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Authors Biography

Moinuddin Sarker, PhD, MCIC, FICER, has been working as the Vice President (VP) of Research and Development and Head of Science Team (VP and CTO); 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 M. Sc (1992) and Ph. D. degree in Chemistry from University of Manchester Institute of Science and Technology (UMIST), Manchester, UK (1996). He has more than 22 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 three patent pending and 105 research publications to his credit in pier reviewed journals and conferences. Dr. Sarker is a distinguished member of 30 professional organizations such as American Association of Naval Engineer (ASNE), Association of Consumer Growth (ACG), 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). In 2010, Dr. Sarker has received, the International Renewable Energy Innovator of the year Awards 2010 at Washington DC and presented by Association of Energy Engineers (AEE), USA. E-mail address: msarker@naturalstateresearch.com

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1. Introduction

Plastic materials are widely used, and their broad applicability in consumer goods, household materials, packaging, and bag materials results in the incorporation of plastic refuse into garbage and litter. The principal types of plastic materials found in refuse are high density polyethylene (HDPE), used in trash bags, milk jugs, and shopping bags, low density polyethylene (LDPE), used for bags, food wrap, and plastic film, vinyl and poly(vinyl chloride) (PVC), used for bottles, packaging, and containers, poly(ethylene terephthalate) (PETE), used predominantly in beverage bottles and similar containers, polystyrene (PS), the spongy, light material used in supermarkets for meat, egg, and miscellaneous product trays, hot beverage cups, and thermally insulated take-home boxes, and polypropylene (PP), used for yogurt containers, straws, diapers, wrapping films, margarine tubs, and special bags. All of these plastics contact food and other products in a predominantly single-use event, after which they are discarded as garbage and/or litter. By far the major environmental impact is generated by plastic bags, made predominantly of polyethylene (HDPE and LDPE) with global usage somewhere between 500 and1000 billion new shopping bags per year, with countries such as Australia using 6.9 billion shopping bags annually [1] and the U.K. using ca. 17 billion bags per year [2]. Introduced in the 1970s, plastic bags have overtaken the shopping market and today almost everyone carries shopping and food in plastic trays, containers, and bags. All of these plastic packaging materials, after occasional reuse, get discarded in trash, garbage, or litter. Even if recycled, most of the recovered plastic winds up in trash as garbage bags or other disposable plastic materials [2].

Plastic materials have been found in all contemporary garbage and litter composition studies and represent the plastic use and disposal patterns of the society. Plastic content in garbage has been found to vary seasonally and with the area where the refuse is generated. The plastic content of garbage is lower in the summer 6.4% (w/w), increasing to 12% (w/w) during the winter holiday season in Calgary, Alberta [3]. Yearly average plastic contents of 9.3-10.4% (w/w) and broad compositions of plastic types, where plastic bags and plastic film represent from 47% to 51% of the total plastic content, have been reported for cities such as Seattle, WA, and Vancouver, BC, Canada, respectively [4, 5]. Litter has a similar compositional variability with total plastic contents ranging from ca. 6% to 11% (w/w) but with higher recyclable plastic levels (2.3-3.1% w/w) than those of garbage (0.6-1.1% w/w) [3, 6]. Plastics are manufactured by polymerization, polycondensation, or polyaddition reactions where monomeric molecules are joined sequentially under controlled conditions to produce high-molecular-weight polymers whose basic properties are defined by their composition, molecular weight distribution, and their degree of branching or cross-linking. To control the polymerization process, a broad range of structurally specific proprietary chemical compounds is used for polymerization initiation, breaking, and cross-linking reactions (peroxides, Ziegler-Natta, and metallocene catalysts). The polymerized materials are admixed with proprietary antioxidants (sterically hindered phenols, organophosphites), UV and light stability improvers (hindered amines and piperidyl esters), antistatic agents (ethoxylated amines), impact modifiers (methacrylatebutadiene- styrene compounds), heat stabilizers (methyl tin mercaptides), lubricants (esters), biostabilizers (arsine, thiazoline, and phenol compounds), and plasticizers used to

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modify the plasticity, softness, and pliability of plastics (phthalates and esters). World production of plastic additives is on the order of 18 billion pounds per year with plasticizers representing a 60% of the total amount [7].

The plastic material itself is environmentally quite stable, but the additives, their reaction and degradation products incorporated into the polymeric material, can be released into the environment as well as into the contacting fluids, products, or food [8, 9]. The main environmental concerns associated with additives used for plastics are related to their (a) potential ecotoxic effects, (b) mobility under conditions of use, (c) capacity to accumulate in the environment or bioaccumulate in organisms, and (d) generation or release of hazardous substances during disposal procedures or under normal geo-environmental conditions. Additives are released from plastics by leaching and contact transference. Diethylhexyl phthalate (DEHP) is a compound of special concern among the plasticizers used in plastic manufacture because it has been described as a probable human carcinogen by the U. S. Environmental Protection Agency, which has set exposure limits for DEHP in water [10-13]. DEHP has also been described as a potential endocrine disruptor to numerous organisms [14-16] and is believed to be harmful by inhalation, generating possible health risks and irreversible effects [17, 18, and 19].

Thermal degradation process comparative experimental study was performed with two types of plastics such as waste plastic of high density polyethylene and standard high density polyethylene (Sigma Aldrich). Both plastics experiment was conducted same temperature and same reactor. Temperature range was used for both experiment 100- 430 ºC. Waste plastic and standard plastic conversion rate was almost close one to another plastic but residue percentage and light gas percentage was different. Produce both plastics fuel was analyzed by gas chromatography and mass spectrometer, FT-IR and DSC. ASTM test result indicate sulfur content present into waste plastic has 3.7 and standard plastic to fuel has 1.0 but both fuel sulfur content less than EPA level. Produced fuel could be use feedstock refinery.

Keywords: waste plastic, standard HDPE, high density polyethylene, fuel, thermal degradation

2. Materials and Method

2.1. Materials

Waste plastic collected from Stamford local coffee shop and HDPE waste plastic was white color milk container with leftover milk and stick with adhesive level. Collected milk container was cleaned manually with liquid soap and water. Collected hard shape milk container was cut into small pieces by using scissor and size was 4-6 inch. Small pieces milk container part into grinder machine for grounded and size was 4-5 mm then transfer into reactor for liquefaction process. Standard HDPE collected from Sigma Aldrich Company and color was transparent. Standard HDPE plastic pellet size was 0.03-0.04 mm. Sigma Aldrich catalog number was 547999 and lot number

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21217PIV, CAS number 9002-88-4 and formula is C_2H_4. Waste plastic and standard plastic was pre-analysis by GC/MS, FT-IR, EA-2400 and TGA. The polymers used in plastics are generally harmless. However they are rarely used in pure form. In almost all commercial plastics, they are “compounded” with monomeric ingredients to improve their processing and end use performance. In order of total volume used, these monomeric additives may be classified as follows; Reinforcing fiber, Fillers, Coupling agent, Plasticizers, Colorants, Stabilizers (halogen stabilizers, antioxidants, ultraviolet absorbers and biological preservatives), Processing aids lubricants, and flow control), Flame Retardants, Peroxide and Antistatic agent[20].

2.3. Experimental section

Grounded waste plastic HDPE and standard HDPE plastic to fuel production process purposed used stainless steel reactor. Grounded waste HDPE plastic put into reactor chamber and setup with condenser unit collection tank, gas cleaning device, gas storage system, purification system and final collection tank was set up properly. HDPE waste plastic to sample used for experiment 1000 gm by weight. Figure 1 showed reactor specification number wise 1= Reactor Chamber, 2= Coil and Insulator, 3= Condenser unit, 4=Temp. controller & display, 5=Electrical outlet, 6= 2’’ ht. & 1’’ dia. for gas pressure monitor, 7=2’’ ht. & 1’’ dia. for Glass monitor, 8= 2’’ ht. & 1’’ dia. for inside temperature monitor, 9=2’’ ht. & 1’’ dia. for Thermocouple, 10=2’’ ht. & 1’’ dia. for Glass monitor, 11=Condenser Inner dia. 2’’, 12=Collection Tank, 13= Light Gas Collection Neck, 14= Fuel Product, 15= RCI Purification System (RCI Technology brand) , 16 =Gas Cleaning Device, 17= Light Gas Collection Teflon Bag, 18=Final Fuel collection tank. Grounded HDPE waste plastic heat start was 100 ºC to up to 430 ºC gradually. Waste plastic was start to melt when temperature was increase from 100 ºC to 200 ºC and start to come out vapor and but was not condense those vapor. Vapor was mixed with moisture because experimental procedure was not vacuums system and did not put any kind of chemical or catalyst. When temperature was increased accordingly 200 - 430 ºC waste plastic melt to liquid slurry and turn into vapor then vapor pass through condenser unit at the end start collection liquid fuel. During production period light gar was generated from this experiment and light gas was collected Teflon bag and before Teflon bag it was passing through liquid alkali solution and removed contamination. Waste plastic HDPE to fuel production process experiment run time was 5:07 hours and electricity was used for this particular experiment 7.03 kWh. HDPE waste plastic to fuel density was 0.79 g/ml. HDPE waste plastic to fuel production conversion rate was liquid fuel 81.01%, residue was 2.76% and light gas was 16.23%. 1000 gm waste HDPE plastic to fuel production mass balance was fuel weight 810.10 g (1025 ml), residue weight 27.6 g, sample weight as gas 162.3 g. For standard HDPE Plastic to fuel production process was applied same as HDPE waste plastic to fuel production process. Standard HDPE plastic was used 1000 gm for experiment and temperature range was applied same procedure for 100 to 430 ºC. Same parameter was used for standard plastic to fuel production and both fuel productions were performed under Labconco fume hood. Standard HDPE plastic to fuel production required time was 5:11 hours and electricity was for this experiment 6.99 kWh.

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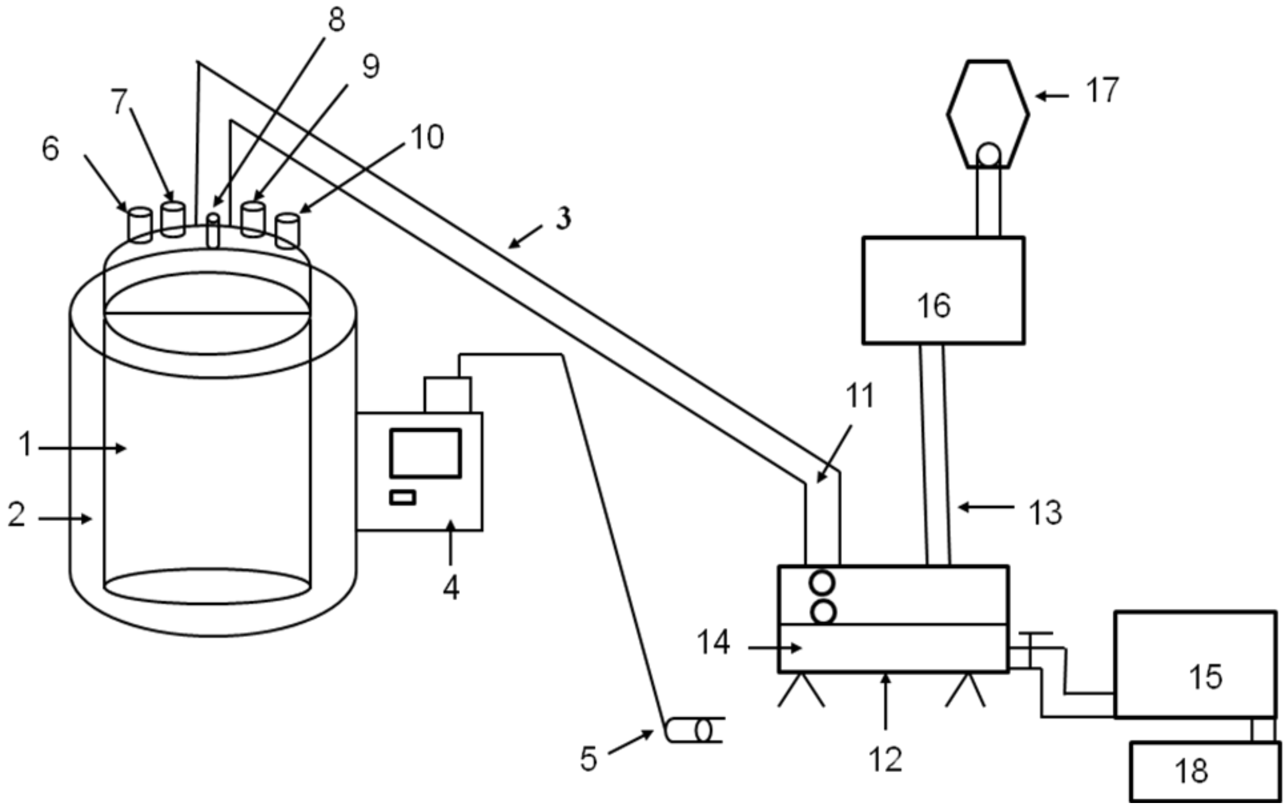

Fig.1: Standard HDPE and waste HDPE plastic to fuel production process

Standard plastic to fuel conversion rate was liquid fuel percentage 84.54%, residue percentage was 0.5 %, and sample as light gas was 14.96 %. HDPE standard fuel density was 0.79 g/ml and production mass balance was fuel weight 845.4 g, residue weight 5.0 g and sample as light gas weight 149.6 g. From HDPE waste plastic and HDPE standard plastic to fuel production process comparative conversion rate was in comparison discussion of above standard and waste plastic experiment noticed that in standard experiment yield percentage as well as other by-products percentage is higher than waste plastic experiment. The most probable factors are involved in that, most of waste plastics are abandoned in nature for long time as a revealed condition and during the time may be it could be interacted with trace soil element and air moisture. Also during the manufacture of waste plastics it's molded together of its reactants and gave shape with different types of additives to make the plastics hard and durable. Vis -a -vis standard plastics resins are made from its pure derivatives with less percentage of additives. Therefore standard waste plastics yield percentage is higher than waste plastics. However in residue and gas yield percentage of waste plastics is more than standard plastic because as mentioned that the same cause of adding additives in to the waste plastics and it's exist long time in the open air and interacted with various components including metals. HDPE Waste plastic Btu value is 18690.00 Btu/lb and from waste HDPE plastic to fuel Btu value is 19699 /lb. HDPE waste plastic to 810.10 gm fuel output Btu value showed based on Btu lab analysis result 102.73 kWh.

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3. Result and Discussion

3.1. Analytical procedure

Gas chromatography and Mass Spectrometer (GC/MS) Perkin Elmer model no Clarus 500 with pyroprobe and auto sampler system for solid sample and liquid fuel analysis proposed was used. Carrier gas helium was used for analysis. Capillary column was used for GC and EI mass detection was use for MS. GC column material number N9316284, Elite-5MS column length was 30 meter, internal diameter was 0.25mm and um df was 0.5. Column temperature maximum is 350 ºC. For GC program was set up initial 40 ºC and final 325 ºC and rate was 10ºC and hold for final temperature 15 min. This program was setup for liquid fuel analysis purpose. Solid sample analysis purpose was used pyroprobe and pyroprobe temperature was used 1200 ºC and GC port temperature was use 300 ºC. MS program was set up for mass detection for solid and liquid sample 35.00-528.00 EI+ and solvent delay was 1 minute. FT-IR was used solid waste plastic and standard plastic analysis purposed. For solid sample analysis was used diamond crystal plate (ATR) and liquid fuel analysis purposed was used NaCl cell and cell thickness was 0.25 mm. for FTIR program was setup for analysis solid and liquid range 4000-400 cm-1, resolution was 4 and scan number was 32 for both samples. EA-2400 was used for solid and liquid fuel analysis purposed and result showed carbon, hydrogen, nitrogen percentage. For EA-2400 analysis purpose carrier gas was used Oxygen, Nitrogen and Helium. TGA (Pyris-1) was used for solid sample analysis and determination onset temperature for solid sample liquefactions process. TGA program temperature was used for solid sample liquefaction process temperature versus weight and range was 50-800 ºC, rate was 15ºC/ minutes and carrier gas Helium was used for TGA. DSC equipment was used for liquid fuel boiling point measuring and carrier gas was Nitrogen. For DSC program temperature was 0-400 ºC and rate was 15 ºC.

