹) functional group is 1.80×10^{-20} J respectively.

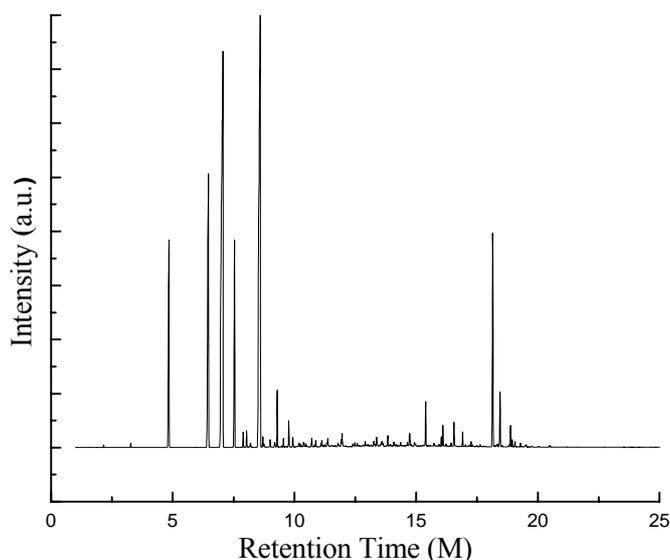


Figure 2. GC/MS Chromatogram of PS waste plastic to aviation or kerosene grade fuel

Table 1. GC/MS Chromatogram of PS waste plastic to aviation or kerosene grade fuel compound list

Number of Peak	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %
1	3.27	78	Benzene	C ₆ H ₆	78	66.9
2	4.85	91	Toluene	C ₇ H ₈	92	27.6
3	6.46	91	Ethylbenzene	C ₈ H ₁₀	106	22.2
4	7.03	51	1,3,5,7-Cyclooctatetraene	C ₈ H ₈	104	34.2
5	7.06	77	1,3,5,7-Cyclooctatetraene	C ₈ H ₈	104	24.5
6	7.54	105	Benzene, 1-ethyl-2-methyl-	C ₉ H ₁₂	120	18.0
7	7.89	117	Benzene, 2-propenyl-	C ₉ H ₁₀	118	19.7
8	8.03	91	Benzene, propyl-	C ₉ H ₁₂	120	78.5
9	8.19	77	Benzaldehyde	C ₇ H ₆ O	106	65.0
10	8.59	78	α -Methylstyrene	C ₉ H ₁₀	118	24.5
11	8.70	117	Benzene, 2-propenyl-	C ₉ H ₁₀	118	22.1
12	8.75	43	1,4-Diphenyl-1-pentanone	C ₁₇ H ₁₈ O	238	12.6
13	9.00	105	Benzene, (1-methylpropyl)-	C ₁₀ H ₁₄	134	21.3
14	9.19	117	Benzene, 2-butenyl-	C ₁₀ H ₁₂	132	12.6
15	9.29	117	Benzene, 2-propenyl-	C ₉ H ₁₀	118	24.4
16	9.55	91	Benzene, 3-butenyl-	C ₁₀ H ₁₂	132	80.7
17	9.77	91	2-Propen-1-ol, 3-phenyl-	C ₉ H ₁₀ O	134	11.1
18	9.93	105	Acetophenone	C ₈ H ₈ O	120	29.7
19	10.18	117	Benzene, (2-methyl-2-propenyl)-	C ₁₀ H ₁₂	132	19.8
20	10.24	41	3-Undecene, (E)-	C ₁₁ H ₂₂	154	7.71
21	10.38	43	Undecane	C ₁₁ H ₂₄	156	14.9
22	10.48	105	Benzene, (1-methylbutyl)-	C ₁₁ H ₁₆	148	34.9
23	10.71	117	Benzene, 2-butenyl-	C ₁₀ H ₁₂	132	12.7
24	10.88	117	Benzene, 1-butenyl-, (E)-	C ₁₀ H ₁₂	132	19.3
25	11.13	118	Benzene, (1-ethyl-2-propenyl)-	C ₁₁ H ₁₄	146	48.9
26	11.37	91	Benzene, pentyl-	C ₁₁ H ₁₆	148	64.5
27	11.79	41	3-Undecene, (E)-	C ₁₁ H ₂₂	154	4.52
28	11.92	43	Dodecane	C ₁₂ H ₂₆	170	12.9
29	11.96	128	Naphthalene	C ₁₀ H ₈	128	45.5
30	12.40	117	trans-1-Phenyl-1-pentene	C ₁₁ H ₁₄	146	28.5
31	12.48	91	Benzene, cyclopentyl-	C ₁₁ H ₁₄	146	40.5
32	12.91	91	Benzene, hexyl-	C ₁₂ H ₁₈	162	63.8
33	13.26	41	7-Tetradecene	C ₁₄ H ₂₈	196	7.45
34	13.37	43	Tridecane	C ₁₃ H ₂₈	184	23.0
35	13.60	142	Bicyclo[4.4.1]undeca-1,3,5,7,9-pentaene	C ₁₁ H ₁₀	142	28.0
36	13.83	142	Benzocycloheptatriene	C ₁₁ H ₁₀	142	20.8
37	13.93	117	Benzene, cyclohexyl-	C ₁₂ H ₁₆	160	12.1
38	14.08	104	Benzene, 3-cyclohexen-1-yl-	C ₁₂ H ₁₄	158	70.0
39	14.36	91	Benzene, heptyl-	C ₁₃ H ₂₀	176	53.5
40	14.73	154	Biphenyl	C ₁₂ H ₁₀	154	54.9
41	14.93	168	Naphthalene, 1-(2-propenyl)-	C ₁₃ H ₁₂	168	18.5
42	15.39	167	Diphenylmethane	C ₁₃ H ₁₂	168	62.7
43	16.04	43	Hexadecane	C ₁₆ H ₃₄	226	12.2
44	16.10	167	Benzene, 1,1'-ethylidenebis-	C ₁₄ H ₁₄	182	37.5
45	16.55	91	Benzene, 1,1'-(1,2ethanediyl)bis-	C ₁₄ H ₁₄	182	88.6

