Aromatic Light Hydrocarbon Fuel Generation from Municipal Polystyrene (PS) Waste Plastic by Using Low Temperature Fractional Distillation Process

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Abstract- **Everyday the use of plastic is increasing because plastic has light weight and durability. After use, all plastics are thrown into garbage station because some plastic are one-off and creating plastic garbage. Worldwide PS waste plastic is generating 9-10%. Polystyrene plastic formula is C_8H_8 and this plastic has benzene compound. Thermal degradation processes PS waste plastic breakdown long chain to short chain hydrocarbon without using any kind of catalyst. Polystyrene waste plastic to light fractional fuel production processes was two steps process. 1st step process temperature range was 100-400 ºC for polystyrene waste plastic to polystyrene fuel production. 2nd step process was polystyrene fuel into light fractional aromatic hydrocarbon fuel production processes and temperature range was 40-60 ºC. Light fractional aromatic hydrocarbon fuel separation done by fractional distillation column process. 1st step PS waste plastic to liquid fuel density is 0.88 gm/ml and 2nd step light fractional liquid fuel density is 0. 84 gm/ml. Produced fuel was analyzed by Gas Chromatography and Mass Spectrometer, Fourier Transform Infrared Spectrometer and Differential Scanning Calorimeter to determine liquid fuel compound structure, fuel band energy and fuel boiling point.**

Keywords- Waste Plastic; Aromatic; Hydrocarbon; Fuel; Polystyrene; Low Temperature; Fractional Distillation

I.   INTRODUCTION

Plastics are wide range of synthetic or semi-synthetic organic solids that are moldable. Plastics are typically organic polymer of high molecular mass, but they often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, but many are partially natural [1]. The vast majority of these polymers are based on chains of carbon atoms alone or with oxygen, sulfur, nitrogen as well. The backbone is that part of the chain on the main path linking a large number of repeat units together. To customize the properties of a plastic, different molecular groups hang from the backbone. The structure of the side chains influences the properties of the polymer. This fine tuning of the properties of the polymer by repeating unit's molecular structure has allowed plastics to become an indispensable part of the twenty-first century. Plastics are usually classified by their chemical structures of the polymer's backbone and side chains. Some important groups in these classifications are the acrylics, polyesters, silicones, polyurethanes, and halogenated plastics. Plastics can also be classified by the chemical process used in their synthesis, such as condensation, polyaddition and cross-linking.

Polystyrene also known as thermocole, abbreviated following ISO standard PS, is an aromatic polymer made from monomer styrene, a liquid hydrocarbon that is manufactured from petroleum by chemical industry. Polystyrene is one of widely used plastics. Polystyrene can be either thermoset or thermoplastic. Thermoplastic polystyrene is in solid (glassy) state at room temperature, but flows if heated above its glass transition temperature of about 100 ⁰C and becomes solid again when cooled. Pure solid polystyrene is colorless, hard plastic with limited flexibility. It can be cast into molds with fine detail. Polystyrene can be transparent or can be made to take on various colors. Solid polystyrene is used for example, in disposable cutlery, plastic models, CD and DVD cases, and smoke detector housing. Products made from foamed polystyrene are nearly ubiquitous, for example packing materials, insulation, and foam drink cups [2-6].

The huge amount of waste plastics that resulted from the dramatic increase in polymer production give rise to serious environmental concerns, as plastic does not degrade and remain municipal refuse tips for decades. Plastic waste being more voluminous than the organic waste takes up a lot of landfill space that is becoming scarce and expensive. Incineration is not an acceptable solution to the problem, as toxic gases are produced and a solid waste problem becomes air pollution. The only sustainable solution is polymer recycling. Between various polymer recycling methods, thermal and/or catalytic degradation of plastic waste to fuel shows the highest potential for a successful future commercial process [7-11], especially as waste plastic can be considered as a cheap source of raw materials in times of accelerated depletion of natural resources. Catalytic degradation of plastic waste offers considerable advantages as compared to pure thermal degradation, as the latter demands relatively high temperatures and its products require further processing for their quality to be upgraded. In such a recycling process, the most valuable product is obviously liquid fuel, although gaseous products are useful too, as their burning can contribute to the energy demand of an endothermic polymer cracking process. This paper reports on the results of an experiment with polystyrene being the polymer sample and products yielded. More specifically, the main products were analyzed using analytical equipments and the results are compared with standard liquid hydrocarbons.

II.   MATERIAL AND METHOD

A.   Materials

Polystyrene (PS) waste plastic collected from Stamford local area restaurant and PS waste plastic color was black and transparent. PS plastic is mainly food container. All PS waste plastic comes with food contain with stick into food container. Collected PS waste plastic was washed with 7th generation liquid soap by manually using sink. PS waste plastic washing period also generates waste water which was not drain into drainage system but put into separate plastic container for

waste water treatment. The main concern was to remove waste plastic from land fill and save the environment and not to generate another waste. Aluminum Potash Sulfate formula {AlK (SO4)2.12H2O}, catalog # 237086, supplier was Sigma Aldrich, Sodium Hydroxide (NaOH) cat. # SX 0590, provider was EMD chemicals Inc and Nanoclay cat. # 682659, supplier was Sigma Aldrich, which was used for waste water treatment process. Washed PS waste plastics was dried in room temperature and cut into small pieces manually with scissor which size was 3-4 inch. 3-4 inch waste plastic was transferred into grinder machine and PS waste plastic grind into 3-4 mm size. Schutte Buffalo hammer mill (model # W6H and serial # S0706045) was used for PS plastic grinding.