3.2. Materials pre-analysis

HDPE waste plastic and standard plastic was pre-analyzed by EA-2400 system and checked their carbon, hydrogen and nitrogen content. Table 1 showed comparative discussion of Elemental Analyzer analysis appeared that standard HDPE plastic contain more carbon content that is 84.47% compare to waste HDPE plastic that is 83.57% as well as hydrogen and nitrogen contents in standard HDPE plastic is 15.23% and 0.3% where as in waste HDPE plastic 14.78% and 0.3%. Here appearing that in standard HDPE element contents percentage is more than waste HDPE plastic. Waste HDPE are collected from nature which is exist long time in the open air as well as interacted with the soil substances and other matters of nature. During the manufacture of waste plastics added some additives to gave the plastic shape and make it durable. On the other hand standard HDPE resins produced form its generic derivatives with very less percentage of additives. So that standard HDPE elements contents obviously would be higher than waste HDPE plastic. HDPE standard and HDPE waste plastics metal contents are showed according to the ICP laboratories analysis data and noticed that in some metal contents differ very much each other. If we consider Aluminum, Nickel, Magnesium contents in the HDPE waste plastics noticed that gradually 130 mg/L, <1.0 mg/L

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and 15.2 mg/L. On the other hand same element contents are very less in the standard HDPE plastics such as Aluminum is 99.3 mg/L, Nickel is 3.7 mg/L, Magnesium is <1.0 mg/L respectively. In accordingly Phosphorus, Silicon, Strontium metal contents are higher in waste HDPE plastic and less contents in standard HDPE plastic (see Table: 2). In comparison discussion we can stated that major element contents are much more in waste HDPE plastic compare to standard HDPE plastic because standard HDPE plastic is pure than waste HDPE plastic. Waste HDPE plastics are fallen in the open nature for long run as well as contaminated with different metal and other materials of soil and air components.

Table 1: HDPE standard and HDPE waste plastic C, H, and N percentage by EA-2400

Test Method Name	Plastic Name	Carbon %	Hydrogen %	Nitrogen %
ASTM D5291.a	HDPE Standard Plastic	84.47	15.23	<0.30
	HDPE Waste Plastic	83.57	14.78	<0.30

Table 2: HDPE standard and HDPE waste plastic trace metal by ICP

Test Method Name	Trace Metal Name	HDPE Waste Plastics (mg/L)	HDPE Standard Plastics (mg/L)
ASTM D 1976	Silver	<1.0	<1.0
	Aluminum	130.0	99.3
	Boron	<1.0	119.16
	Barium	<1.0	49.4
	Calcium	452.1	876.8
	Chromium	<1.0	20.0
	Copper	<1.0	3.9
	Iron	20.3	<1.0
	Potassium	<1.0	<50.0
	Lithium	<1.0	<1.0
	Magnesium	15.2	<1.0
	Molybdenum	<1.0	<1.0
	Sodium	23.4	11218
	Nickel	<1.0	3.7
	Phosphorus	39.3	<1.0
	Lead	<1.0	<1.0

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Antimony	<1.0	<1.0
Silicon	104.2	<1.0
Tin	<1.0	<1.0
Strontium	-	6.1
Titanium	2.2	<1.0
Thallium	-	<1.0
Vanadium	<1.0	10.2
Zinc	2.2	8.5

TGA (pyris-1) analysis result showed of standard HDPE (Sigma Aldrich) plastic onset temperature is 466.08 ºC and inflection point temperature is 495.17 ºC and sample was used for TGA analysis 2.99 mg. For analysis of standard raw sample by TGA temperature was used 50 -800 ºC and rate was 15 ºC/min and 1 minute was isothermal at 50 ºC then temperature increase gradually up to 800 ºC. HDPE waste plastic analyzed by TGA and result showed onset temperature is 418.30 and inflection point temperature is 437.60 ºC and raw sample was used for TGA analysis 2.877 mg and same procedure was applied for waste plastic and standard plastic TGA analysis. By using this TGA analysis both plastic rate of conversion was determined because temperature increase and sample was liquefaction and volatile gradually. Once sample fully volatile due to heat increase at the end we can get left over residue into TGA crucible and residue percentage was 2-3 % and both sample conversion rate was 97-98%.

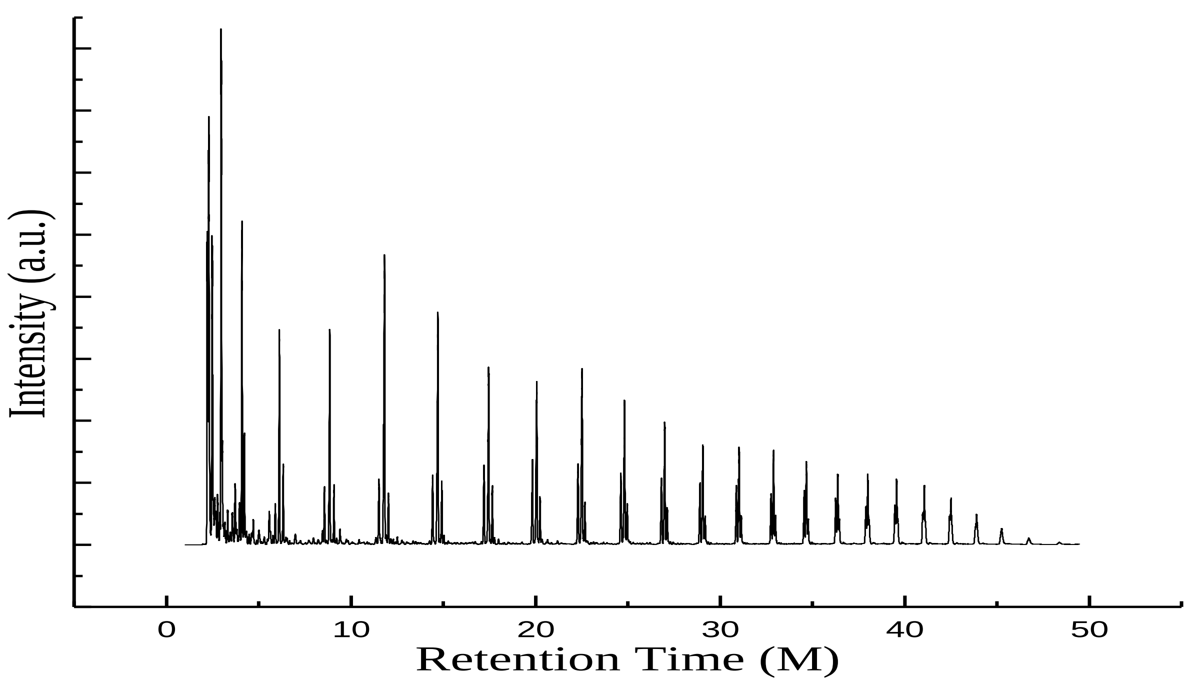

Fig.2: GC/MS Chromatogram of Standard HDPE plastic

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Table 3: GC/MS Chromatogram of Standard HDPE plastic compound list

Peak Number	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	2.20	41	Propane	C_3H_8	44	33.1	18863
2	2.21	42	β-Butyrolactone	$C_4H_6O_2$	86	26.1	191127
3	2.22	42	Cyclopropane	C_3H_6	42	65.0	18854
4	2.28	39	2-Butene, (E)-	C_4H_8	56	18.01	105
5	2.29	39	Butane, 1-isocyano-	C_5H_9N	83	11.2	156701
6	2.48	42	Cyclopropane, ethyl-	C_5H_{10}	70	27.1	114410
7	2.49	42	Cyclobutane, methyl-	C_5H_{10}	70	20.2	118539
8	2.77	67	Cyclopentene	C_5H_8	68	25.4	19032
9	2.90	67	1,5-Hexadiene	C_6H_{10}	82	48.6	227588
10	2.96	42	Cyclopropane, 1-ethyl-2-methyl-, cis-	C_6H_{12}	84	14.1	113658
11	2.96	43	1-Hexene	C_6H_{12}	84	28.2	500
12	3.03	41	Hexane	C_6H_{14}	86	63.1	61280
13	3.73	78	Benzene	C_6H_6	78	73.0	114388
14	3.96	67	Cyclohexene	C_6H_{10}	82	20.3	114431
15	4.10	41	1-Heptene	C_7H_{14}	98	36.3	107734
16	4.42	43	Heptane	C_7H_{16}	100	56.6	61276
17	4.34	55	2-Heptene	C_7H_{14}	98	31.6	113119
18	4.61	81	Cyclopentane, 1-methyl-2-methylene-	C_7H_{12}	96	19.7	62523
19	4.71	83	Cyclohexane, methyl-	C_7H_{14}	98	39.4	61214
20	4.89	69	Cyclopentane, ethyl-	C_7H_{14}	98	43.2	940
21	5.02	81	Cyclohexene, 4-methyl-	C_7H_{12}	96	25.0	125422
22	5.58	91	1,3,5-Cycloheptatriene	C_7H_8	92	29.7	230230
23	5.78	67	Cis-bicyclo[4.2.0]octane	C_8H_{14}	110	18.2	215126
24	5.90	67	1,7-Octadiene	C_8H_{14}	110	22.5	62191
25	6.12	41	1-Octene	C_8H_{16}	112	24.8	1604

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26	6.33	43	Octane	C_8H_{18}	114	45.3	61242
27	6.68	55	3-Octene, (Z)-	C_8H_{16}	112	18.3	113895
28	6.99	67	1,4-Octadiene	C_8H_{14}	110	16.3	113431
29	7.27	83	Cyclohexane, ethyl-	C_8H_{16}	112	18.4	113476
30	8.46	55	Cyclohexane, cyclopropyl-	C_9H_{16}	124	26.3	26670
31	8.56	54	1,8-Nonadiene	C_9H_{16}	124	46.8	107523
32	8.85	56	1-Nonene	C_9H_{18}	126	9.81	142583
33	9.08	43	Nonane	C_9H_{20}	128	32.7	249212
34	9.40	83	Cyclopentane, 1-methyl-2-(2-propenyl)-, trans-	C_9H_{16}	124	42.0	26931
35	11.52	55	1,9-Decadiene	$C_{10}H_{18}$	138	39.2	118291
36	11.82	41	1-Decene	$C_{10}H_{20}$	140	12.1	107686
37	12.03	57	Decane	$C_{10}H_{22}$	142	45.7	114147
38	12.51	55	Cyclohexane, 1-methyl-2-propyl-	$C_{10}H_{20}$	140	16.9	114020
39	14.43	55	1,10-Undecadiene	$C_{11}H_{20}$	152	49.2	113574
40	14.71	55	1-Undecene	$C_{11}H_{22}$	154	10.4	5022
41	14.92	57	Undecane	$C_{11}H_{24}$	156	24.4	114185
42	15.04	55	5-Undecene, (E)-	$C_{11}H_{22}$	154	9.16	114227
43	17.21	41	1,11-Dodecadiene	$C_{12}H_{22}$	166	31.3	113595
44	17.46	41	1-Dodecene	$C_{12}H_{24}$	168	4.98	107688
45	17.66	57	Dodecane	$C_{12}H_{26}$	170	30.5	291499
46	17.77	55	3-Dodecene, (E)-	$C_{12}H_{24}$	168	12.2	113960
47	17.99	41	1-Octadecyne	$C_{18}H_{34}$	250	6.67	233010
48	19.83	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	22.2	113612
49	20.07	41	1-Tridecene	$C_{13}H_{26}$	182	9.05	107768
50	20.24	57	Tridecane	$C_{13}H_{28}$	184	37.6	114282
51	22.30	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	23.6	113612
52	22.53	55	Cyclotetradecane	$C_{14}H_{28}$	196	5.88	45415
53	22.67	57	Tetradecane	$C_{14}H_{30}$	198	35.6	113925
54	24.62	41	1,13-Tetradecadiene	$C_{14}H_{26}$	194	17.2	113612

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55	24.82	55	Cyclopentadecane	$C_{15}H_{30}$	210	6.91	114876
56	24.97	57	Pentadecane	$C_{15}H_{32}$	212	15.2	107761
57	26.82	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	12.0	108369
58	27.00	55	1-Hexadecene	$C_{16}H_{32}$	224	9.52	118882
59	27.13	57	Hexadecane	$C_{16}H_{34}$	226	31.7	114191
60	28.91	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	8.58	108369
61	29.06	41	E-14-Hexadecenal	$C_{16}H_{30}O$	238	7.01	130980
62	29.07	69	Hexadecen-1-ol, trans-9-	$C_{16}H_{32}O$	240	8.69	141055
63	29.19	43	Heptadecane	$C_{17}H_{36}$	240	18.1	107308
64	30.89	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	7.68	108369
65	31.03	57	E-15-Heptadecenal	$C_{17}H_{32}O$	252	8.65	130979
66	31.14	57	Octadecane	$C_{18}H_{38}$	254	22.9	57273
67	32.77	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	10.5	241604
68	32.90	57	1-Nonadecene	$C_{19}H_{38}$	266	9.15	113626
69	33.1	57	Nonadecane	$C_{19}H_{40}$	268	29.7	114098
70	34.56	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	12.8	241604
71	34.68	43	1-Docosene	$C_{22}H_{44}$	308	9.01	113878
72	34.77	57	Eicosane	$C_{20}H_{42}$	282	14.5	290513
73	36.26	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	13.2	241604
74	36.38	43	1-Docosene	$C_{22}H_{44}$	308	11.4	113878
75	36.46	57	Heneicosane	$C_{21}H_{44}$	296	24.8	107569
76	37.91	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	19.8	241604
77	38.00	57	1-Docosene	$C_{22}H_{44}$	308	13.4	113878
78	38.08	57	Octacosane	$C_{28}H_{58}$	394	7.97	149865
79	39.47	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	22.8	241604
80	39.56	55	1-Docosene	$C_{22}H_{44}$	308	11.7	113878
81	39.64	57	Heneicosane	$C_{21}H_{44}$	296	7.39	107569
82	40.99	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	17.6	241604
83	41.07	57	Cyclotetracosane	$C_{24}H_{48}$	336	11.1	151227
84	42.51	97	Cyclotetracosane	$C_{24}H_{48}$	336	6.86	151227
85	43.89	57	1-Docosene	$C_{22}H_{44}$	308	7.71	113878

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86	45.26	43	1-Eicosanol	$C_{20}H_{42}O$	298	10.8	113075
87	46.72	43	1-Eicosanol	$C_{20}H_{42}O$	298	15.1	113075

Gas Chromatography and Mass Spectrometer (GC/MS) with Pyroprobe run sample analysis of standard HDPE plastic in (Fig.2 and table 3) in accordance with retention time and trace mass indicate various types of compound are present. In Pyroprobe at temperature 1200 °C HDPE standard plastics are turns into volatile gas in the GC and passed through the column to the mass spectroscopy. High intensity compounds are preferred in the analysis. An investigated carbon range in the analyzed plastic is C_3 to C_{24} because by in Pyroprobe large carbon chains are breaking down into small chain resulting in lower carbon range. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, in accordance to retention time 2.20 and trace mass 41 derived compound is Propane (C_3H_8), retention time 2.21 and trace mass 42, compound is β-Butyrolactone -($C_4H_6O_2$), retention time 2.22, trace mass 42 compound is Cyclopropane (C_3H_6), retention time 2.28, trace mass 39, compound is 2-Butene, (E)- (C_4H_8), retention time 2.29 and trace mass 39, compound is Butane, 1-isocyano- (C_5H_9N), retention time 2.48, trace mass 42, compound is Cyclopropane, ethyl- (C_5H_{10}), retention time 2.96 and trace mass 43, compound is Cyclopropane, 1-ethyl-2-methyl-, cis- (C_6H_{12}), retention time 2.77 and trace mass 67, compound is Cyclopentene,(C_5H_8), retention time 3.96 and trace mass 67, compound is Cyclohexene, (C_6H_{10}), retention time 4.89 and trace mass 69, compound is Cyclopentane, ethyl- (C_7H_{14}), retention time 5.90 and trace mass 67, compound is 1,7-Octadiene (C_8H_{14}), retention time 6.99 and trace mass 67, compound is 1,4-Octadiene (C_8H_{14}), retention time 7.27 and trace mass 83,compound is Cyclohexane, ethyl- ($C_{18}H_{16}$), retention time 8.85 and trace mass 56, compound is 1-Nonene -(C_9H_{18}) etc. Also in the middle of the analysis index retention time 11.82 and trace mass 41, compound is 1-Decene, ($C_{10}H_{20}$), retention time 12.51 and trace mass 55, compound is Cyclohexene, 1-methyl-, ($C_{10}H_{20}$), retention time 14.92 and trace mass 57, compound is Undecane, ($C_{11}H_{24}$), retention time 17.99 and trace mass 41, compound is 1-Octadecyne ($C_{18}H_{34}$), retention time 22.67 and trace mass 57, compound is Tetradecane ($C_{14}H_{30}$), retention time 26.82 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z)-, ($C_{16}H_{32}O$), retention time 28.91 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z)- ($C_{16}H_{32}O$). At the middle phase of the analysis retention time 32.90 and trace mass 57, Compound is 1-Nonadecene ($C_{19}H_{38}$), retention time 34.56 and trace mass 55, compound is 1,19-Eicosadiene, ($C_{20}H_{38}$), retention time 37.91 and trace mass 55, compound is 1,19-Eicosadiene ($C_{20}H_{38}$) etc. At the end phase of the analysis index high retention time and trace mass such as retention time 39.47, trace mass 55, compound is 1,19-Eicosadiene ($C_{20}H_{38}$), retention time 39.64 and trace mass 57, compound is Heneicosane ($C_{21}H_{44}$), retention time 43.89 and trace mass 57 compound is 1-Docosene ($C_{22}H_{44}$), and ultimately retention time 46.72 and trace mass 43, compound is 1-Eicosanol ($C_{20}H_{42}O$) etc. Here appearing that several oxygen compounds are produced because in the reactor during reaction phase oxygen induces from steam and water.