Table 1. (Continued)

46	16.91	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	C ₁₅ H ₁₆	196	72.0
47	17.26	43	Hexadecane	C ₁₆ H ₃₄	226	21.2
48	18.15	105	Benzene, 1,1'-(1,3-propanediyl)bis-	C ₁₅ H ₁₆	196	89.7
49	18.45	105	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	C ₁₆ H ₁₈	210	76.0
50	18.88	91	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	C ₁₆ H ₁₆	208	39.4
51	18.95	105	Benzene, (1-methyl-3-butenyl)-	C ₁₁ H ₁₄	146	18.4
52	19.06	115	1,2-Diphenylcyclopropane	C ₁₅ H ₁₄	194	58.3
53	19.28	91	Benzene, 1,1'-(1,4-butanediyl)bis-	C ₁₆ H ₁₈	210	88.1
54	19.50	44	Naphthalene, 1,2,3,4-tetrahydro-1-phenyl-	C ₁₆ H ₁₆	208	55.1
55	19.74	44	Benzene, 1,1'-(1-butenylidene)bis-	C ₁₆ H ₁₆	208	38.6
56	20.02	44	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	C ₁₆ H ₁₆	208	13.0
57	20.49	203	Naphthalene, 1-phenyl-	C ₁₆ H ₁₂	204	13.5