Grounded waste plastic was transferred into reactor for liquefaction process.

B. Pre-Analysis

Table 1 indicates that Polystyrene waste plastic has metal content present measured by mg/L because solid PS waste plastic run by ICP water or aqueous metrics process and Table 2 is indicating PS waste plastic Carbon, Hydrogen and Nitrogen percentage by EA-2400 analysis. From EA-2400 analysis result, the percentage of C, H and N is 78.90 % and rest of percentage used as additives when plastic company plastic manufacturing. Analysis Table 1 also showed PS waste plastic calcium trace metal percentage was high from other metal.

TABLE I POLYSTYRENE WASTE PLASTIC METAL CONTENT ANALYSIS BY ICP

Test Method Name	Trace Metal Name	PS Waste Plastic mg/L
ASTM D 1976	Silver	<1.0
	Aluminum	59.8
	Boron	2.8
	Barium	2.7
	Calcium	33420
	Chromium	<1.0
	Copper	<1.0
	Iron	47.2
	Potassium	28.4
	Lithium	16.8
	Magnesium	842.7
	Molybdenum	<1.0
	Sodium	118.8
	Nickel	<1.0
	Phosphorus	<1.0
	Lead	<1.0
	Antimony	<1.0
	Silicon	17.2
	Tin	<1.0
	Titanium	60.8
	Vanadium	<1.0
	Zinc	89.9

TABLE II CARBON, HYDROGEN AND NITROGEN PERCENTAGE BY EA- 2400

Waste Plastic Name	Method Name	Carbon %	Hydrogen %	Nitrogen %
Polystyrene	ASTM D5291.a	78.60	7.21	<0.30

C. Experimental Section

A Stainless steel reactor was used for PS grounded waste plastic melting process. Reactor heat range capacity is 0- 500 °C and a temperature controller is used to maintain that temperature. Reactor chamber is a 316 stainless steel and reactor chamber filled up with grounded PS waste plastic and placed inside the reactor, and the top portion of the reactor was covered and a condenser unit was fitted. Condenser unit was a 70 ° angle, and length was 49 inch and dia was 2 inch (see Fig. 1). 1000 gm of plastic sample was used for this experiment. Reactor bottom portion and reactor top portion were tightened with eight screws and a Teflon gas kit was inserted to maintain the pressure. Reactor set up was fully air tight shut under a fume hood. Reactor setup was fully closed but without vacuum. Condensation unit one sets up with reactor and other ends set up with fuel collection device. No water circulation system was set up with this process. Grounded waste PS plastic start to heat from room temperature to 400 °C and temperature was increased 10 °C every 15 minutes. PS plastic started to melt when temperature was increased gradually at desire time constantly. PS waste plastic melting temperature is 240 °C. When temperature rose more than 240 °C, plastic was melt then start to liquid formation, at the end vapor starts to come out. Vapor touch condenser inside surface and liquid was collected into collection tank.
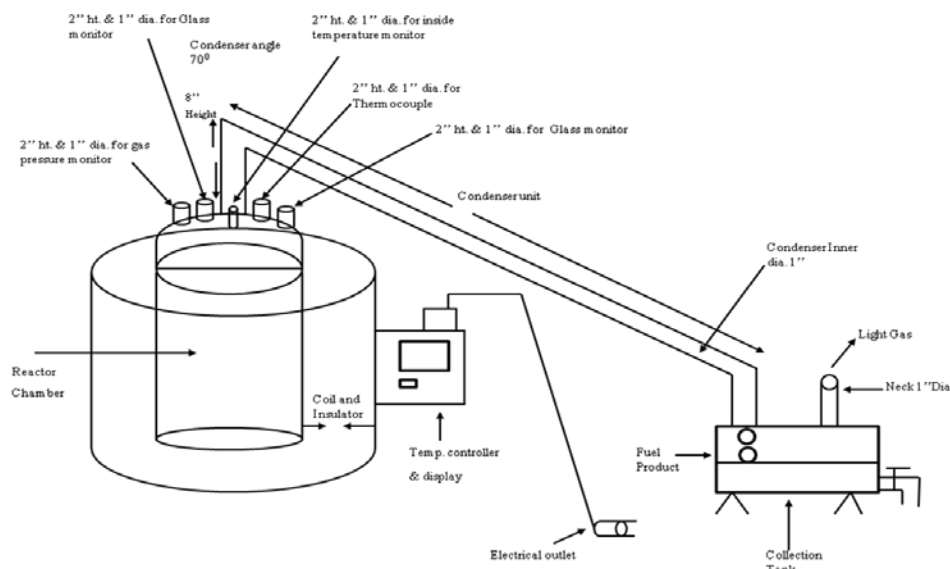
Fig.1 Polystyrene waste plastic to liquid fuel production process diagram

Experimental process was set up without vacuum system and without adding any kind of catalyst, because before setup experiment raw PS waste plastic was analyzed by ICP and ICP result indicate that huge amount of trace metal are present in the raw polystyrene waste plastic materials. This kind of trace metal acts as a catalyst for reaction PS waste conversion into liquid hydrocarbon fuel production for that reason catalyst doesn't need to waste plastic conversion into fuel production (patent pending). PS waste plastic has aromatic compounds with aliphatic hydrocarbon. Produced fuel collection tank is transferred into another collection container and purified using a RCI purification unit (Model # PP50) with micron filter. Waste PS Plastic to fuel production period some light gas (C1-C4) also produced as methane, ethane, propane and butane category and all light gas come out in mixture gas.