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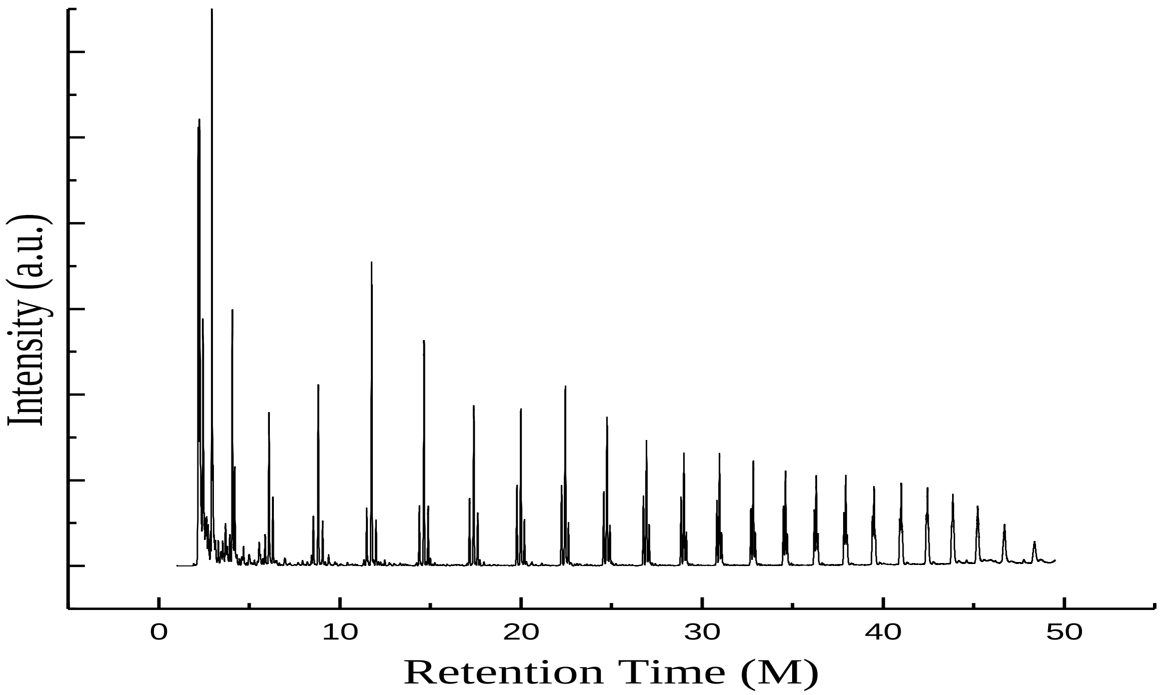

Fig.3: GC/MS Chromatogram of HDPE waste plastic

Table 4: GC/MS Chromatogram of HDPE waste plastic compound list

Peak Number	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	2.18	41	Cyclopropane	C_3H_6	42	45.4	18854
2	2.26	41	2-Butene, (E)-	C_4H_8	56	16.4	105
3	2.44	42	Cyclopropane, ethyl-	C_5H_{10}	70	38.0	114410
4	2.64	67	1,3-Pentadiene	C_5H_8	68	18.4	291890
5	2.94	56	1-Hexene	C_6H_{12}	84	27.4	227613
6	3.70	78	Benzene	C_6H_6	78	75.6	221957
7	4.07	41	1-Heptene	C_7H_{14}	98	28.2	107734
8	4.21	43	Heptane	C_7H_{16}	100	39.9	61276
9	4.46	81	3-Hepten-1-ol	$C_7H_{14}O$	114	9.16	113238
10	5.69	55	Cyclohexane, methyl-	C_7H_{14}	98	42.8	118503

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11	5.00	81	Cyclohexene, 4-methyl-	C_7H_{12}	96	15.5	125422
12	5.56	91	Toluene	C_7H_8	92	27.1	19585
13	5.88	41	1,7-Octadiene	C_8H_{14}	110	15.3	62191
14	6.09	41	1-Octene	C_8H_{16}	112	21.1	1604
15	6.31	43	Octane	C_8H_{18}	114	35.0	61242
16	6.96	67	1-Methyl-2-methylenecyclohexane	C_8H_{14}	110	9.97	113437
17	6.96	67	1,4-Octadiene	C_8H_{14}	110	26.1	113431
18	8.44	55	Cyclohexane, cyclopropyl-	C_9H_{16}	124	29.6	26670
19	8.54	54	1,8-Nonadiene	C_9H_{16}	124	38.4	107523
20	8.81	55	1-Nonene	C_9H_{18}	126	10.4	107756
21	9.06	57	Nonane	C_9H_{20}	128	34.9	249212
22	9.38	83	Cyclopentane, 1-methyl-2-(2-propenyl)-, trans-	C_9H_{16}	124	55.0	26931
23	9.74	55	Cyclohexane, 2-propenyl-	C_9H_{16}	124	48.5	114217
24	11.49	55	1,9-Decadiene	$C_{10}H_{18}$	138	34.5	118291
25	11.77	56	1-Decene	$C_{10}H_{20}$	140	15.1	118883
26	12.00	57	Decane	$C_{10}H_{22}$	142	35.5	114147
27	12.49	55	Cyclohexane, 1-methyl-2-propyl-	$C_{10}H_{20}$	140	26.1	114020
28	12.74	55	1,11-Dodecadiene	$C_{12}H_{22}$	166	19.0	113595
29	14.40	55	1,10-Undecadiene	$C_{11}H_{20}$	152	35.1	113574
30	14.65	41	Cyclopropane, 1-heptyl-2-methyl-	$C_{11}H_{22}$	154	6.67	62622
31	14.89	57	Undecane	$C_{11}H_{24}$	156	36.7	114185
32	15.1	55	3-Undecene, (Z)-	$C_{11}H_{22}$	154	12.6	142598
33	17.17	55	1,11-Dodecadiene	$C_{12}H_{22}$	166	27.7	113595
34	17.40	41	3-Dodecene, (E)-	$C_{12}H_{24}$	168	5.80	113960
35	17.62	57	Dodecane	$C_{12}H_{26}$	170	33.1	291499
36	17.74	55	3-Dodecene, (E)-	$C_{12}H_{24}$	168	12.8	113960
37	19.78	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	18.0	113612

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38	20.00	55	1-Tridecene	$C_{13}H_{26}$	182	18.8	107768
39	20.20	57	Tridecane	$C_{13}H_{28}$	184	34.0	107767
40	22.25	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	18.3	113612
41	22.46	41	1-Tridecene	$C_{13}H_{26}$	182	6.0	107768
42	22.63	57	Tetradecane	$C_{14}H_{30}$	198	35.3	113925
43	24.58	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	15.4	113612
44	24.76	55	Cyclopentadecane	$C_{15}H_{30}$	210	8.45	114876
45	24.92	57	Pentadecane	$C_{15}H_{32}$	212	38.2	107761
46	26.76	55	1,13-Tetradecadiene	$C_{14}H_{26}$	194	9.97	113612
47	26.94	55	1-Hexadecene	$C_{16}H_{32}$	224	17.2	118882
48	27.08	57	Hexadecane	$C_{16}H_{34}$	226	29.4	114191
49	28.85	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	6.56	108369
50	29.00	55	E-14-Hexadecenal	$C_{16}H_{30}O$	238	11.3	130980
51	29.13	57	Heptadecane	$C_{17}H_{36}$	240	18.2	107308
52	30.83	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	8.61	108369
53	30.97	41	E-15-Heptadecenal	$C_{17}H_{32}O$	252	6.94	130979
54	31.09	57	Octadecane	$C_{18}H_{38}$	254	20.2	57273
55	32.71	55	11-Hexadecen-1-ol, (Z)-	$C_{16}H_{32}O$	240	9.89	108369
56	32.83	55	1-Nonadecene	$C_{19}H_{38}$	266	10.3	113626
57	32.94	57	Nonadecane	$C_{19}H_{40}$	268	20.1	114098
58	34.51	55	1,15-Hexadecadiene	$C_{16}H_{30}$	222	7.05	155378
59	34.61	55	1-Heptadecanol	$C_{17}H_{36}O$	256	8.37	113250
60	34.71	57	Nonadecane	$C_{19}H_{40}$	268	13.6	114098
61	36.21	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	7.71	241604
62	36.31	55	1-Nonadecene	$C_{19}H_{38}$	266	9.27	113626
63	36.40	57	Heneicosane	$C_{21}H_{44}$	296	19.8	107569
64	37.85	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	16.9	241604
65	37.94	57	1-Docosene	$C_{22}H_{44}$	308	10.4	113878
66	38.02	57	Docosane	$C_{22}H_{46}$	310	7.81	109506
67	39.41	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	13.4	241604
68	39.50	55	1-Docosene	$C_{22}H_{44}$	308	12.5	113878
69	39.58	57	Octacosane	$C_{28}H_{58}$	394	8.44	149865

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70	40.93	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	8.80	241604
71	41.01	55	1-Docosene	$C_{22}H_{44}$	308	9.68	113878
72	42.39	55	1,19-Eicosadiene	$C_{20}H_{38}$	278	14.5	241604
73	42.45	55	1-Docosene	$C_{22}H_{44}$	308	6.63	113878
74	43.85	55	1-Eicosanol	$C_{20}H_{42}O$	298	8.42	113075
75	45.23	57	1-Eicosanol	$C_{20}H_{42}O$	298	8.26	113075
76	46.71	57	1-Eicosanol	$C_{20}H_{42}O$	298	7.69	113075
77	48.37	57	1-Eicosanol	$C_{20}H_{42}O$	298	9.65	113075

Gas Chromatography and Mass Spectrometer with Pyroprobe analysis of solid waste of HDPE plastic in (Fig.3 and table 4) in accordance with retention time and trace mass indicate various types of compound are present. In Pyroprobe at temperature 1400 °C HDPE waste plastics are turns into volatile gas in the GC and passed through the column to the mass spectroscopy. High intensity compounds are preferred in the analysis. An investigated carbon range in the analyzed plastic is C_3 to C_{28} because in Pyroprobe large carbon chains are breaking down into small chain resulting in lower carbon range. Sometimes noticed that for high peak intensity compound probability factor is low percentage, where as in low peak intensity compound probability factor is high percentage. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, in accordance to retention time 2.18 and trace mass 41 derived compound is Cyclopropane (C_3H_6) with probability 45.4%, retention time 2.26 and trace mass 41, compound is 2-Butene, (E)-(C_4H_8) with probability 16.4%, retention time 3.70 and trace mass 78 compound is Benzene (C_6H_6) with probability 75.6%, retention time 4.46 and trace mass 81, compound is 3-Hepten-1-ol ($C_7H_{14}O$) with probability factor 9.1%, retention time 5.88 and trace mass 41, compound is 1,7-Octadiene (C_8H_{14}) with probability 15.3%, retention time 6.96, trace mass 67, compound is 1,4-Octadiene (C_8H_{14}) with probability 26.1%, retention time 8.81 and trace mass 55, compound is 1-Nonene, (C_9H_{18}) with probability 10.4%, retention time 9.74 and trace mass 55, compound is Cyclohexane, 2-propenyl-,(C_9H_{16}) with probability 48.5%, retention time 11.77 and trace mass 56, compound is 1-Decene, ($C_{10}H_{20}$) with probability 15.1%, retention time 12.74 and trace mass 55, compound is 1,11-Dodecadiene ($C_{11}H_{22}$) with probability 19.0%, retention time 14.89 and trace mass 57, compound is Undecane ($C_{11}H_{24}$) with probability 36.7%, retention time 17.74 and trace mass 55, compound is 3-Dodecene, (E)- ($C_{12}H_{24}$) with probability 12.8%, retention time 19.78 and trace mass 55,compound is 1,13-Tetradecadiene ($C_{14}H_{26}$) with probability 18%, retention time 20.20 and trace mass 57, compound is Tridecane ($C_{13}H_{28}$) with probability 34% etc. Also in the middle of the analysis index retention time 22.63 and trace mass 57, compound is Tetradecane ($C_{14}H_{30}$) with probability 35.3%, retention time 24.92 and trace mass 57, compound is Pentadecane ($C_{15}H_{32}$) with probability 38.2%, retention time 26.94 and trace mass 55, compound is 1-Hexadecene ($C_{16}H_{32}$) with probability 17.2%, retention time 28.85 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z) - ($C_{16}H_{32}O$) with probability 6.56%. As well Retention time 29.13 and trace mass 57, compound is Heptadecane ($C_{17}H_{36}$) with probability 18.2%, retention time 31.09 and trace mass 57, compound is

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Octadecane ($C_{18}H_{38}$) with probability 20.2%, retention time 34.51 and trace mass 55, compound is 1,15-Hexadecadiene ($C_{16}H_{30}$) with the probability 7.05%. Also at the middle phase of the analysis retention time 36.21 and trace mass 55, Compound is 1,19-Eicosadiene ($C_{20}H_{38}$) with probability 7.71%, retention time 39.58 and trace mass 57, compound is Heneicosane ($C_{21}H_{44}$) with probability 19.8% , retention time 38.02 and trace mass 57, compound is Docosane ($C_{28}H_{58}$) with probability 12.5% etc. At the end phase of the analysis index high retention time and trace mass such as retention time 42.39 and trace mass 55, compound is 1, 19-Eicosadiene ($C_{20}H_{38}$) with probability 6.63%, retention time 43.58 and trace mass 55, compound is 1-Eicosanol ($C_{20}H_{42}O$) with probability 8.42%, and ultimately retention time 48.37 and trace mass 57, compound is 1-Eicosanol ($C_{20}H_{42}O$) etc. In the analysis appearing that in several oxygen compounds are produced because in the reactor during reaction oxygen induces from steam and water. Also noticed that including most of double bond compound was as well as benzene and benzene derivatives compounds are available in the waste HDPE plastics.

In the comparison discussion of GC/MS Pyroprobe Analysis of standard HDPE and waste HDPE found that numerous similar and dissimilar compounds are available in the analysis. In pyroprobe at temperature 1400 °C standard HDPE and waste HDPE both plastics are turns into volatile gas in the GC and passed through the column to the mass spectroscopy. High intensity compounds are preferred in the analysis for both plastics. An investigated carbon range in the both analyzed plastic is C_3 to C_{28} because by in pyroprobe large carbon chains are breaking down into small chain resulting in lower carbon range. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, such as in raw HDPE standard plastic in accordance with the retention time and trace mass only few of compounds are taken for distinguishing with waste HDPE compound analysis such as in standard HDPE retention time 2.20 (retention time in minute) and trace mass 41 derived compound is Propane (C_3H_8), retention time 2.21 and trace mass 42, compound is β-Butyrolactone - ($C_4H_6O_2$), retention time 2.22, trace mass 42 compound is Cyclopropane (C_3H_6), retention time 2.28, trace mass 39, compound is 2-Butene, (E)- (C_4H_8), retention time 2.29 and trace mass 39, compound is Butane, 1-isocyano- (C_5H_9N), retention time 2.48, trace mass 42, compound is Cyclopropane, ethyl- (C_5H_{10}), retention time 2.96 and trace mass 43, compound is Cyclopropane, 1-ethyl-2-methyl-, cis- (C_6H_{12}), retention time 2.77 and trace mass 67, compound is Cyclopentene,(C_5H_8), retention time 3.96 and trace mass 67, compound is Cyclohexene, (C_6H_{10}), retention time 4.89 and trace mass 69, compound is Cyclopentane, ethyl- (C_7H_{14}), retention time 5.90 and trace mass 67, compound is 1,7-Octadiene (C_8H_{14}), retention time 6.99 and trace mass 67, compound is 1,4-Octadiene (C_8H_{14}), retention time 7.27 and trace mass 83,compound is Cyclohexane, ethyl- ($C_{18}H_{16}$), retention time 8.85 and trace mass 56, compound is 1-Nonene -(C_9H_{18}) etc. Also in the middle of the analysis index retention time 11.82 and trace mass 41, compound is 1-Decene, ($C_{10}H_{20}$), retention time 12.51 and trace mass 55, compound is Cyclohexene, 1-methyl-, ($C_{10}H_{20}$), retention time 14.92 and trace mass 57, compound is Undecane, ($C_{11}H_{24}$), retention time 17.99 and trace mass 41, compound is 1-Octadecyne ($C_{18}H_{34}$), retention time 22.67 and trace mass 57, compound is Tetradecane ($C_{14}H_{30}$), retention time 26.82 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z)-, ($C_{16}H_{32}O$), retention time 28.91 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z)- ($C_{16}H_{32}O$). At the middle phase of the analysis retention time 32.90 and trace mass 57, Compound is 1-Nonadecene ($C_{19}H_{38}$), retention time 34.56 and trace mass