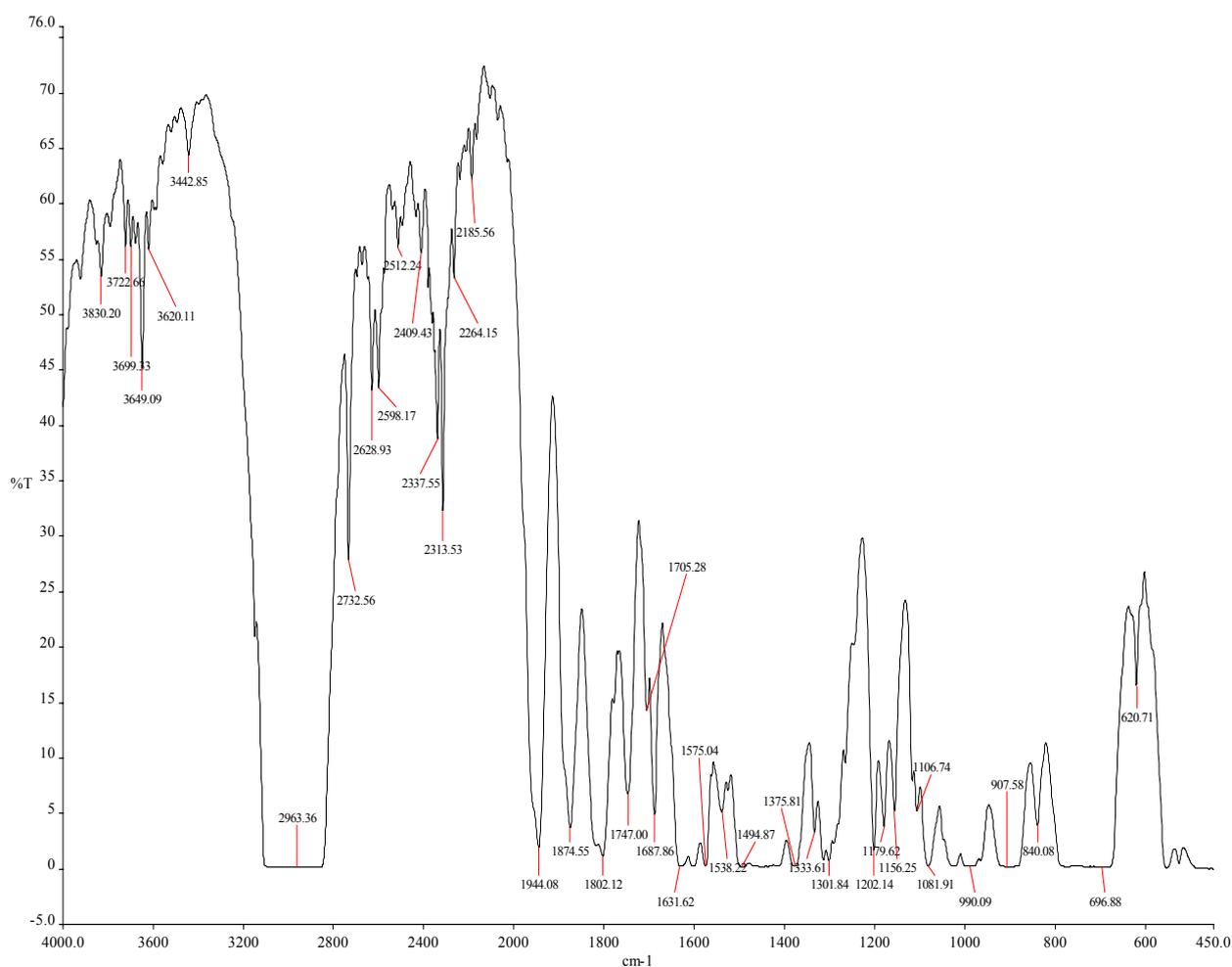


Figure 3. FT-IR Spectrum of PS waste plastic to aviation or kerosene grade fuel

Table 2. PS waste plastic to aviation or kerosene grade fuel functional group name

Number of Wave	Wave Number (cm ⁻¹)	Functional Group
5	3620.11	Free OH (Sharp)
6	3442.85	Intermolecular H Bonds (broad)
7	2963.36	C-CH ₃
8	2732.56	C-CH ₃
16	2185.56	C-C=C-C=CH
17	2163.53	C-C=C-C=CH
19	1874.55	Non-Conjugated
16	1802.12	Non-Conjugated
17	1747.00	Non-Conjugated
18	1705.28	Non-Conjugated
19	1631.62	Non-Conjugated
20	1603.97	Non-Conjugated
21	1687.86	Non-Conjugated
23	1375.81	CH ₃
26	1028.47	Acetates
27	990.09	-CH=CH ₂
28	907.58	-CH=CH ₂
29	696.88	-CH=CH-(cis)