Light gas pass through into alkali solution removed contamination if present into light gas then transferred into a Teflon bag for future uses age. PS waste plastic to fuel production process was 6-7 hours process because sometimes temperature increases and sometimes temperature decreases

for good quality liquid product collection. Electricity input was 6.66 kWh for 912 ml fuel production. Production yield percentage was liquid fuel 80.29%, solid residue was 15.59% and light gas was 4.12% and mass balance calculation for 1000 mg PS waste plastic to fuel weights 802.9 g, residue weights 155.9 g and sample as light gas weights 41.2 g.

PS waste fuel was transferred into another reactor chamber for light fractional fuel production and reactor used glass fractional distillation column. Fractional distillation column setup was properly for light fraction fuel production (see Fig. 2) with low temperature range. PS waste plastic fuel was used for light fraction fuel production and temperature range was at 40-65 °C. Aromatic compound related light fraction fuel production percentage was 10% only and fuel density was 0.84 g/ml. By using fractional distillation column, the produced fuel breaks down into shorter chain hydrocarbon compound, for light fraction production did not apply any catalyst and setup was fully closed. During this production light gas also generated 2% and the rest was other grade fuel. 1st fraction fuel was cleaned by RCI purification unit and light gas was cleaned also same procedure.
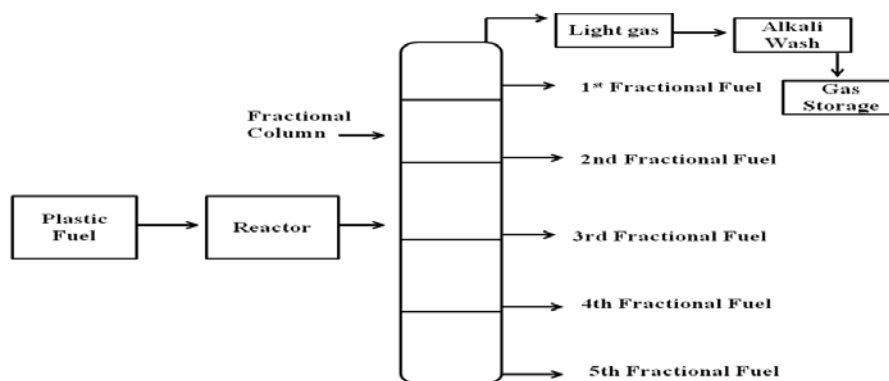

Fig. 2 Polystyrene fuel to light fractional aromatic fuel production process diagram

III. RESULTS AND DISCUSSION

A. Analytical Technique

GCMS (Clarus 500) was used for liquid sample run by auto sampler method Syringe Capacity: 5.0 µL, Injection

Speed: Normal, Viscosity Delay: 0, Pre-injection Solvent Washes: 2, Post-injection Solvent Washes (A): 6, Injection Volume: 0.5 µL, Sample Pumps: 6, Wash / Waste Vial Set: 2.Carrier Parameters: Carrier A control: Press-PSIG, Carrier A set point: 0.0 PSIG. Carrier B control: PFlow-He, Column B length: 30.00 m, Vacuum Compensation:

ON, Split Flow: 101.0 mL/min, Initial Set point: 1.00 ML/MIN, Diameter: 250 µm, Initial Hold: 999.00. Valve configuration and settings Valve 1: SPLIT on, Valve 2: SPLIT on, Valve 3: NONE, Valve 4: NONE, Valve 5: NONE, Valve 6: NONE. Detector Parameters: Detector A, Detector NONE, Range 1, Time Constant 200, Auto zero: ON, Polarity: None. Detector B: NONE, Range 1, Time Constant: 200, Auto zero: ON, Polarity: None. Heated Zones Injection A: CAP, Setpoint: OFF, Injector B: PSSI, Initial Setpoint: 280 °C, Initial Hold: 999.00 min, Detector A: 0 °C, Detector B: 0 °C, Auxiliary (NONE): 0 °C. Oven Program Cryogenics: Off, Initial Temp: 40 °C, Initial Hold: 1.00, Total Run Time: 44.50 min, Maximum Temp: 330 0 °C, Equilibrium Time: 0.5 min. Ramp 1: 10.0 0/min to 325 °C, Ramp 1: 10.0 0/min to 325 0 °C, hold for 15.00 min. GC methods are sets following criterion such as experiment name: Instrument Identifier Version Number: 1.0, Duration (min): 45.0, Solvent Delay Start 1: 0.0, Solvent Delay End 1:1.0, Number of functions: 1. Function 1: MS Scan, Time 1.00 to 44.50, Mass 35.00 to 528.00EI$^+$, Type: MS Scan, Ion Mode: EI$^+$, Data Format: Centroid, Start Mass : 35.00, End Mass :528.00, Scan Time(Sec):0.25, Inter Scan Time (Sec):0.15, Start Time(min):1.00, End Time(min):44.50 as described. Perkin Elmer Column Specification: Elite-5MS, 30 meter, 0.25 mmID, 0.5 um df, Max Prog. Temp. 350 °C, Min. Bleed at 330°C, Cat. # N9316284, Serial # 875181. Differential Scanning Calorimeter was used for liquid sample analysis purposes. Used carrier gas N$_2$'s flow rate was 20 ml/min. 50 µL aluminum pans were used for sample holding and used sample 50 µL. Temperature range was 0 °C to 400 0 °C. Ramping rate was 15 °C per minute. FT-IR Spectrum 100 was used for liquid sample analysis purposes. Sodium Chloride cell was used for sample holding. Cell thickness is 0.025 mm. FT-IR range was 4000 cm^{-1} to 450 cm^{-1}, Used Resolution : 4 and Scan number : 32 .