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55, compound is 1,19-Eicosadiene, ($C_{20}H_{38}$), retention time 37.91 and trace mass 55, compound is 1,19-Eicosadiene ($C_{20}H_{38}$) etc. At the end phase of the analysis index high retention time and trace mass such as retention time 39.47, trace mass 55, compound is 1, 19-Eicosadiene ($C_{20}H_{38}$), retention time 39.64 and trace mass 57, compound is Heneicosane ($C_{21}H_{44}$), retention time 43.89 and trace mass 57 compound is 1-Docosene ($C_{22}H_{44}$), and ultimately retention time 46.72 and trace mass 43, compound is 1-Eicosanol ($C_{20}H_{42}O$) etc. On the other hand in waste HDPE plastics analysis each retention time and trace mass are different than standard HDPE plastic as well as most of similar and different compounds are emerged. In some case noticed that at same retention time and trace mass compounds available where different retention time and trace mass compounds are also available in the analysis. In accordance to retention time 2.18 and trace mass 41 derived compound is Cyclopropane (C_3H_6) with probability 45.4%, retention time 2.26 and trace mass 41, compound is 2-Butene, (E)-(C_4H_8), retention time 3.70 and trace mass 78 compound is Benzene (C_6H_6)\, retention time 4.46 and trace mass 81, compound is 3-Hepten-1-ol ($C_7H_{14}O$), retention time 5.88 and trace mass 41, compound is 1,7-Octadiene (C_8H_{14}), retention time 6.96, trace mass 67, compound is 1,4-Octadiene (C_8H_{14}), retention time 8.81 and trace mass 55, compound is 1-Nonene, (C_9H_{18}), retention time 9.74 and trace mass 55, compound is Cyclohexane, 2-propenyl-,(C_9H_{16}), retention time 11.77 and trace mass 56, compound is 1-Decene, ($C_{10}H_{20}$), retention time 12.74 and trace mass 55, compound is 1,11-Dodecadiene ($C_{11}H_{22}$) with probability 19.0%, retention time 14.89 and trace mass 57, compound is Undecane ($C_{11}H_{24}$), retention time 17.74 and trace mass 55, compound is 3-Dodecene, (E)- ($C_{12}H_{24}$), retention time 19.78 and trace mass 55,compound is 1,13-Tetradecadiene ($C_{14}H_{26}$), retention time 20.20 and trace mass 57, compound is Tridecane ($C_{13}H_{28}$) etc. Also in the middle of the analysis index retention time 22.63 and trace mass 57, compound is Tetradecane ($C_{14}H_{30}$), retention time 24.92 and trace mass 57, compound is Pentadecane ($C_{15}H_{32}$), retention time 26.94 and trace mass 55, compound is 1-Hexadecene ($C_{16}H_{32}$), retention time 28.85 and trace mass 55, compound is 11-Hexadecen-1-ol, (Z) - ($C_{16}H_{32}O$) etc. At the end phase of the analysis index high retention time and trace mass such as retention time 42.39 and trace mass 55, compound is 1, 19-Eicosadiene ($C_{20}H_{38}$), retention time 43.58 and trace mass 55, compound is 1-Eicosanol ($C_{20}H_{42}O$) and ultimately retention time 48.37 and trace mass 57, compound is 1-Eicosanol ($C_{20}H_{42}O$) etc. Eventually in comparison discussion of both standard and waste HDPE significant differences are noticed in retention time as well as in trace mass field with maximum different types of aromatic and aliphatic hydrocarbon compounds appeared.

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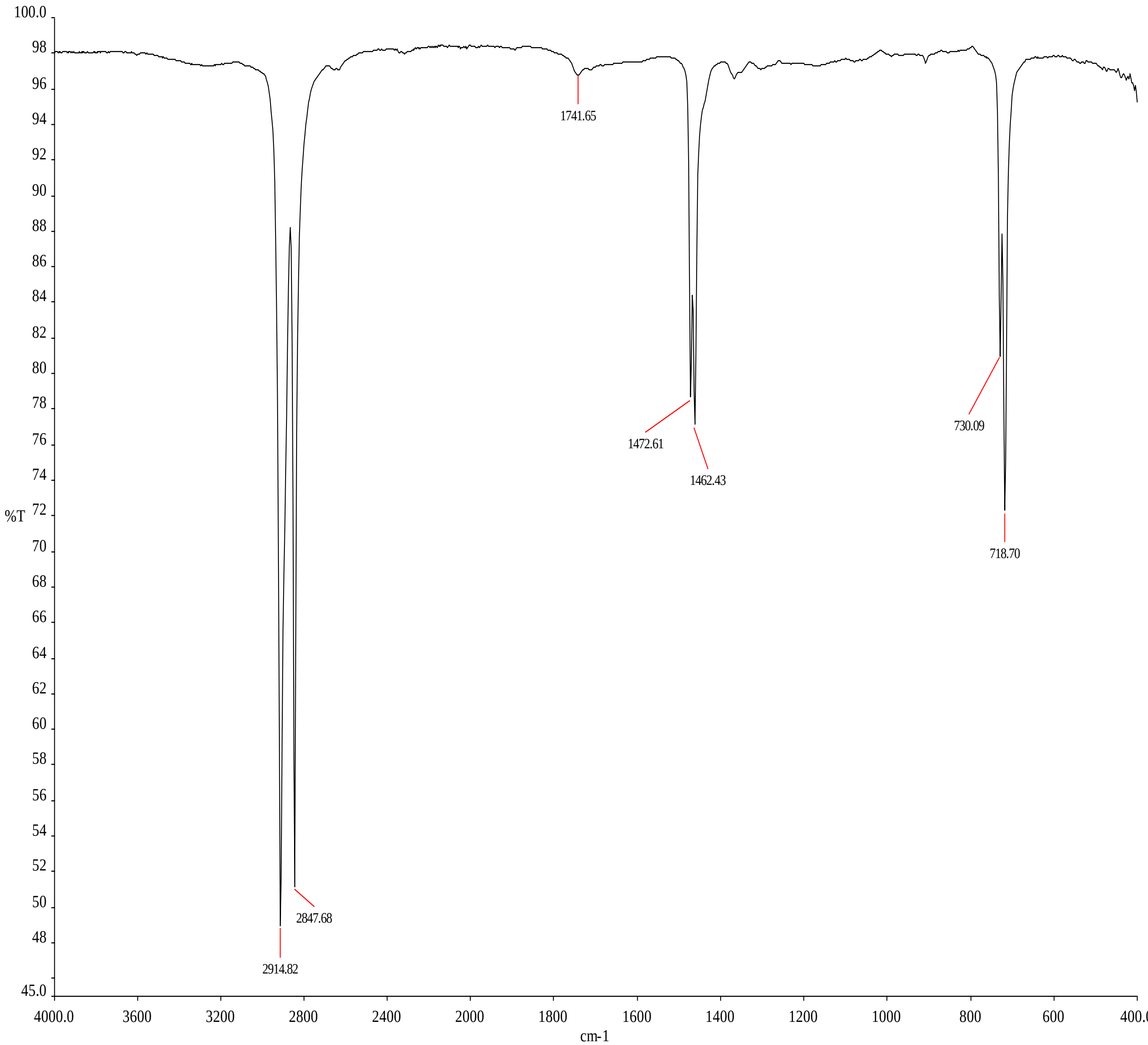

Fig. 4: FT-IR spectrum of Standard HDPE plastic

HDPE standard raw plastic run (fig.4) by FT-IR ATR (Attenuated Reflectance Resonance) appeared that following types of functional groups are present such as wave number 2914.82 cm^{-1} functional group is C-$CH_{3,}$ wave number 2847.68 cm^{-1}, functional group is $CH_{2,}$ wave number 1741.65 cm^{-1}, functional group is Non-Conjugated, wave number 1472.61 cm^{-1} and 1462.43 cm^{-1}, functional group is CH_3 and at the end phase of the analysis wave number 730.09 cm^{-1} and 718.70 cm^{-1}, functional group is –CH=CH-(cis) as well.

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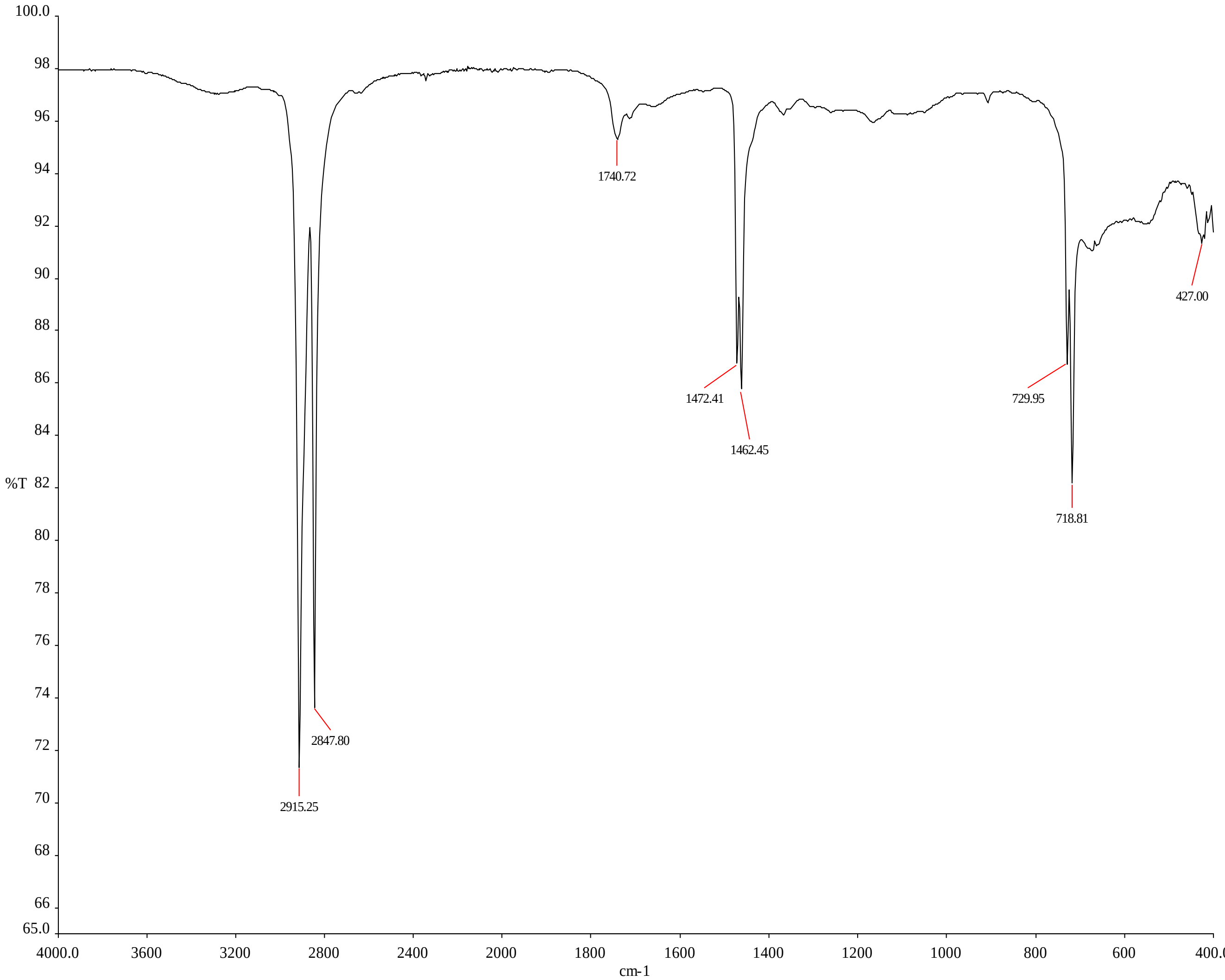

Fig.5: FT-IR spectrum of HDPE waste plastic

Waste HDPE raw plastic (fig.5) run by FT-IR ATR (Attenuated Reflectance Resonance) appeared that following types of functional groups are present such as wave number 2915.25 cm^{-1} functional group is C-CH_3, wave number 2847.80 cm^{-1}, functional group is CH_2, wave number 1740.72 cm^{-1}, functional group is Non-Conjugated, wave number 1472.41 cm^{-1} and 1462.45 cm^{-1}, functional group is CH_3 and at the end phase of the analysis wave number 729.95 cm^{-1} and 718.81 cm^{-1}, functional group is –CH=CH-(cis) etc.

From FT-IR (spectrum 100) analysis by ATR (Attenuated Total Reflectance) comparison was found that standard plastic HDPE-2 contains following functional groups C-CH_3, CH_2, CH_3 , Non-Conjugated, and -CH=CH-(cis). On the other hand, FTIR analysis by ATR (Attenuated Total Reflectance) of waste plastic HDPE contains C-CH_3, Non-Conjugated, CH_2, CH_3, and -CH=CH-(cis) etc. In the comparative discussion same functional groups are appearing in the both analysis. Most of the functional groups of waste HDPE's are identical with standard HDPE-2 plastic,

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significant differences are noticed in the spectrum wave number each and every functional group wave number are different compare to each other, such as for standard plastic wave number 2914.82 cm^{-1}, functional group is $C\text{-}CH_3$ and for waste plastics wave number 2915.25 cm^{-1}, functional group is same as $C\text{-}CH_3$ etc.

3.3. Liquid Fuel Analysis

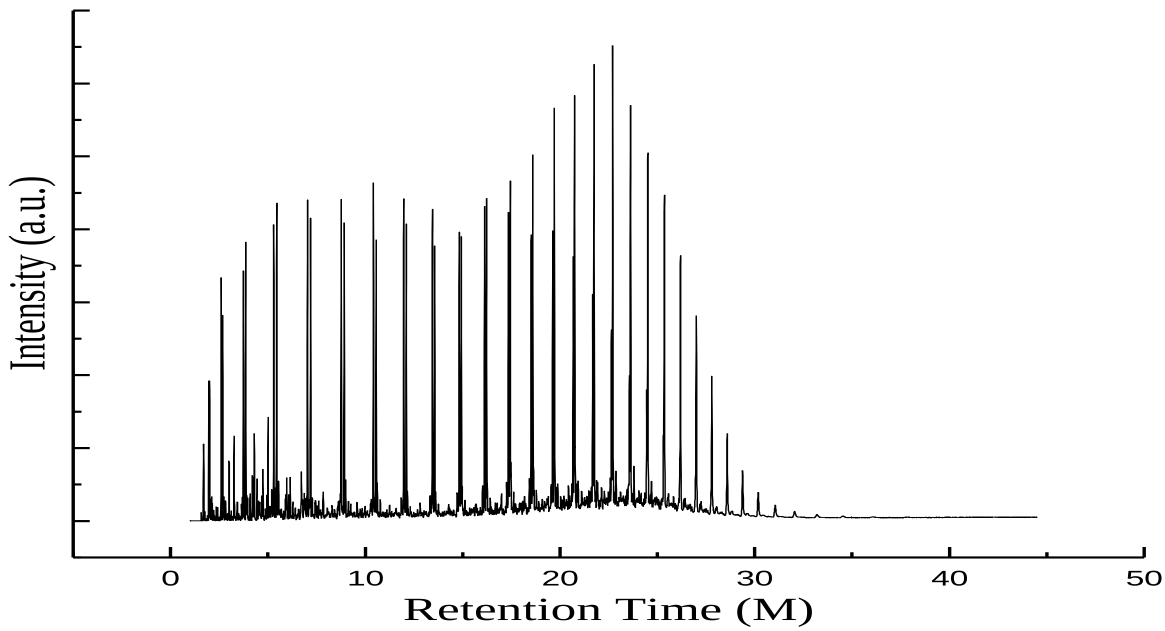

Fig. 6: GC/MS Chromatogram of Standard HDPE plastic to fuel

Table 5: GC/MS Chromatogram of Standard HDPE plastic to fuel compound list

Peak Number	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.58	39	Propane	C_3H_8	44	93.0	18863
2	1.70	43	Butane	C_4H_{10}	58	64.9	18940
3	1.75	41	2-Butene, (E)-	C_4H_8	56	27.8	105
4	1.90	41	Butane, 2-methyl-	C_5H_{12}	72	66.5	291251
5	1.96	42	Cyclopropane, ethyl-	C_5H_{10}	70	17.5	114410
6	2.00	43	Pentane	C_5H_{12}	72	69.8	114462
7	2.04	55	Cyclopropane, 1,2-dimethyl-, cis-	C_5H_{10}	70	19.1	19070