Aviation or kerosene grade fuel (Figure 4) collected from PS waste plastic and fuel collection temperature range was use at 180-205 °C and fuel analysis by using of DSC for boiling point measuring and enthalpy value. Aviation or kerosene grade fuel analysis result indication boiling point temperature is 138.63 °C. Fuel boil start at temperature X1=5.22 °C, Y1= 0.0302 mW and onset temperature is 134.44 °C. Peak en temperature showed from graph 137.54 °C and peak temperature is 138.63 °C. Heat enthalpy value delta H is 17084.6623 J/g and area is 17084.662 mJ. Boiling peak height indicating from graph 110.0731 mW and X2= 393.46 °C, Y2= 0.1321mW. Aviation or kerosene grade fuel has medium range aromatic hydrocarbon compound showed in GC/MS analysis.

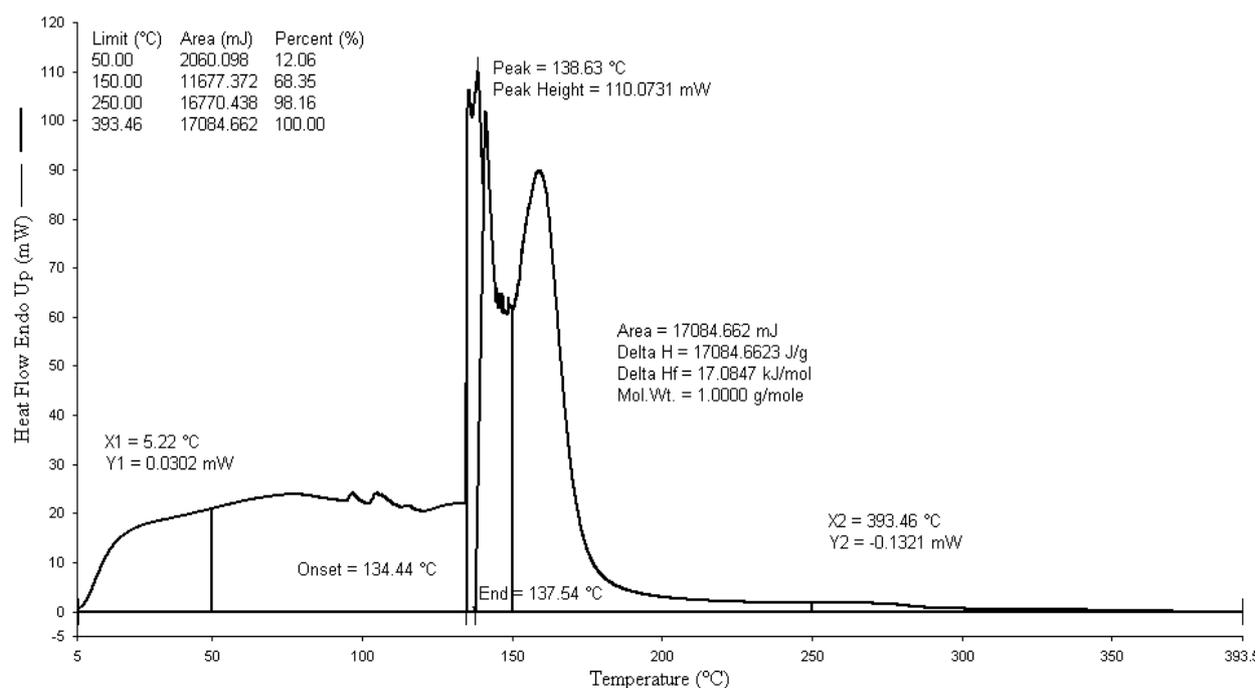


Figure 4. DSC graph of PS waste plastic to aviation or kerosene grade fuel

4. Conclusion

PS waste plastic to kerosene or aviation grade fuel production purposed two type temperature profile was used one for PS solid to liquefaction and 2nd temperature profile for fractional distillation column. Collected fuel density is 0.89 g/ml and fuel was analysis by GC/MS, FT-IR and DSC. By using GC/MS analysis result showed aromatic related hydrocarbon compound and aliphatic hydrocarbon compound. Long straight chains are break down into shorter hydrocarbon chain by using thermal degradation and fractional process. GC/MS result showed starting hydrocarbon chain C₆ to C₁₆. This fuel has combination of aromatic and aliphatic compounds such as Benzene, Toluene, Ethylbenzene, α -Methylstyrene, Benzene, 2-butenyl-, Acetophenone, Benzene, cyclopentyl-, Naphthalene, 1-(2-propenyl)-, Benzene, 1,1'-(1,3-propanediyl)bis-, Benzene, (1-methyl-3-butenyl)-, Naphthalene, 1-phenyl-etc. FT-IR analysis result showed wave band energy value which is resemble to calorific value. DSC analysis result showed boiling point and enthalpy value. From this experiment we noticed that fuel production percentage 23% and other grade fuel and residue was 77%. The produced fuel could be use for feed stock refinery further modification need to be done and would be appropriate for commercial use.

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Moinuddin Sarker, PhD, MCIC, is the Executive Vice President (EVP), CTO and Chief Operating Officer (COO) at the Natural State Research (NSR), Inc at Stamford, CT and the inventor of NSR's award winning technology to convert municipal waste plastics into liquid hydrocarbon fuel. He has a Ph. D. degree in Chemistry from University of Manchester Institute of Science and Technology (UMIST), Manchester, UK (1996). He has more than 20 years of professional research experience in different universities and research organizations all over the world including the US, Canada, the Netherlands, Germany, Taiwan, Bangladesh and the UK. During his research work, he carried out research in four different synchrotron radiation sources around the world: CRCL