Differential scanning calorimeter (DSC) was used for identifying the boiling and freezing point of the produced fuel. It measures the onset temperature and the lowest temperature tolerable by the compound. For this experiment only the boiling point was measured. The program setup temperature ranges from 0 – 400 ^{0}C. The ramping rate is 15^{0}C / min. The carrier gas is nitrogen (N$_2$) 20 ml/min. The aluminum sample holder is 50µL and sample amount 50µL.

B. Liquid Product Analysis

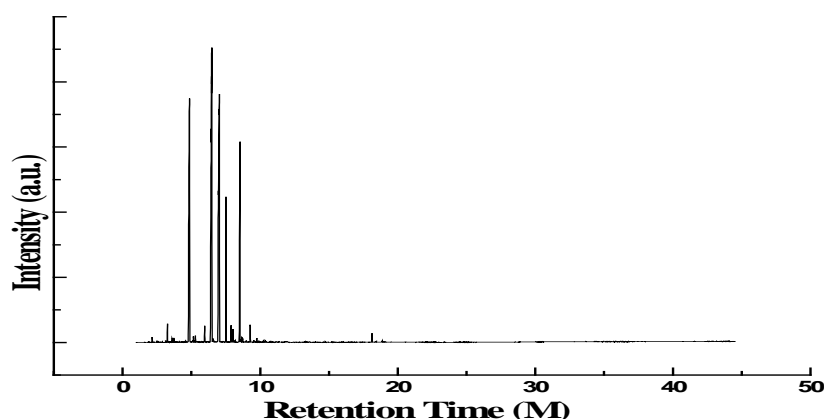GC-MS Analysis of PS fuel to 1st fractional fuel (Fig. 3

and Table 3) in accordance with the various retention time and trace mass in different types of hydrocarbon compound and benzene derivatives compounds are presented in the analysis result index. Many compounds emerged on the analysis carbon range C$_5$ 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 1.87 and trace mass 42, compound is Cyclopropane, ethyl- (C$_5$H$_{10}$); retention time 1.91 and trace mass 43, compound is Pentane (C$_5$H$_{12}$); retention time 2.06 and trace mass 67, compound is Cyclopropane, 1-ethyl-2-methyl-,cis- (C$_6$H$_{12}$); retention time 2.56 and trace mass 41, compound is 1,4 -Pentadiene (C$_5$H$_8$); retention time 2.24 and trace mass 67, compound is Cyclopentene (C$_7$H$_{16}$); retention time 2.49 and trace mass 41, compound is Cyclopropane, 1-ethyl-2-methyl-, cis- (C$_6$H$_{12}$); retention time 2.56 and trace mass 41, compound is Hexane (C$_6$H$_{14}$); retention time 3.13 and trace mass 67,compound name is Cyclopentene, 3-methyl-, (C$_6$H$_{10}$); retention time 3.72 and trace mass 43, compound name is Hexane, 3-methyl-, (C$_7$H$_{16}$); retention time 4.87 and trace mass 50, compound is 1,5-Heptadien-3-yne (C$_7$H$_8$); retention time 4.96 and trace mass 67, compound is 1,3-Butadiene, 2-ethyl- (C$_6$H$_{10}$); retention time 5.39 and trace mass 55, compound is 2-Octene (C$_8$H$_{16}$); retention time 5.96 and trace mass 54, compound is Cyclohexene, 4-ethenyl- (C$_8$H$_{12}$); retention time 6.46 and trace mass 92 compound is 3,5-Octadiyne (C$_8$H$_{10}$); retention time 7.88 and trace mass 117, compound is Benzene, cyclopropyl- (C$_9$H$_{10}$); retention time 8.99 and trace mass 105, compound is Benzene, (1-methylpropyl)- (C$_{10}$H$_{14}$); retention time 9.19 and trace mass 117, compound is Benzene, 1-methyl-4-(2-propenyl)- (C$_{10}$H$_{12}$); benzene compounds are formed because when raw polystyrene are made benzene are added into the reactants. Also at retention time 9.75 and trace mass 91, compound is Benzene, butyl- (C$_{10}$H$_{14}$); retention time 10.23 and trace mass 41, compound is 2-Undecene, (Z)-, (C$_{11}$H$_{22}$) etc. In the ultimate phase of the analysis index several compounds are detected according to their retention time and trace masses. Such as retention time 11.78 and trace mass 41, compound is 3-Dodecene, (E)-(C$_{12}$H$_{24}$); retention time 18.13 and trace mass 91, compound is Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis- (C$_{16}$H$_{16}$); and ultimately retention time 18.84 and retention time 91, compound is Benzene, 1,1'-(2-butene-1,4-diyl)bis- (C$_{16}$H$_{16}$) as well.