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8	2.08	55	2-Pentene, (E)-	C_5H_{10}	70	17.4	231217
9	2.15	67	1,3-Pentadiene	C_5H_8	68	24.2	291890
10	2.34	67	Bicyclo[2.1.0]pentane	C_5H_8	68	12.2	192491
11	2.42	42	1-Pentene	C_5H_{10}	70	11.5	19081
12	2.60	56	2-Hexene, (Z)-	C_6H_{12}	84	10.8	114458
13	2.68	56	Hexane	C_6H_{14}	86	73.2	291337
14	2.74	55	3-Hexene, (Z)-	C_6H_{12}	84	26.6	114381
15	2.82	67	1,3-Butadiene, 2-ethyl-	C_6H_{10}	82	8.42	118159
16	3.00	56	Cyclopentane, methyl-	C_6H_{12}	84	64.6	114428
17	3.12	79	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	13.6	113646
18	3.26	67	Cyclopentene, 1-methyl-	C_6H_{10}	82	12.9	107747
19	3.42	41	Cyclohexane	C_6H_{12}	84	28.3	291493
20	3.69	56	1-Hexene, 2-methyl-	C_7H_{14}	98	41.9	114433
21	3.74	55	1-Heptene	C_7H_{14}	98	24.6	107734
22	3.86	41	Heptane	C_7H_{16}	100	68.0	61276
23	3.90	81	1,4-Hexadiene, 4-methyl-	C_7H_{12}	96	11.8	113135
24	3.96	41	2-Heptene	C_7H_{14}	98	28.8	113119
25	4.09	81	1,4-Hexadiene, 2-methyl-	C_7H_{12}	96	11.4	840
26	4.20	81	Cyclohexene, 1-methyl-	C_7H_{12}	96	11.8	846
27	4.30	83	Cyclohexane, methyl-	C_7H_{14}	98	60.3	118503
28	4.75	67	1-Ethylcyclopentene	C_7H_{12}	96	48.1	114407
29	4.95	91	1,3,5-Cycloheptatriene	C_7H_8	92	31.7	230230
30	5.01	81	Cyclohexene, 1-methyl-	C_7H_{12}	96	13.1	139432
31	5.20	79	2-Cyclohexen-1-ol, 1-methyl-	$C_7H_{12}O$	112	6.89	196278
32	5.30	69	Cyclooctane	C_8H_{16}	112	13.9	1625
33	5.38	55	Cyclopentane, 1-ethyl-2-methyl-, cis-	C_8H_{16}	112	10.2	118884
34	5.45	85	Octane	C_8H_{18}	114	29.6	229407

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35	5.55	55	Cyclohexane, 1,2-dimethyl-, cis-	C_8H_{16}	112	13.6	113985
36	5.69	41	2-Octene, (Z)-	C_8H_{16}	112	25.8	113889
37	5.92	67	1-Methyl-2-methylenecyclohexane	C_8H_{14}	110	19.8	113437
38	6.08	41	Bicyclo[3.1.1]heptan-3-one, 2,6,6-trimethyl-, (1α,2β,5α)-	$C_{10}H_{16}O$	152	8.10	155199
39	6.14	83	Cyclohexane, ethyl-	C_8H_{16}	112	62.9	113476
40	6.29	67	4-Octyne	C_8H_{14}	110	10.3	118189
41	6.72	81	Cyclohexene, 1,2-dimethyl-	C_8H_{14}	110	12.3	113912
42	7.04	41	1-Nonene	C_9H_{18}	126	9.68	107756
43	7.19	71	Nonane	C_9H_{20}	128	22.6	228006
44	7.27	55	cis-2-Nonene	C_9H_{18}	126	18.1	113508
45	7.45	55	2,4-Pentadien-1-ol, 3-propyl-, (2Z)-	$C_8H_{14}O$	126	13.7	142179
46	7.61	67	Ethylidenecycloheptan	C_9H_{16}	124	22.5	113500
47	7.84	55	Cyclopentane, butyl-	C_9H_{18}	126	15.7	114172
48	8.05	67	Cyclopentene, 1-butyl-	C_9H_{16}	124	45.4	113491
49	8.29	81	3,4-Octadiene, 7-methyl-	C_9H_{16}	124	13.7	54090
50	8.77	69	1-Decene	$C_{10}H_{20}$	140	9.78	118883
51	8.92	71	Decane	$C_{10}H_{22}$	142	48.4	114147
52	8.99	55	2-Decene, (Z)-	$C_{10}H_{20}$	140	16.6	114151
53	9.13	55	5-Decene, (E)-	$C_{10}H_{20}$	140	11.0	114178
54	9.26	41	2-Decyn-1-ol	$C_{10}H_{18}O$	154	5.29	53366
55	9.57	55	Cyclohexane, butyl-	$C_{10}H_{20}$	140	9.65	118766
56	10.30	56	3-Undecene, (E)-	$C_{11}H_{22}$	154	6.92	60565
57	10.42	41	1-Undecene	$C_{11}H_{22}$	154	7.13	34717
58	10.56	57	Undecane	$C_{11}H_{24}$	156	46.5	114185
59	10.62	55	5-Undecene, (E)-	$C_{11}H_{22}$	154	13.6	114227
60	1077	41	2-Pentadecyn-1-ol	$C_{15}H_{28}O$	224	8.98	36724
61	11.84	41	Z-1,8-Dodecadiene	$C_{12}H_{22}$	166	7.50	245715

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62	11.98	56	1-Dodecene	$C_{12}H_{24}$	168	7.67	107688
63	12.11	43	Dodecane	$C_{12}H_{26}$	170	33.0	291499
64	12.16	55	3-Dodecene, (E)-	$C_{12}H_{24}$	168	13.7	70642
65	12.81	41	Cyclododecane	$C_{12}H_{24}$	168	11.2	60982
66	13.45	69	1-Tridecene	$C_{13}H_{26}$	182	11.6	107768
67	13.56	43	Tridecane	$C_{13}H_{28}$	184	31.3	114282
68	13.61	55	5-Tridecene, (E)-	$C_{13}H_{26}$	182	9.82	142619
69	14.72	41	Z-10-Pentadecen-1-ol	$C_{15}H_{30}O$	226	13.6	245485
70	14.82	69	1-Tetradecene	$C_{14}H_{28}$	196	6.07	34720
71	14.94	57	Tetradecane	$C_{14}H_{30}$	198	36.6	158968
72	14.98	55	4-Tetradecene, (E)-	$C_{14}H_{28}$	196	7.99	142625
73	16.13	55	1-Pentadecene	$C_{15}H_{30}$	210	7.61	69726
74	16.23	71	Pentadecane	$C_{15}H_{32}$	212	35.4	107761
75	17.35	41	1-Hexadecene	$C_{16}H_{32}$	224	10.5	118882
76	17.45	71	Hexadecane	$C_{16}H_{34}$	226	38.9	114191
77	18.43	41	E-2-Octadecadecen-1-ol	$C_{18}H_{36}O$	268	24.1	131102
78	18.52	41	E-14-Hexadecenal	$C_{16}H_{30}O$	238	9.0	130980
79	18.60	85	Heptadecane	$C_{17}H_{36}$	240	31.6	107308
80	19.62	55	E-15-Heptadecenal	$C_{17}H_{32}O$	252	6.79	130979
81	19.70	57	Octadecane	$C_{18}H_{38}$	254	20.6	57273
82	20.68	55	9-Nonadecene	$C_{19}H_{38}$	266	9.33	113627
83	20.75	71	Eicosane	$C_{20}H_{42}$	282	24.6	290513
84	21.68	57	1-Docosene	$C_{22}H_{44}$	308	8.99	113878
85	21.75	85	Eicosane	$C_{20}H_{42}$	282	47.3	290513
86	22.64	55	1-Docosene	$C_{22}H_{44}$	308	11.0	113878
87	22.71	85	Heneicosane	$C_{21}H_{44}$	296	29.4	107569
88	23.56	43	1-Docosene	$C_{22}H_{44}$	308		113878
89	23.62	85	Heneicosane	$C_{21}H_{44}$	296	15.4	107569
90	24.51	85	Heneicosane	$C_{21}H_{44}$	296	10.7	107569
91	25.36	57	Octacosane	$C_{28}H_{58}$	394	21.6	134306
92	26.19	43	Octacosane	$C_{28}H_{58}$	394	22.3	134306

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93	27.00	57	Octacosane	$C_{28}H_{58}$	394	16.1	134306
94	27.80	57	Octacosane	$C_{28}H_{58}$	394	17.7	134306
95	28.59	57	Octacosane	$C_{28}H_{58}$	394	14.6	134306
96	29.38	57	Octacosane	$C_{28}H_{58}$	394	15.9	134306
97	30.18	57	Heptacosane	$C_{27}H_{56}$	380	12.0	79427
98	31.05	57	Heptacosane	$C_{27}H_{56}$	380	22.1	79427
100	32.05	44	Heptacosane	$C_{27}H_{56}$	380	25.0	79427

Gas Chromatography and Mass Spectrometer (GC/MS) analysis of solid waste of standard HDPE plastic to fuel (Fig. 6 and table 5) in accordance with retention time and trace mass indicate various types of compound are present. High intensity compounds are preferred in the analysis. An investigated carbon range in the analyzed plastic is C_3 to C_{27} because large carbon chains are breaking down into small chain resulting in lower carbon range. Sometimes noticed that for high peak intensity compound probability factor is low percentage, where as in low peak intensity compound probability factor is high percentage. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, in accordance to retention time 1.58 and trace mass 39, derived compound is Propane (C_3H_6) with probability 93%, retention time 1.70 and trace mass 43, compound is Butane, (C_4H_{10}) with probability 64.9%, retention time 1.96 and trace mass 42, compound is Cyclopropane, ethyl- (C_5H_{10}) with probability 17.5%, retention time 2.00 and trace mass 43, compound is Pentane (C_5H_{12}) with probability factor 69.8%, retention time 2.04 and trace mass 55, compound is Cyclopropane, 1,2-dimethyl-, cis- (C_5H_{10}) with probability 19.1%, retention time 2.08, trace mass 55, compound is 2-Pentene, (E)- (C_5H_{10}) with probability 17.4%, retention time 2.82 and trace mass 67, compound is 1,3-Butadiene, 2-ethyl-, (C_5H_{10}) with probability 8.42%, retention time 3.00 and trace mass 56, compound is Cyclopentane, methyl-,(C_6H_{12}) with probability 64.6%, retention time 3.69 and trace mass 56, compound is 1-Hexene, 2-methyl-, (C_7H_{14}) with probability 41.9%, retention time 3.96 and trace mass 41, compound is 2-Heptene (C_7H_{14}) with probability 28.8%, retention time 4.09 and trace mass 81, compound is 1,4-Hexadiene, 2-methyl- (C_7H_{12}) with probability 11.4%, retention time 4.95 and trace mass 91, compound is 1,3,5-Cycloheptatriene (C_7H_8) with probability 31.7%, retention time 5.92 and trace mass 67,compound is 1-Methyl-2-methylenecyclohexane (C_8H_{14}) with probability 19.8%, retention time 6.72 and trace mass 81, compound is Cyclohexene, 1,2-dimethyl- (C_8H_{14}) with probability 19.8% etc. Also in the middle of the analysis index retention time 6.72 and trace mass 81, compound is Tetradecane ($C_{14}H_{30}$) with probability 35.3%, retention time 24.92 and trace mass 81, compound is Cyclohexene, 1,2-dimethyl- (C_8H_{14}) with probability 12.3%, retention time 7.84 and trace mass 55, compound is Cyclopentane, butyl- (C_9H_{18}) with probability 15.7%, retention time 8.99 and trace mass 55, compound is 2-Decene, (Z) - ($C_{10}H_{20}$) with probability 16.6% etc. As well as Retention time 9.57 and trace mass 55, compound is Cyclohexane, butyl- ($C_{10}H_{20}$) with probability 9.65%, retention time 10.077 and trace mass 41, compound is 2-Pentadecyn-1-ol ($C_{15}H_{28}O$) with

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probability 8.98%, retention time 12.81 and trace mass 41, compound is Cyclododecane ($C_{12}H_{24}$) with the probability 11.2% accordingly. Also at the middle phase of the analysis retention time 13.61 and trace mass 55, Compound is 5-Tridecene, (E)- ($C_{13}H_{26}$) with probability 9.82%, retention time 39.58 and trace mass 57, compound is Heneicosane ($C_{21}H_{44}$) with probability 19.8% , retention time 14.98 and trace mass 55, compound is 4-Tetradecene, (E)- ($C_{14}H_{28}$) with probability 7.99% etc. At the end phase of the analysis index high retention time and trace mass such as retention time 17.45 and trace mass 71, compound is Hexadecane ($C_{16}H_{34}$) with probability 38.9%, retention time 19.62 and trace mass 55, compound is E-15-Heptadecenal ($C_{17}H_{32}O$) with probability 6.79%, and ultimately retention time 27.80 and trace mass 57, compound is Octacosane ($C_{28}H_{58}$) with probability 15.9% and ultimately retention time 32.05 and trace mass 44 ,compound is Heptacosane ($C_{27}H_{56}$) with probability 25% as well. In the analysis appearing that in several oxygen compounds are produced because in the reactor during reaction oxygen induced from steam and water. Also noticed in the standard HDPE plastics including double bond compound as well as benzene and benzene derivatives compounds are available.

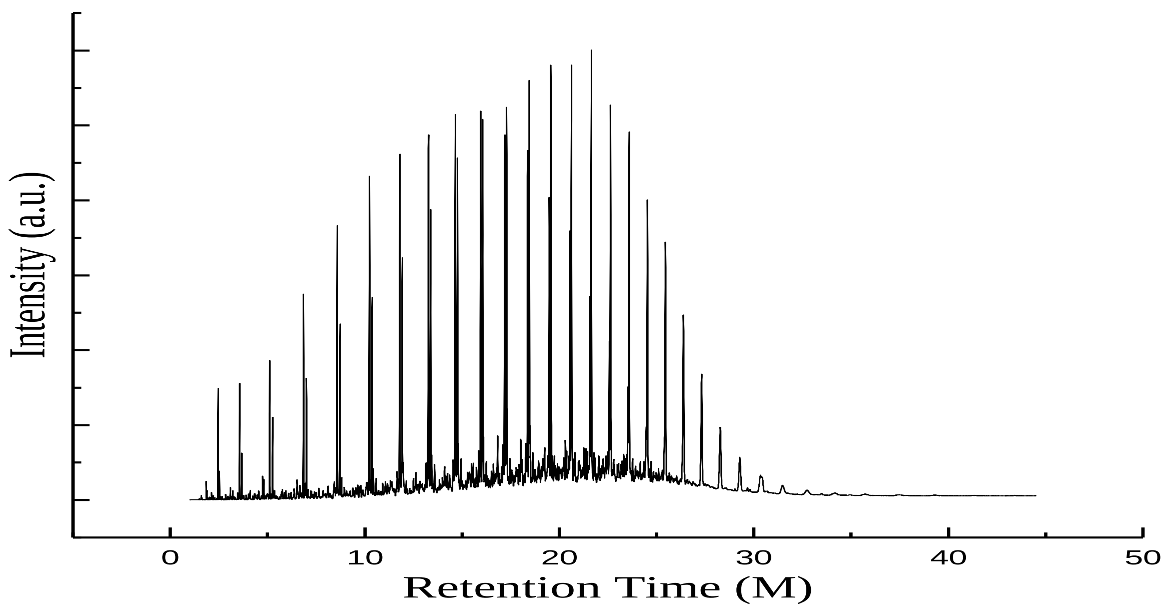

Fig. 7: GC/MS Chromatogram of HDPE waste plastic to fuel

Table 6: GC/MS Chromatogram of HDPE waste plastic to fuel compound list

Peak Number	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number

ISBN: 978-0-9886890-5-3

1	1.49	41	Cyclopropane	C_3H_6	42	67.2	18854
2	1.59	41	2-Butene, (E)-	C_4H_8	56	18.5	105
3	1.63	41	1-Propene, 2-methyl-	C_4H_8	56	17.6	18910
4	1.65	41	2-Butene	C_4H_8	56	15.5	61292
5	1.85	42	Cyclopropane, ethyl-	C_5H_{10}	70	22.4	19072
6	1.89	43	Pentane	C_5H_{12}	72	79.8	114462
7	2.03	67	1,3-Pentadiene	C_5H_8	68	17.4	291890
8	2.21	67	Bicyclo[2.1.0]pentane	C_5H_8	68	15.5	192491
9	2.46	41	1-Hexene	C_6H_{12}	84	16.7	500
10	2.53	41	Hexane	C_6H_{14}	86	73.6	61280
11	2.58	55	3-Hexene, (Z)-	C_6H_{12}	84	39.5	114381
12	2.67	67	1,3-Butadiene, 2-ethyl-	C_6H_{10}	82	10.9	118159
13	2.79	67	3-Hexyne	C_6H_{10}	82	9.28	114499
14	2.84	56	Cyclopentane, methyl-	C_6H_{12}	84	56.7	114428
15	2.96	79	1,3-Cyclopentadiene, 5-methyl-	C_6H_8	80	30.0	419
16	3.09	67	Cyclopentene, 3-methyl-	C_6H_{10}	82	12.2	114408
17	3.22	78	Benzene	C_6H_6	78	70.8	114388
18	3.16	41	3-Octyn-1-ol	$C_8H_{14}O$	126	16.4	113251
19	3.46	67	Cyclohexene	C_6H_{10}	82	31.3	114431
20	3.56	41	Cyclopentane, 1,2-dimethyl-, cis-	C_7H_{14}	98	19.6	114027
21	3.68	43	Heptane	C_7H_{16}	100	65.8	61276
22	3.90	81	2,3-Dimethyl-1,4-pentadiene	C_7H_{12}	96	7.20	113670
23	4.01	81	Cyclohexene, 3-methyl-	C_7H_{12}	96	9.73	139433
24	4.11	83	Cyclohexane, methyl-	C_7H_{14}	98	52.1	118503
25	4.50	81	3,5-Dimethylcyclopentene	C_7H_{12}	96	11.5	113640
26	4.55	67	1-Ethylcyclopentene	C_7H_{12}	96	38.9	114407
27	4.68	41	1-Octyn-3-ol	$C_8H_{14}O$	126	9.96	113255
28	4.75	91	Toluene	C_7H_8	92	35.9	291301
29	4.81	81	Cyclohexene, 3-methyl-	C_7H_{12}	96	8.73	19639