lab. Daresbury, Warrington, Cheshire, UK (1991-1996), Synchrotron Radiation Research Center (SRRC), Hsinchu, Taiwan, R.O.C (1996-1999), Berlin Electron Storage Ring Company for Synchrotron Radiation (BESSY II) (2000) and Advance Photon Sources (APS), Chicago, USA (2001-2004). He has two patent pending and 55 research publications to his credit in peer reviewed journals and conferences. Dr. Sarker is a distinguished member of 25 professional organizations such as Society of Automobile International (SAE), American Chemical Society (ACS), American Physical Society (APS), American Institute of Chemical Engineering (AIChE), International Union of Pure and Applied Chemistry (IUPAC), Canadian Society for Chemistry (CSC), Chemical Institute of Canada (CIC), Canada and many more. Dr. Sarker has been invited speaker various conferences in around the USA and World. Dr. Sarker is the inventor of the technology and product entitles: "Method for converting waste plastics to lower – molecular weight hydrocarbons, particularly hydrocarbon fuel materials and the hydrocarbon material produced thereby" (US and International Patent Pending). Dr. Sarker also heads a humanitarian effort in Bangladesh, the Moinuddin Foundation (www.moinuddinfoundation.org) which helps provide essentials for the poor and underprivileged.

E-mail address: msarker@naturalstateresearch.com



Mohammad Mamunor Rashid born in 1976 into Bangladesh and now he becomes USA citizen. He finished his M. Sc degree in Chemistry from Jagannath University College under National University in Bangladesh. He received his B. Sc and M. Sc degree 2000 and 2002. He is working now Natural State Research, Inc. since 2006 as Plant Manager waste plastic to fuel conversion process and save the environment field. He is co-author of several publications about waste plastic to fuel related journal. He has almost 35 publications into various journals. He has participated seminar and conference.

E-mail address: mamun@naturalstateresearch.com



Muhammad Sadikur Rahman, from Bangladesh, Permanent Resident of USA, lives in New York. He obtained his B. Sc (Hon's) 2001, M. Sc in Chemistry 2003 from M.C College under National University of Bangladesh. He has been working in the research and development field as a laboratory Chemist in the company of Natural State Research, Inc. He is co-author of several publications about waste plastic to fuel related journal. He has almost 15 publications into various journals. He has participated seminar and conference.

E-mail address: sadik@naturalstateresearch.com



Mohammed Molla, he is born in 1986 into Bangladesh and now he is USA Citizen. He is studying B. Sc at City College of NY under CUNY. He is working Natural State Research, Inc as an Intern. He is co-author of several publications about waste plastic to fuel related journal. He has almost 20 publications into various journals. He has participated seminar and conference.

E-mail address: mmolla@naturalstateresearch.com