Fig. 3 GC/MS chromatogram of polystyrene fuel to 1st fractional fuel

TABLE III GC/MS CHROMATOGRAM OF 1st FRACTIONAL FUEL COMPOUND LIST WITH DIFFERENT RETENTION TIME

Number of Peak	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.87	42	Cyclopropane, ethyl-	C_5H_{10}	70	12.0	114410
2	1.91	43	Pentane	C_5H_{12}	72	32.8	114462
3	2.06	67	1,4-Pentadiene	C_5H_8	68	16.9	114494
4	2.24	67	Cyclopentene	C_5H_8	68	21.4	19032
5	2.49	41	Cyclopropane, 1-ethyl-2-methyl-, cis-	C_6H_{12}	84	19.9	113658
6	2.56	41	Hexane	C_6H_{14}	86	67.4	291337
7	3.13	67	Cyclopentene, 3-methyl-	C_6H_{10}	82	12.3	114408
8	3.26	78	Benzene	C_6H_6	78	66.5	114388
9	3.37	79	1,4-Cyclohexadiene	C_6H_8	80	16.9	114497
10	3.60	41	1-Heptene	C_7H_{14}	98	21.0	107734
11	3.72	43	Hexane, 3-methyl-	C_7H_{16}	100	42.4	113081
12	4.87	50	1,5-Heptadien-3-yne	C_7H_8	92	46.9	142710
13	4.96	67	1,3-Butadiene, 2-ethyl-	C_6H_{10}	82	7.92	118159
14	5.07	56	1-Heptene, 2-methyl-	C_8H_{16}	112	24.2	113675
15	5.11	70	Heptane, 3-methylene-	C_8H_{16}	112	42.0	114011
16	5.15	41	2-Octene	C_8H_{16}	112	18.0	118191
17	5.23	56	3-Octene, (Z)-	C_8H_{16}	112	9.36	113895
18	5.29	43	Octane	C_8H_{18}	114	37.5	229407
19	5.39	55	2-Octene	C_8H_{16}	112	15.6	118191
20	5.46	207	1-Methyl-2-methylenecyclohexane	C_8H_{14}	110	5.05	113437
21	5.96	54	Cyclohexene, 4-ethenyl-	C_8H_{12}	108	29.5	118901
22	6.13	67	3-Octen-1-ol, (E)-	$C_8H_{16}O$	128	7.71	53354
23	6.44	91	Benzene, 1,3-dimethyl-	C_8H_{10}	106	15.9	291455
24	6.46	92	3,5-Octadiyne	C_8H_{10}	106	31.9	231838
25	6.48	50	2H-Tetrazole-5-carboxylic acid, 2-phenyl-	$C_8H_6N_4O_2$	190	40.0	8253
26	6.96	78	1,3,5,7-Cyclooctatetraene	C_8H_8	104	39.5	113230
27	7.01	51	Benzene, 1-azido-4-methyl-	$C_7H_7N_3$	133	9.65	39082
28	7.04	52	Benzene, 1-azido-4-methyl-	$C_7H_7N_3$	133	11.5	39082
29	7.52	77	1-Hexen-4-yne, 3-ethylidene-2-methyl-	C_9H_{12}	120	19.7	150222
30	7.88	117	Benzene, cyclopropyl-	C_9H_{10}	118	16.1	113961
31	8.02	91	Benzene, propyl-	C_9H_{12}	120	78.8	113930
32	8.53	77	α-Methylstyrene	C_9H_{10}	118	40.7	2021
33	8.67	117	Benzene, 2-propenyl-	C_9H_{10}	118	21.2	114744
34	8.73	43	Decane	$C_{10}H_{22}$	142	43.5	114147
35	8.99	105	Benzene, (1-methylpropyl)-	$C_{10}H_{14}$	134	13.2	118593
36	9.19	117	Benzene, 1-methyl-4-(2-propenyl)-	$C_{10}H_{12}$	132	13.1	113549
37	9.27	117	Benzene, 2-propenyl-	C_9H_{10}	118	21.1	114744
38	9.53	91	Benzene, 3-butenyl-	$C_{10}H_{12}$	132	71.7	113933
39	9.75	91	Benzene, butyl-	$C_{10}H_{14}$	134	17.6	228741
40	10.23	41	2-Undecene, (Z)-	$C_{11}H_{22}$	154	8.13	60564
41	10.37	43	Undecane	$C_{11}H_{24}$	156	20.2	114185
42	11.78	41	3-Dodecene, (E)-	$C_{12}H_{24}$	168	4.23	113960
43	11.91	43	Dodecane	$C_{12}H_{26}$	170	8.07	22004
44	18.13	91	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	85.8	150655
45	18.44	105	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	$C_{16}H_{18}$	210	45.3	149665
46	18.88	91	Benzene, 1,1'-(2-butene-1,4-diyl)bis-	$C_{16}H_{16}$	208	27.3	152950