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30	5.11	41	1-Octene	C_8H_{16}	112	19.8	1604
31	5.26	43	Octane	C_8H_{18}	114	38.8	229407
32	5.35	55	3-Octene, (Z)-	C_8H_{16}	112	12.6	113895
33	5.73	67	1-Methyl-2-methylenecyclohexane	C_8H_{14}	110	20.2	113437
34	5.94	83	Cyclohexane, ethyl-	C_8H_{16}	112	56.2	113476
35	6.09	67	4-Octyne	C_8H_{14}	110	13.3	118189
36	6.21	81	3-Octen-1-ol, (Z)-	$C_8H_{16}O$	128	9.32	53353
37	6.37	91	Ethylbenzene	C_8H_{10}	106	56.4	114918
38	6.52	91	Cyclohexanol, 1-ethynyl-, carbamate	$C_9H_{13}NO_2$	167	20.7	313023
39	6.68	41	Cyclononene	C_9H_{16}	124	11.2	281779
40	6.74	56	trans-7-Methyl-3-octene	C_9H_{18}	126	27.5	113528
41	6.85	41	cis-2-Nonene	C_9H_{18}	126	12.3	113508
42	7.00	43	Nonane	C_9H_{20}	128	28.8	228006
43	7.08	41	4-Nonene	C_9H_{18}	126	12.9	113904
44	7.64	41	Cyclopentane, butyl-	C_9H_{18}	126	13.5	114172
45	7.85	67	Cyclopentene, 1-butyl-	C_9H_{16}	124	42.9	113491
46	8.12	105	Benzene, 1-ethyl-3-methyl-	C_9H_{12}	120	22.7	114040
47	8.43	41	Dihydromyrcene	$C_{10}H_{18}$	138	26.3	292831
48	8.59	55	1-Decene	$C_{10}H_{20}$	140	13.4	118883
49	8.73	43	Decane	$C_{10}H_{22}$	142	60.1	114147
50	8.80	41	2-Decene, (Z)-	$C_{10}H_{20}$	140	16.6	114151
51	10.24	41	1-Undecene	$C_{11}H_{22}$	154	8.04	34717
52	10.38	71	Undecane	$C_{11}H_{24}$	156	50.2	114185
53	10.44	41	5-Undecene, (E)-	$C_{11}H_{22}$	154	10.9	114227
54	10.58	41	2-Pentadecyn-1-ol	$C_{15}H_{28}O$	224	11.9	36724
55	11.66	41	E-1,8-Dodecadiene	$C_{12}H_{22}$	166	10.9	245716
56	11.80	41	3-Dodecene, (E)-	$C_{12}H_{24}$	168	9.09	113960
57	11.92	43	Dodecane	$C_{12}H_{26}$	170	33.1	291499
58	11.98	41	3-Dodecene, (E)-	$C_{12}H_{24}$	168	10.2	70642
59	12.50	41	1,12-Tridecadiene	$C_{13}H_{24}$	180	15.3	7380

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60	13.27	41	1-Tridecene	$C_{13}H_{26}$	182	9.91	107768
61	13.39	41	Tridecane	$C_{13}H_{28}$	184	33.2	114282
62	13.59	142	Bicyclo[4.4.1]undeca-1,3,5,7,9-pentaene	$C_{11}H_{10}$	$C_{11}H_{10}$	29.2	142
63	14.10	41	1-Heptadecanol	$C_{17}H_{36}O$	256	3.87	12450
64	14.66	41	Cyclotetradecane	$C_{14}H_{28}$	196	6.00	196
65	14.76	41	Tetradecane	$C_{14}H_{30}$	198	34.3	158968
66	14.95	41	Dodecylsuccinic anhydride	$C_{16}H_{28}O_3$	268	4.78	233097
67	15.48	41	1-Nonadecanol	$C_{19}H_{40}O$	284	5.20	13666
68	15.57	41	Octadecane, 6-methyl-	$C_{19}H_{40}$	268	7.20	35803
69	15.96	41	Cyclopentadecane	$C_{15}H_{30}$	210	7.23	114876
70	16.06	43	Pentadecane	$C_{15}H_{32}$	212	39.7	34728
71	16.10	41	E-2-Hexadecacen-1-ol	$C_{16}H_{32}O$	240	10.9	131101
72	19.19	83	1-Hexadecene	$C_{16}H_{32}$	224	10.9	118882
73	17.29	43	Hexadecane	$C_{16}H_{34}$	226	27.4	114191
74	18.37	43	1-Heptadecanol	$C_{17}H_{36}O$	256	5.86	113250
75	18.46	85	Heptadecane	$C_{17}H_{36}$	240	30.9	107308
76	19.48	41	E-15-Heptadecenal	$C_{17}H_{32}O$	252	6.15	130979
77	19.56	56	Octadecane	$C_{18}H_{38}$	254	18.5	12337
78	20.55	41	9-Nonadecene	$C_{19}H_{38}$	266	10.7	113627
79	20.63	57	Eicosane	$C_{20}H_{42}$	282	17.8	290513
80	21.58	43	1-Docosene	$C_{22}H_{44}$	308	7.32	113878
81	21.65	43	Eicosane	$C_{20}H_{42}$	282	41.2	290513
82	22.57	43	1-Docosene	$C_{22}H_{44}$	308	8.70	113878
83	22.64	57	Heneicosane	$C_{21}H_{44}$	296	31.7	107569
84	23.59	85	Heneicosane	$C_{21}H_{44}$	296	10.8	107569
85	24.53	57	Octacosane	$C_{28}H_{58}$	394	10.7	134306
86	25.45	57	Octacosane	$C_{28}H_{58}$	394	15.2	134306
87	26.38	57	Octacosane	$C_{28}H_{58}$	394	10.1	134306
88	27.32	57	Octacosane	$C_{28}H_{58}$	394	12.7	134306
89	28.27	57	Octacosane	$C_{28}H_{58}$	394	11.8	134306

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90	29.28	57	Heptacosane	$C_{27}H_{56}$	380	22.4	79427
91	30.34	57	Heptacosane	$C_{27}H_{56}$	380	15.6	79427
92	31.48	57	Heptacosane	$C_{27}H_{56}$	380	15.0	79427

GC/MS analysis of waste HDPE plastic to fuel (Fig.7 and table 6) in accordance with retention time and trace mass indicate various types of compound are present. High intensity compounds are preferred in the analysis. An investigated carbon range in the analyzed plastic is C_3 to C_{28} because large carbon chains are breaking down into small chain resulting in lower carbon range. Sometimes noticed that for high peak intensity compound probability factor is low percentage, where as in low peak intensity compound probability factor is high percentage. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, in accordance to retention time 1.49 and trace mass 41, derived compound is Cyclopropane (C_3H_6) with probability 67.2%, retention time 1.59 and trace mass 41, compound is 2-Butene, (E)-, (C_4H_8) with probability 18.5%, retention time 1.89 and trace mass 43, compound is Pentane (C_5H_{12}) with probability 79.8%, retention time 2.03 and trace mass 67, compound is 1,3-Pentadiene (C_5H_8) with probability factor 17.4%, retention time 2.96 and trace mass 79, compound is 1,3-Cyclopentadiene, 5-methyl- (C_6H_8) with probability 30.0%, retention time 3.09, trace mass 67, compound is Cyclopentene, 3-methyl- (C_6H_{10}) with probability 12.2%, retention time 3.90 and trace mass 81, compound is 2,3-Dimethyl-1,4-pentadiene, (C_7H_{12}) with probability 7.20%, retention time 4.01 and trace mass 81, compound is Cyclohexene, 3-methyl-, (C_7H_{12}) with probability 9.73%, retention time 4.81 and trace mass 81, compound is Cyclohexene, 3-methyl-, (C_7H_{12}) with probability 8.73%, retention time 5.11 and trace mass 41, compound is 1-Octene (C_8H_{16}) with probability 19.8%, retention time 5.94 and trace mass 83, compound is Cyclohexane, ethyl-, (C_8H_{16}) with probability 56.2%, retention time 6.85 and trace mass 56, compound is trans-7-Methyl-3-octene (C_9H_{18}) with probability 27.5%, retention time 7.00 and trace mass 43,compound is Nonane (C_9H_{20}) with probability 28.8%, retention time 7.85 and trace mass 67, compound is Cyclopentene, 1-butyl- (C_9H_{16}) with probability 42.9% etc. Also in the middle of the analysis index retention time 8.80 and trace mass 41, compound is 2-Decene, (Z)- ($C_{10}H_{20}$) with probability 16.6%, retention time 10.24 and trace mass 41, compound is 1-Undecene ($C_{11}H_{22}$) with probability 8.04%, retention time 10.58 and trace mass 41, compound is 2-Pentadecyn-1-ol, ($C_{15}H_{28}O$) with probability 11.9%, retention time 11.98 and trace mass 41, compound is 3-Dodecene, (E)- ($C_{12}H_{24}$) with probability 10.2% etc. As well as Retention time 13.59 and trace mass 142, compound is Bicyclo[4.4.1]undeca-1,3,5,7,9-pentaene, ($C_{11}H_{10}$) with probability 29.2%, retention time 14.95 and trace mass 41, compound is Dodecylsuccinic anhydride ($C_{16}H_{28}O_3$) with probability 4.78%, retention time 15.96 and trace mass 41, compound is Cyclopentadecane ($C_{15}H_{30}$) with the probability 7.23% etc. Accordingly retention time 16.10 and trace mass 41, Compound is E-2-Hexadecacen-1-ol ($C_{16}H_{32}O$) with probability 10.9%, retention time 20.55 and trace mass 41, compound is 9-Nonadecene ($C_{19}H_{38}$) with probability 10.7% , retention time 21.65 and trace mass 43, compound is 4-Tetradecene, (E)- ($C_{20}H_{42}$) with probability 41.2% etc. At the end phase of the analysis index high retention time and trace mass such as retention time 22.64 and trace mass 57, compound is Hexadecane ($C_{21}H_{42}$) with probability 31.7%, retention time 23.59 and trace mass 85, compound is Heneicosane ($C_{21}H_{44}$) with probability

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10.8%, and ultimately retention time 27.80 and trace mass 57, compound is Octacosane ($C_{28}H_{58}$) with probability 15.9% and retention time 24.53 and trace mass 57 ,compound is Octacosane ($C_{28}H_{58}$) with probability 10.7% and ultimately retention time 31.48 and trace mass 57,compound is Heptacosane ($C_{27}H_{56}$) as well. In the earlier phase analysis appearing that in several oxygen compounds are produced because in the reactor during reaction oxygen induced from steam and water. Also noticed in the standard HDPE plastic to fuel including double bond compound as well as benzene and benzene derivatives compounds are available. In the middle of the analysis index also noticed that one or more alcoholic compounds are appeared as well.

In the comparison discussion of GCMS Analysis of standard HDPE plastic to fuel and waste HDPE plastic to fuel found that numerous similar and dissimilar compounds are available in the analysis. High intensity compounds are preferred in the analysis for both fuels. An investigated carbon range in the both analyzed plastic to fuel is C_3 to C_{27} because large carbon chains are breaking down into small chain resulting in lower carbon range. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, such as in standard HDPE plastic to fuel in accordance with the retention time and trace mass only few of compounds are taken for distinguishing with waste HDPE plastic to fuel compound analysis such as in standard HDPE plastic to fuel , in accordance to retention time 1.58 and trace mass 39, derived compound is Propane (C_3H_6) with probability 93%, retention time 1.70 and trace mass 43, compound is Butane, (C_4H_{10}) with probability 64.9%, retention time 1.96 and trace mass 42, compound is Cyclopropane, ethyl- (C_5H_{10}) with probability 17.5%, retention time 2.00 and trace mass 43, compound is Pentane (C_5H_{12}) with probability factor 69.8%, retention time 2.04 and trace mass 55, compound is Cyclopropane, 1,2-dimethyl-, cis- (C_5H_{10}) with probability 19.1%, retention time 2.08, trace mass 55, compound is 2-Pentene, (E)- (C_5H_{10}) with probability 17.4%, retention time 2.82 and trace mass 67, compound is 1,3-Butadiene, 2-ethyl-, (C_5H_{10}) with probability 8.42%, retention time 3.00 and trace mass 56, compound is Cyclopentane, methyl-,(C_6H_{12}) with probability 64.6%, retention time 3.69 and trace mass 56, compound is 1-Hexene, 2-methyl-, (C_7H_{14}) with probability 41.9%, retention time 3.96 and trace mass 41, compound is 2-Heptene (C_7H_{14}) with probability 28.8%, retention time 4.09 and trace mass 81, compound is 1,4-Hexadiene, 2-methyl- (C_7H_{12}) with probability 11.4%, retention time 4.95 and trace mass 91, compound is 1,3,5-Cycloheptatriene (C_7H_8) with probability 31.7%, retention time 5.92 and trace mass 67,compound is 1-Methyl-2-methylenecyclohexane (C_8H_{14}) with probability 19.8%, retention time 6.72 and trace mass 81, compound is Cyclohexene, 1,2-dimethyl- (C_8H_{14}) with probability 19.8%,retention time 7.84 and trace mass 55, compound is Cyclopentane, butyl- (C_9H_{18}) with probability 15.7%, retention time 8.99 and trace mass 55, compound is 2-Decene, (Z) - ($C_{10}H_{20}$) with probability 16.6% etc. As well as retention time 9.57 and trace mass 55, compound is Cyclohexane, butyl- ($C_{10}H_{20}$) with probability 9.65%, retention time 10.077 and trace mass 41, compound is 2-Pentadecyn-1-ol ($C_{15}H_{28}O$) with probability 8.98%, retention time 12.81 and trace mass 41, compound is Cyclododecane ($C_{12}H_{24}$) with the probability 11.2% accordingly. retention time 19.62 and trace mass 55, compound is E-15-Heptadecenal ($C_{17}H_{32}O$) with probability 6.79%, and ultimately retention time 32.05 and trace mass 44 ,compound is Heptacosane ($C_{27}H_{56}$) with probability 25% etc. On the other hand in waste HDPE plastic to fuel an investigated carbon range in the

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analyzed plastic is C_3 to C_{28} because large carbon chains are breaking down into small chain resulting in lower carbon range. Sometimes noticed that for high peak intensity compound probability factor is low percentage, where as in low peak intensity compound probability factor is high percentage. Most of the peaks are considered in the analysis and as per their retention time and trace mass maximum peaks are mentioned, in accordance to analysis each retention time and trace mass are different than standard HDPE plastic to fuel as well as most of similar and different compounds are emerged. In some case noticed that at same retention time and trace mass compounds available where different retention time and trace mass compounds are also available in the analysis. Initially in accordance to retention time 1.49 and trace mass 41, derived compound is Cyclopropane (C_3H_6) with probability 67.2%, retention time 1.59 and trace mass 41, compound is 2-Butene, (E)-, (C_4H_8) with probability 18.5%, retention time 1.89 and trace mass 43, compound is Pentane (C_5H_{12}) with probability 79.8%, retention time 2.03 and trace mass 67, compound is 1,3-Pentadiene (C_5H_8) with probability factor 17.4%, retention time 2.96 and trace mass 79, compound is 1,3-Cyclopentadiene, 5-methyl- (C_6H_8) with probability 30.0%, retention time 3.09, trace mass 67, compound is Cyclopentene, 3-methyl- (C_6H_{10}) with probability 12.2%, retention time 3.90 and trace mass 81, compound is 2,3-Dimethyl-1,4-pentadiene, (C_7H_{12}) with probability 7.20%, retention time 4.01 and trace mass 81, compound is Cyclohexene, 3-methyl-, (C_7H_{12}) with probability 9.73%, retention time 4.81 and trace mass 81, compound is Cyclohexene, 3-methyl-, (C_7H_{12}) with probability 8.73%, retention time 5.11 and trace mass 41, compound is 1-Octene (C_8H_{16}) with probability 19.8%, retention time 5.94 and trace mass 83, compound is Cyclohexane, ethyl-, (C_8H_{16}) with probability 56.2%, retention time 6.85 and trace mass 56, compound is trans-7-Methyl-3-octene (C_9H_{18}) with probability 27.5%, retention time 7.00 and trace mass 43,compound is Nonane (C_9H_{20}) with probability 28.8%, retention time 7.85 and trace mass 67, compound is Cyclopentene, 1-butyl- (C_9H_{16}) with probability 42.9% etc. At the end phase of the analysis index high retention time and trace mass such as retention time 22.64 and trace mass 57, compound is Hexadecane ($C_{21}H_{42}$) with probability 31.7%, retention time 23.59 and trace mass 85, compound is Heneicosane ($C_{21}H_{44}$) with probability 10.8%, and ultimately retention time 27.80 and trace mass 57, compound is Octacosane ($C_{28}H_{58}$) with probability 15.9% and retention time 24.53 and trace mass 57 ,compound is Octacosane ($C_{28}H_{58}$) with probability 10.7% and ultimately retention time 31.48 and trace mass 57,compound is Heptacosane ($C_{27}H_{56}$) as well. In the earlier phase analysis of both fuel appearing that in several oxygen compounds are produced because in the reactor during reaction oxygen induced from steam and water. Also noticed in the standard HDPE plastic to fuel and waste HDPE plastic to fuel including double bond compound as well as benzene and benzene derivatives compounds are available. In the middle of the analysis index of both fuel also noticed that one or more alcoholic compounds are appeared as well. In the comparison discussion only several compounds are introduced from both fuels to comparison purposes.