FT-IR analysis of PS waste plastic fuel to 1st fractional fuel (Fig. 4 and Table 4) according to their wave numbers and spectrum band following types of functional groups are appeared in the analysis. In the spectrum field we noticed that higher wave numbers 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 3648.65 cm^1 functional group is Intermolecular H bonds; wave number 3621.23 cm^1 functional group is Free OH (Sharp); wave number 2963.15 cm^{-1} and 2732.48 cm^{-1} functional group is C-CH$_3$; wave number 1870.81 cm^{-1},1802.23 cm^{-1},1745.41.08 cm^{-1},1704.68 cm^{-1}, 1688.00 cm^{-1} and 1629.64 cm^{-1} functional group is Non-Conjugated, wave number 1454.06 cm^{-1} and 1376.12 cm^{-1} functional group is CH$_3$; wave number 1028.42 cm^{-1} functional group is Acetates; and ultimately wave number 892.30 cm^{-1} functional group is C=CH$_2$ etc. Energy values are calculated, using formula is E=hυ, Where h=Planks Constant, h =6.626x10^{-34} J, υ= Frequency in Hertz (sec^{-1}), Where υ=c/λ, c=Speed of light, where, c=3x10^{10} m/s, W=1/λ, where λ is wave length and W is wave number in cm^{-1}. Therefore the equation E=hυ, can substitute by the following equation, E=hcW. According to their wave number several energy values are calculated such as for 2963.15 (cm^{-1}) calculated energy, E=5.80x10^{-20} J. Similarly, wave number 1870.81 (cm^{-1}) energy, E =3.61x10^{-20} J, wave number 1376.12 (cm^{-1}) energy, E = 2.73x10^{-20} J and eventually wave number 892.30 (cm^{-1}) functional group is 1.77x10^{-20} J respectively.
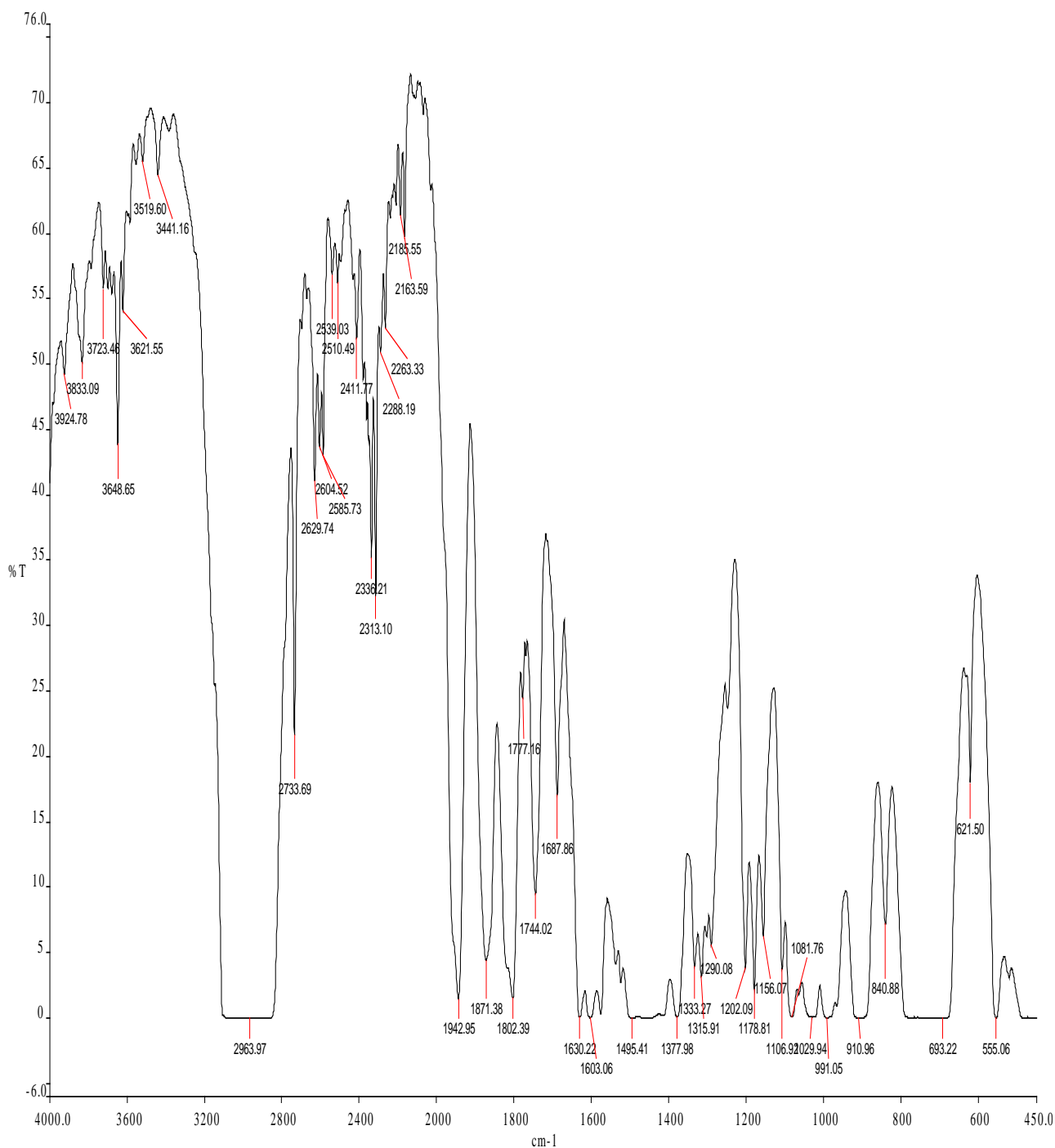

Fig. 4 FT-IR spectrum of polystyrene fuel to 1st fractional fuel

TABLE IV FT-IR SPECTRUM PS 1st FRACTIONAL FUEL FUNCTIONAL GROUP NAME

Number of Wave	Wave Number (cm^{-1})	Functional Group Name
4	3621.23	Free OH (Sharp)
5	3441.05	Intermolecular H Bonds (Sharp)
6	2963.15	C-CH$_3$
7	2732.48	C-CH$_3$
15	1870.81	Non-Conjugated
16	1802.33	Non-Conjugated
17	1745.41	Non-Conjugated
18	1704.68	Non-Conjugated
19	1688.00	Non-Conjugated
20	1629.64	Non-Conjugated
21	1604.03	Non-Conjugated
23	1454.06	CH$_3$
24	1376.12	CH$_3$
31	1028.42	Acetates
32	892.30	C=CH$_2$

Polystyrene waste plastic fuel to 1st fractional fuel was produce by using low temperature range 40-65 °C with fractional distillation column process. Produced fuel was analyzed by DSC and measurement boiling point temperature and delta H value. PS 1st fractional fuel DSC analysis result shows figure 5 and analysis results are showing fuel boiling start at temperature X1=5.18 °C and heat flow Endo up was Y1= 0.0267 mW. Onset temperature is 136.61 °C and boiling point peak temperature is 152.02 °C, peak height is 154.9850 mW. Peak end temperature 160.86 °C, peak area is 17275.018 mJ and enthalpy delta H value is 17275.0184 J/g. Finished temperature was X2=393.48 °C and heat flow Endo up Y2=2.9263 mW. At 50 °C fuel was boiling 13.33%, 78.03% when temperature was 150 °C because this fuel has light fraction aromatic and aliphatic hydrocarbon combination compound. Fuel boiling was finish 100% at temperature 308.19 °C.

Table 5 showed ASTM test result performed from 3rd party INTERTEK laboratory New Jersey, USA. Table 6 showed after fuel production from PS waste plastic to solid black left over residue present trace metal content and Table 7 showed solid black left over residue present carbon, hydrogen and nitrogen percentage.
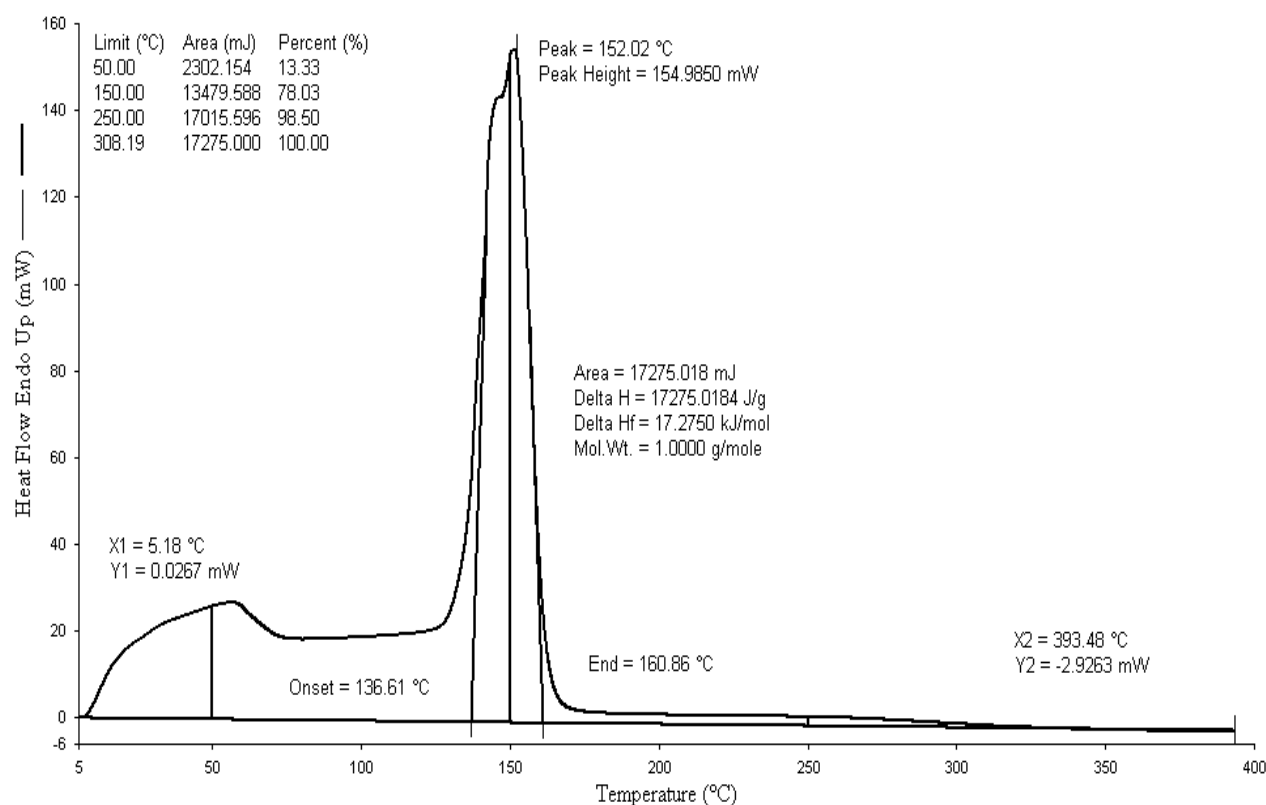