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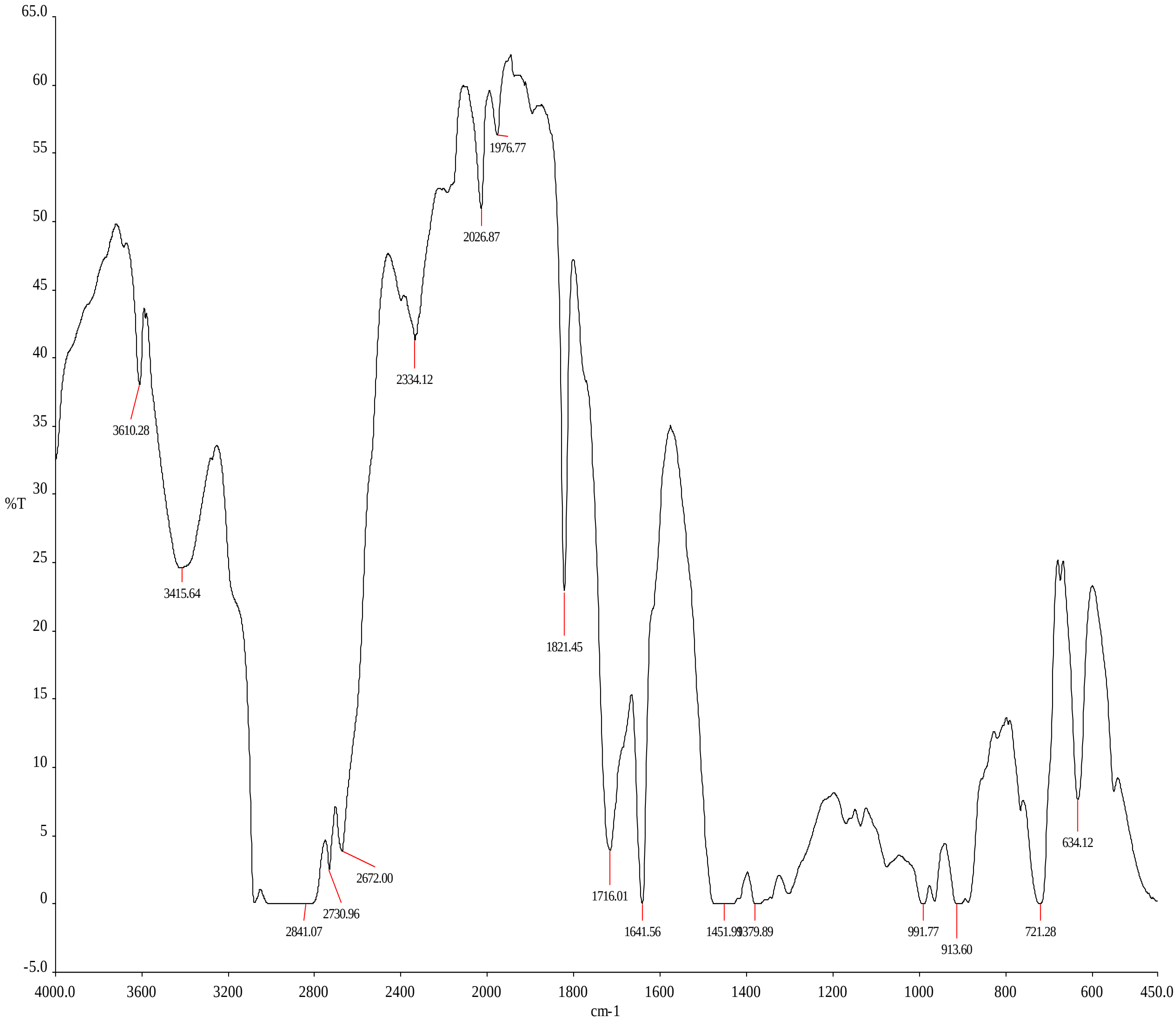

Fig. 8: FT-IR spectrum of standard HDPE plastic to fuel

FT-IR analysis of standard HDPE-2 (High Density Polyethylene, Polymer Structure unit is -CH_2-CH_2-) produced fuel (fig. 8) following types of wave number and functional group are appeared in the spectrum. In the experiment if we noticed to the structure of standard polymer of HDPE-2, C=C and C-H bonds appeared that's double bonds breaking down to single bonds after the polymerization of polyethylene. In the analysis many wave number and functional groups are found, as example wave number 3610.28 (cm^{-1}), functional group is Free OH, wave number 3415.64 (cm^{-1}), functional group is Intermolecular H bonds and wave number 2849.07 (cm^{-1}), 2730.96 (cm^{-1}) and 2672.00 (cm^{-1}) functional group is C-CH_3, wave number 1821.45 (cm^{-1}), 1716.01 (cm^{-1}), functional group is Non-

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Conjugated, wave number 1641.56 (cm^{-1}) functional group is Conjugated as well as wave number 1451.99 (cm^{-1}) and 1379.89 (cm^{-1}) functional group is CH_3, and accordingly wave number 991.77 (cm^{-1}) and 913.60 (cm^{-1}) functional group is $–CH=CH_2$ as well and ultimately wave number 721.28 (cm^{-1}), functional group is –CH=CH-(cis) 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 some of functional groups energy values are calculated such as for 2849.07 (cm^{-1}) calculated energy, E=$5.65x10^{-20}$ J. Similarly, wave number 1821.45 (cm^{-1}) energy, E =$3.61x10^{-20}$ J, wave number 1379.89 (cm^{-1}) energy, E = $2.74x10^{-20}$ J and eventually wave number 991.94 (cm^{-1}) functional group is $1.97x10^{-20}$ J respectively.

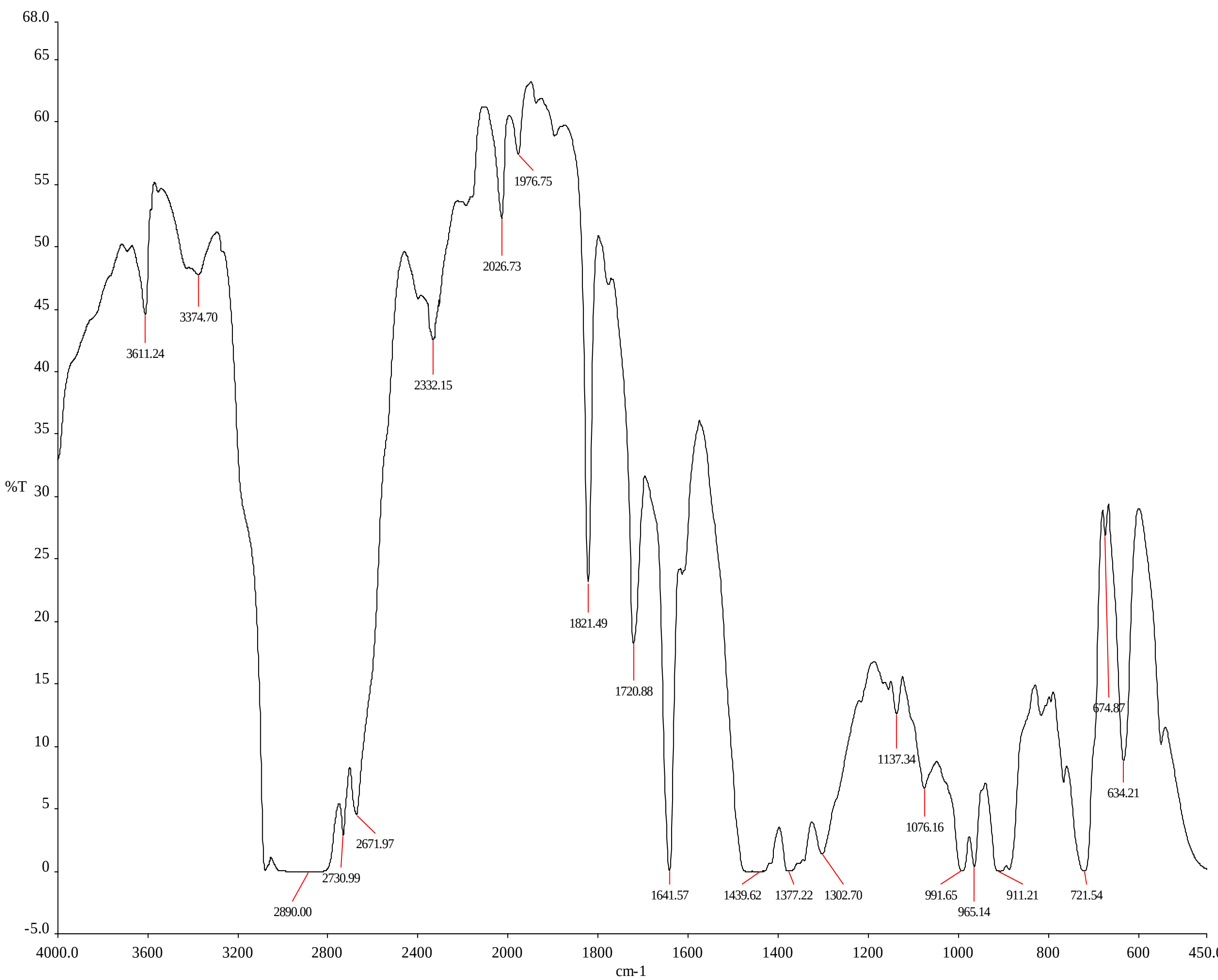

Fig. 9: FT-IR spectrum of HDPE waste plastic to fuel

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FT-IR analysis of waste HDPE (High Density Polyethylene) Polymer Structure repeating unit is – (CH_2-CH_2) - and HDPE to produced fuel (fig.9) following types of wave number and functional group are appeared in the spectrum. In the experiment if we noticed to the structure of waste polymer of HDPE-2, C=C and C-H bonds appeared that's double bonds breaking down to single bonds after the polymerization of polyethylene. In the analysis many wave number and functional groups are found, as example wave number 3611.24 (cm^{-1}), functional group is Free OH, wave number 3374.70 (cm^{-1}), functional group is Intermolecular H bonds and wave number 2890.00 (cm^{-1}), 2730.99 (cm^{-1}) and 2671.97 (cm^{-1}) functional group is C-CH_3, wave number 1821.49 (cm^{-1}), 1720.88 (cm^{-1}), functional group is Non-Conjugated, wave number 1641.57 (cm^{-1}) functional group is Conjugated as well as wave number 1439.62 (cm^{-1}) and 1377.22 (cm^{-1}) functional group is CH_3, and accordingly wave number 991.65 (cm^{-1}), and 911.21 (cm^{-1}) functional group is –CH=CH_2 ,wave number 965.14 (cm^{-1}), functional group is –CH=CH-(trans) as well and ultimately wave number 721.54 (cm^{-1}) and 674.87 (cm^{-1}) , functional group is –CH=CH-(cis) 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 2890.00 (cm^{-1}) calculated energy, E=$5.74x10^{-20}$ J. Similarly, wave number 1821.49 (cm^{-1}) energy, E =$3.61x10^{-20}$ J, wave number 1377.22 (cm^{-1}) energy, E = $2.74x10^{-20}$ J and eventually wave number 991.65 (cm^{-1}) functional group is $1.97x10^{-20}$ J respectively.

In the FTIR analysis NaCl cell were used to analyze liquid fuel and found that in standard HDPE-2 fuel contains following functional groups such as C-CH_3, CH_2, CH_3 , Non-Conjugated, and -CH=CH-(cis).On the other hand, FTIR analysis of waste HDPE-2 plastic to fuel found that it contains almost same functional groups compare with standard HDPE-2 fuel, such as C-CH_3, Non-Conjugated, CH_2, CH_3, and -CH=CH-(cis) etc. In the comparative discussion most of the functional groups of waste HDPE's fuel are identical with standard HDPE-2 plastic to fuel, significant differences are noticed in the spectrum wave number each and every functional group wave number are different compare to each other, such as for standard HDPE fuel wave number 2914.82 cm^{-1}, functional group is C-CH_3 and for waste HDPE fuel wave number 2915.25 cm^{-1}, functional group is same as C-CH_3 etc. Several energy values are calculated for both fuel such as for standard HDPE-2 fuel calculated energy values are following such as wave number 2849.07 (cm^{-1}) calculated energy, E=$5.65x10^{-20}$ J. Similarly, wave number 1821.45 (cm^{-1}) energy, E =$3.61x10^{-20}$ J, wave number 1379.89 (cm^{-1}) energy, E = $2.74x10^{-20}$ J and eventually wave number 991.94 (cm^{-1}) functional group is $1.97x10^{-20}$ J respectively. Waste HDPE-2 fuel calculated energy values following such as wave number some of functional groups energy values are calculated such as for 2849.07 (cm^{-1}) calculated energy, E=$5.65x10^{-20}$ J. Similarly, wave number 1821.45 (cm^{-1}) energy, E =$3.61x10^{-20}$ J, wave number 1379.89 (cm^{-1}) energy, E = $2.74x10^{-20}$ J and eventually wave number 991.94 (cm^{-1}) functional group is $1.97x10^{-20}$ J as well.

3.4. ASTM Test Results

Table 7: HDPE standard plastic to fuel ASTM test results

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Method Name	Test Name	Results	Units
ASTM D240	Gross Heat of Combustion	19317	BTU/lb
ASTM D240	Gross Heat of Combustion (Calculated)	127065	BTU/gal
ASTM D4052	API Gravity @ 60°F	47.5	°API
ASTM D86-07b	IBP Recovery	67.9	°C
ASTM D86-07b	5% Recovery	112.8	°C
ASTM D86-07b	10% Recovery	134.4	°C
ASTM D86-07b	20% Recovery	172.4	°C
ASTM D86-07b	30% Recovery	207.4	°C
ASTM D86-07b	40% Recovery	236.9	°C
ASTM D86-07b	50% Recovery	263.1	°C
ASTM D86-07b	60% Recovery	287.9	°C
ASTM D86-07b	70% Recovery	312.3	°C
ASTM D86-07b	80% Recovery	338.3	°C
ASTM D86-07b	90% Recovery	-	°C
ASTM D86-07b	95% Recovery	-	°C
ASTM D86-07b	FBP Recovery	385.8	°C
ASTM D86-07b	Recovery	85.2	Vol%
ASTM D86-07b	Residue	-	Vol%
ASTM D2500	Cloud point	20.7	°C
ASTM D2500	Cloud Point	69.3	°F
ASTM D97	Pour point	24.0	°C
ASTM D97	Pour point	75.2	°F
ASTM D2386	Freezing Point	18.0	°C
ASTM D2386	Freezing Point	64.4	°F
ASTM D2624	Temperature	76.0	°C
ASTM D2624	Electrical Conductivity	<1	pS/M
ASTM D5453	Sulfur	1.0	mg/kg
ASTM D1500	ASTM Color	<4.5	
ASTM D4176	Appearance: Clean and Bright	Fail-Hazy	
ASTM D4176	Free Water Content/Particles	No water particles	mg/kg
ASTM D4176	Haze Rating	5.0	
ASTM D4176	Special Observation	-	
ASTM D4737	Cetane Index by D4737 (Procedure A)	64.2	
ASTM D5708_MOD	Vanadium	<1.0	ppm
ASTM D5708_MOD	Nickel	<1.0	ppm

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ASTM D5708_MOD	Iron	<1.0	ppm OR, mg/Kg
ASTM D482	Ash	<0.001	Wt%
ASTM D93	Procedure Used		
ASTM D93	Corrected Flash Point	Below room temperature	°C
ASTM D4530	Average Micro Method Carbon Residue 10% distillation	0.3	Wt%
ASTM D664	Procedure Used	A	
ASTM D664	Acid Number	0.20	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	86.08	Wt%
ASTM D5291	Hydrogen Content	13.87	Wt%
ASTM D5291	Nitrogen Content	<0.75	Wt%

American Standard and Testing Method (ASTM) analysis of standard HDPE fuel (table 7) has developed various kinds of parameter and explains their results and units. In the detailed analysis of HDPE fuel noticed that in different types of method following parameters are appeared in the analysis such as Gross Heat of Combustion results 19371 BTU/Ib, Gross Heat of Combustion (Calculated) 127065 BTU/gal, API gravity @ 60°F results 47.5 °API, IBP Recovery are found in different percentage at temperature 67.9°C, such as 5% recovery at 112.8°C,10% recovery at 134.4°C,20% recovery 172.4°C, 30% recovery 207.4°C,40% recovery at 236.9°C,50% recovery at 263.1°C, 60% recovery 287.9°C,70% recovery 312.3°C,80% recovery at 338.3°C etc. FBP recovery 385.8 °C, recovery 0 volume %, ASTM D2500, cloud point at 20.7 °F, ASTM D2500, cloud point at 69.3 °F, ASTM D97, Pour point at 24°C, ASTM D97, Pour point at 75.2°C, ASTM D2386, Freezing Point 18°C, ASTM D2386, Freezing Point 64.4°C, ASTM D2624, Temperature 76 °C, ASTM D2624, Electrical Conductivity, <1 pS/M, ASTM D5453, Sulfur 1 mg/kg, ASTM D1500, ASTM Color <4.5, ASTM D4176 Appearance: Clean and Bright, Fail-Hazy, ASTM D4176 Free Water Content/Particles, No water particles mg/kg, ASTM D4176 Haze Rating 5.0, ASTM D4176, Special Observation, ASTM D4737 Cetane Index by D4737 (Procedure A) 64.2, 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, ASTM D93 Corrected Flash Point Below room temperature in °C, ASTM D4530 Average Micro Method Carbon Residue 10% distillation 0.3 Wt%, ASTM D664 Procedure Used A, ASTM D664 Acid Number 0.20 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 86.08 Wt%, ASTM D5291 Hydrogen Content 13.87 Wt% and ultimately ASTM D5291 Nitrogen Content <0.75 Wt% etc.