Fig. 5 DSC graph of Polystyrene fuel to 1st fractional fuel

TABLE V POLYSTYRENE WASTE PLASTIC TO LIQUID FUEL ASTM TEST ANALYSIS RESULT

Method	Test Name	Results	Units
ASTM D240	Gross Heat of Combustion	16716	BTU/lb
ASTM D240	Gross Heat of Combustion (Calculated)	126590	BTU/gal
ASTM D4052	API Gravity @ 60°F	24.1	°API
ASTM D86-07b	IBP Recovery	124.4	°C
ASTM D86-07b	5% Recovery	130.0	°C
ASTM D86-07b	10% Recovery	134.4	°C
ASTM D86-07b	20% Recovery	137.8	°C
ASTM D86-07b	30% Recovery	140.0	°C
ASTM D86-07b	40% Recovery	142.2	°C
ASTM D86-07b	50% Recovery	144.4	°C
ASTM D86-07b	60% Recovery	147.8	°C
ASTM D86-07b	70% Recovery	152.2	°C
ASTM D86-07b	80% Recovery	168.9	°C
ASTM D86-07b	90% Recovery	292.2	°C
ASTM D86-07b	95% Recovery	322.2	°C
ASTM D86-07b	FBP Recovery	326.7	°C
ASTM D86-07b	Recovery	95.0	Vol%
ASTM D86-07b	Residue	4.2	Vol%
ASTM D2500	Cloud point	-11.2	°C
ASTM D2500	Cloud Point	11.8	°F
ASTM D97	Pour point	-45.0	°C
ASTM D97	Pour point	-49.0	°F
ASTM D2386	Freezing Point	-14.0	°C
ASTM D2386	Freezing Point	6.8	°F
ASTM D2624	Temperature	24.0	°C
ASTM D2624	Electrical Conductivity	1159	pS/M
ASTM D5453	Sulfur	1.3	Mg/kg
ASTM D1500	ASTM Color	<6.0	
ASTM D4176	Appearance: Clean and Bright	Fail	
ASTM D4176	Free Water Content/Particles	No water	Mg/kg
ASTM D4176	Haze Rating	6.0	
ASTM D4176	Special Observation	Darker than usual	
ASTM D4737	Cetane Index (Procedure A)	25.1	
ASTM D5708_MOD	Vanadium	<1.0	ppm
ASTM D5708_MOD	Nickel	<1.0	ppm
ASTM D5708_MOD	Iron	<1.0	ppm, or, mg/Kg
ASTM D482	Ash	<0.001	Wt%
ASTM D93	Procedure Used	A	
ASTM D93	Corrected Flash Point	32.0	°C
ASTM D4530	Average Micro Method Carbon Residue 10% distillation	0.4	Wt%
ASTM D664	Procedure Used	A	
ASTM D664	Acid Number	<0.10	mgKOH/gm
ASTM D130	Copper Corrosion @ 50°C (122°F)/3 hrs.	1a	
ASTM D2709	Sediment and Water	<0.005	Vol%
ASTM D5291	Carbon Content	98.85	Wt%
ASTM D5291	Hydrogen Content	8.68	Wt%
ASTM D5291	Nitrogen Content	<0.75	Wt%

TABLE VI SOLID BLACK RESIDUE ANALYSIS RESULT FROM PS WASTE PLASTIC TO FUEL PRODUCTION

Test Method Name	Trace Metal Name	PS Waste Plastic to Residue	Units
ASTM D1976	Silver	<1.0	mg/L
	Aluminum	<1.0	
	Arsenic	<1.0	
	Boron	3.9	
	Barium	<1.0	
	Beryllium	<1.0	
	Calcium	<1.0	
	Cadmium	<1.0	
	Chromium	<1.0	
	Copper	3.5	
	Iron	219.9	
	Potassium	70.5	
	Lithium	<1.0	
	Magnesium	<1.0	
	Manganese	8.2	
	Sodium	303.6	
	Nickel	4.9	
	Lead	<1.0	
	Antimony	<1.0	
	Selenium	<1.0	
	Silicon	35.4	
	Tin	<1.0	
	Titanium	<1.0	
	Vanadium	<1.0	
	Zinc	86.0	

TABLE VII CARBON, HYDROGEN AND NITROGEN PERCENTAGE FRO LEFT OVER RESIDUE

Test Method Name	Sample Name	Carbon %	Hydrogen %	Nitrogen %
ASTM D5291.a	Residue	52.62	1.04	<0.30

IV. CONCLUSION

Polystyrene waste plastic to fuel production process left over residue percentage is little bit high because PS plastic additive percentage is high. For this process PS plastic to fuel conversion rate is 80% but residue percentage is also 15%. Produce fuel to further fractional distillation process light aromatic hydrocarbon fuel percentage is only 10%. Fuel analysis by GC/MS, FT-IR and DSC and results indicate that produce fuel has aliphatic and lots of aromatic hydrocarbon compound such as Benzene, Benzene, 1,3-dimethyl-, 1,3,5,7-Cyclooctatetraene, Benzene, 1-azido-4-methyl-, etc.. Light fraction fuel has carbon range C_5 to C_{16} and light gas carbon range C_1-C_4. Produced fuel is similar to gasoline and fuel has high octane rating. The carbon range proves that PS fuel has a high flammable capacity and its contents are highly combustible. Given that the PS plastic is the one that provides the most energy to the fuel that is produced through it. Overall the PS plastic is one of the most valuable out of the 4 plastic types because it contains and provides the most efficient results.

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