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Table 8: HDPE waste plastic to fuel ASTM test results

Method Name	Test Name	Results	Units
ASTM D240	Gross Heat of Combustion	19699	BTU/lb
ASTM D240	Gross Heat of Combustion (Calculated)	129502	BTU/gal
ASTM D4052	API Gravity @ 60°F	47.7	°API
ASTM D86-07b	IBP Recovery	61.1	°C
ASTM D86-07b	5% Recovery	111.8	°C
ASTM D86-07b	10% Recovery	134.2	°C
ASTM D86-07b	20% Recovery	171.8	°C
ASTM D86-07b	30% Recovery	203.0	°C
ASTM D86-07b	40% Recovery	235.7	°C
ASTM D86-07b	50% Recovery	261.0	°C
ASTM D86-07b	60% Recovery	286.5	°C
ASTM D86-07b	70% Recovery	311.5	°C
ASTM D86-07b	80% Recovery	338.7	°C
ASTM D86-07b	90% Recovery	382.6	°C
ASTM D86-07b	95% Recovery	-	°C
ASTM D86-07b	FBP Recovery	388.5	°C
ASTM D86-07b	Recovery	90.4	Vol%
ASTM D86-07b	Residue	-	Vol%
ASTM D2500	Cloud point	20.7	°C
ASTM D2500	Cloud Point	69.3	°F
ASTM D97	Pour point	24	°C
ASTM D97	Pour point	75.2	°F
ASTM D2386	Freezing Point	18.0	°C
ASTM D2386	Freezing Point	64.4	°F
ASTM D2624	Temperature	76.0	°C
ASTM D2624	Electrical Conductivity	2.0	pS/M
ASTM D5453	Sulfur	3.7	mg/kg
AST M D1500	ASTM Color	<5.5	
ASTM D4176	Appearance: Clean and Bright	Fail-Hazy	
ASTM D4176	Free Water Content/Particles	No water	mg/kg
ASTM D4176	Haze Rating	5.0	
ASTM D4176	Special Observation	-	
ASTM D4737	Cetane Index by D4737 (Procedure A)	64.2	

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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	-	
ASTM D93	Corrected Flash Point	Below room temperature	°C
ASTM D4530	Average Micro Method Carbon Residue 10% distillation	0.3	Wt%
ASTM D664	Procedure Used	A	
ASTM D664	Acid Number	0.20	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	86.08	Wt%
ASTM D5291	Hydrogen Content	13.87	Wt%
ASTM D5291	Nitrogen Content	<0.75	Wt%

American Standard and Testing Method (ASTM) analysis of waste HDPE fuel (table 8) has developed various kinds of parameter and explains their results and units. In the detailed analysis of HDPE fuel noticed that in different types of method following parameters are appeared in the analysis such as Gross Heat of Combustion results 19699 BTU/Ib, Gross Heat of Combustion (Calculated) 129502 BTU/gal, API gravity @ 60°F results 47.7 ºAPI, IBP Recovery are found in different percentage at temperature 61.1°C, such as 5% recovery at 111.8°C,10% recovery at 134.2°C,20% recovery 171.8°C, 30% recovery 203.0°C,40% recovery at 235.7°C,50% recovery at 261.0°C, 60% recovery 286.5°C,70% recovery 311.5°C,80% recovery at 338.7°C etc. FBP recovery 388.5 °C, recovery 90.4 volume %, ASTM D2500, cloud point at 20.7 °F, ASTM D2500, cloud point at 69.3 °F, ASTM D97, Pour point at 24°C, ASTM D97, Pour point at 75.2°C, ASTM D2386, Freezing Point 18°C, ASTM D2386, Freezing Point 64.4°C, ASTM D2624, Temperature 76 °C, ASTM D2624, Electrical Conductivity, 2.00 pS/M, ASTM D5453, Sulfur 3.7 mg/kg, ASTM D1500, ASTM Color <5.5, ASTM D4176 Appearance: Clean and Bright, Fail-Hazy, ASTM D4176 Free Water Content/Particles, No water particles mg/kg, ASTM D4176 Haze Rating 5.0, ASTM D4176, Special Observation, ASTM D4737 Cetane Index by D4737 (Procedure A) 64.2, 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, ASTM D93 Corrected Flash Point Below room temperature in °C, ASTM D4530 Average Micro Method Carbon Residue 10% distillation 0.3 Wt%, ASTM D664 Procedure Used A, ASTM D664 Acid Number 0.20 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 86.08 Wt%, ASTM D5291 Hydrogen Content 13.87 Wt% and ultimately ASTM D5291 Nitrogen Content <0.75 Wt% etc.

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Comparison analysis of ASTM (American Standard and Testing Institute) between standard HDPE fuel and waste HDPE fuel various parameter are found similar as well in some parameter has dissimilarity and some parameter varying each other in the both analysis comparative discussion. In the comparative discussion some parameter are mention from standard HDPE and waste HDPE in order to accomplish successful comparison. As example in standard HDPE found parameters are following such as such as Gross Heat of Combustion results 19371 BTU/Ib, Gross Heat of Combustion (Calculated) 127065 BTU/gal, API gravity @ 60°F results 47.5 ºAPI, IBP Recovery are found in different percentage at temperature 67.9°C, such as 5% recovery at 112.8°C,10% recovery at 134.4°C,20% recovery 172.4°C, 30% recovery 207.4°C,40% recovery at 236.9°C,50% recovery at 263.1°C, 60% recovery 287.9°C,70% recovery 312.3°C,80% recovery at 338.3°C etc. FBP recovery 385.8 °C, recovery 0 volume %, ASTM D2500, cloud point at 20.7 °F, ASTM D2500, cloud point at 69.3 °F, ASTM D97, Pour point at 24°C, ASTM D97, Pour point at 75.2°C, ASTM D2386, Freezing Point 18°C, ASTM D2386, Freezing Point 64.4°C, ASTM D2624, Temperature 76 °C, ASTM D2624, Electrical Conductivity, <1 pS/M, ASTM D5453, Sulfur 1 mg/kg, ASTM D1500, ASTM Color <4.5, ASTM D4176 Appearance: Clean and Bright, Fail-Hazy, ASTM D4176 Free Water Content/Particles, No water particles mg/kg, ASTM D4176 Haze Rating 5.0, ASTM D4176, Special Observation, ASTM D4737 Cetane Index by D4737 (Procedure A) 64.2, 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, ASTM D93 Corrected Flash Point Below room temperature in °C and ultimately ASTM D5291 Nitrogen Content <0.75 Wt% etc. On the other hand in waste HDPE plastic to fuel follwing parameters are available in the analysis such as Gross Heat of Combustion results 19699 BTU/Ib, Gross Heat of Combustion (Calculated) 129502 BTU/gal, API gravity @ 60°F results 47.7 ºAPI, IBP Recovery are found in different percentage at temperature 61.1°C, such as 5% recovery at 111.8°C,10% recovery at 134.2°C,20% recovery 171.8°C, 30% recovery 203.0°C,40% recovery at 235.7°C,50% recovery at 261.0°C, 60% recovery 286.5°C,70% recovery 311.5°C,80% recovery at 338.7°C etc. FBP recovery 388.5 °C, recovery 90.4 volume %, ASTM D2500, cloud point at 20.7 °F, ASTM D2500, cloud point at 69.3 °F, ASTM D97, Pour point at 24°C, ASTM D97, Pour point at 75.2°C, ASTM D2386, Freezing Point 18°C, ASTM D2386, Freezing Point 64.4°C, ASTM D2624, Temperature 76 °C, ASTM D2624, Electrical Conductivity, 2.00 pS/M, ASTM D5453, Sulfur 3.7 mg/kg, ASTM D1500, ASTM Color <5.5, ASTM D4176 Appearance: Clean and Bright, Fail-Hazy, ASTM D4176 Free Water Content/Particles, No water particles mg/kg, ASTM D4176 Haze Rating 5.0, ASTM D4176, Special Observation, ASTM D4737 Cetane Index by D4737 (Procedure A) 64.2, 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, ASTM D93 Corrected Flash Point Below room temperature in °C and ultimately ASTM D5291 Nitrogen Content <0.75 Wt% etc.So appearing that in standard HDPE electricity conductivity <1 pS/M, where as in waste HDPE electricity conductivity IS 2.00 pS/M pS/M, freezing point in standard HDPE fuel is 18°C other hand in waste HDPE freezing point is 18°C which is same each other. Flash point of standard HDPE Below room temperature in °C and flash point of waste HDPE are also below in room temperature in °C, Nitrogen

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content in standard HDPE fuel <0.75 Wt% and in waste HDPE fuel <0.75 Wt%, in standard HDPE cloud point is 20.7 °F and in waste HDPE cloud point is also similar such as 20.7 °F etc.

3.5. Residue Analysis

Table 9: HDPE standard plastic to residue and HDPE waste plastic to residue metal analysis result

Test Method Name	Trace Metal Name	HDPE Waste Plastic to Residue (mg/L)	HDPE Standard Plastic to Residue (mg/L)
ASTM D 1976	Silver	<1.0	<1.0
	Aluminum	11810	189.6
	Arsenic	10.9	<1.0
	Boron	9.3	9.6
	Barium	359.3	13.2
	Beryllium	<1.0	<1.0
	Calcium	35000	4599
	Cadmium	<1.0	<1.0
	Chromium	33.3	19.8
	Copper	40.3	22.2
	Iron	1596	1642
	Potassium	478.9	<1.0
	Lithium	10.7	<1.0
	Magnesium	1173	52.3
	Manganese	9.7	12.3
	Sodium	1446	42.8
	Nickel	26.3	143.7
	Lead	<1.0	<1.0
	Antimony	<1.0	<1.0
	Selenium	<1.0	<1.0
	Silicon	35.8	11.5
	Tin	92.5	114.7
	Titanium	576.6	88.7
	Vanadium	8.4	79.1
	Zinc	382.8	38.5

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American Standard and Testing Method (ASTM) analysis of Waste HDPE plastic to black solid residue (table 9) numerous metal contents are found in the analysis. Analysis noticed that some metal content are very high compare to less contents metal in the residue. High and low contents metal elements are Silver <1.0 mg/L, Aluminum 11810 mg/L, Arsenic 10.9 mg/L, Boron 9.3 mg/L, Barium 359.3 mg/L, Beryllium <1.0 mg/L, Calcium 35000 mg/L, Cadmium <1.0 mg/L ,Chromium 33.3 mg/L, Copper 40.3 mg/L, Iron 1596 mg/L, Potassium 478.9 mg/L, Lithium 10.7 mg/L, Magnesium 1173 mg/L, Manganese 9.7 mg/L, Sodium 1446 mg/L, Nickel 26.3 mg/L, Lead <1.0 mg/L, Antimony <1.0 mg/L, Selenium <1.0 mg/L, Silicon 35.8 mg/L, Tin 92.5 mg/L, Titanium 576.6 mg/L, Vanadium 8.4 mg/L and Zinc 382.8 mg/L etc. On the other hand Standard HDPE plastic to black residue same metal contents are appeared in the analysis but metal quantity contents are making differ of each other. In some case found same quantity but in some case quantity varies on metal to metal including less content and high content. In the analysis of standard HDPE plastic to residue less metal quantity contents are found comparative with waste HDPE plastic to residue those are following such as Silver <1.0 mg/L, Aluminum 189.6 mg/L, Arsenic <1.0 mg/L, Boron 9.6 mg/L, Barium 13.2 mg/L, Beryllium <1.0 mg/L, Calcium 4599 mg/L, Cadmium <1.0 mg/L ,Chromium 19.8 mg/L, Copper 22.2 mg/L, Iron 1642 mg/L, Potassium <1.0 mg/L, Lithium <1.0 mg/L, Magnesium 52.3 mg/L, Manganese 12.3 mg/L, Sodium 42.8 mg/L, Nickel 143.7 mg/L, Lead <1.0 mg/L, Antimony <1.0 mg/L, Selenium <1.0 mg/L, Silicon 11.5 mg/L, Tin 114.7 mg/L, Titanium 88.7 mg/L, Vanadium 79.1 mg/L and Zinc 38.5 mg/L etc. In some parameter found that standard HDPE residue and waste HDPE residue quantity contents are similar. On the other hand Standard HDPE plastic to black residue same metal contents are appeared in the analysis but metal quantity contents are making differ of each other. In some case found same quantity but in some case quantity varies on metal to metal including less content and high content as well. HDPE Waste plastics are fallen in the open nature for long run as well as contaminated with different types of metal as appeared in the analysis.

Table 10: HDPE standard and waste plastic to residue C, H, and N percentage

Test Method Name	Residue Name	Carbon %	Hydrogen %	Nitrogen %
ASTM D5291.a	HDPE Waste Plastic to Residue	26.23	0.51	<0.30
	HDPE Standard Plastic to Residue	73.59	2.58	<0.30

ASTM (American Standard and Testing Method) D5291.a (table 10) analysis of waste HDPE plastic to residue and Standard HDPE plastic to residue analysis following percentage of Carbon, Hydrogen and Nitrogen content are appeared. In the analysis of both residue such as in waste HDPE residue Carbon 26.23%, Hydrogen 0.51% and ultimately Nitrogen <0.30% as well .On the other hand HDPE standard waste plastics to residue Carbon 73.59%, Hydrogen 2.58% and ultimately Nitrogen <0.30% respectively. In the comparative analysis of carbon, hydrogen and nitrogen contents found that standard HDPE waste plastic to residue has more carbon and hydrogen percentage content than waste HDPE plastic to residue and Nitrogen contents are same percentage <0.30% in the both residue as well. Fundamentally Standard HDPE plastic is more pure than waste HDPE plastic and waste HDPE plastic are

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exists in the nature for long run as well as contaminated with metal and other substances. Also during manufacturing different type's additives and dyes are added into the waste HDPE plastics in order to give durable shape and color of waste plastics. Therefore standard HDPE plastic more pure, than waste HDPE plastic as aspect of carbon and hydrogen percentage contents.

4. Conclusion

HDPE waste plastic and HDPE standard plastic to fuel production process was investigated fully based on their chemical structure and their additives level. Both experiments was conducted same temperature profile and GC/MS analysis result showed HDPE waste plastic hydrocarbon range C3 to C28 and standard plastic to fuel hydrocarbon range C3-C28. ASTM test result showed Btu value for HDPE waste plastic to fuel 129502 Btu/gallon and Standard plastic to fuel Btu value is 127065 Btu/gallon. From this two Btu value showed waste plastic fuel Btu value little bit higher than Standard plastic Btu value. Both plastics to produced fuel sulfur content also less then environmental protection agency level. HDPE waste plastic has different types of additives and this additives level higher than HDPE standard plastic and HDPE standard plastic was fully pure grade and this plastic has less amount of additives. From ICP analysis result showed both plastics have additives and this type of additives (metals) was react as a catalyst. From this two type of plastics to fuel conversion doesn't need any kind of catalyst because metal content already present into raw materials which was help to break down long chain hydrocarbon to short chain hydrocarbon fuel. All information is proprietary (patent pending) information and this produced fuel could be use as feed stock refinery.

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