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FOOD CONTAINER WASTE PLASTIC CONVERSION INTO FUEL

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ABSTRACT

Black color non coded food container hard shape waste plastic to fuel product was perform into laboratory scale in the batch process at temperature 400 ºC. Food container waste plastic to fuel product process was two step processes. First step process was muffle furnace process was plastic liquefaction and 2nd step process was condensation process. First step process and 2nd step process was separately under laboratory fume hood without vacuumed and catalyst. Sample was use for experimental purpose 125 gm and fuel product production conversion rate was 87.3%. Product fuel density is 0.76 g/ml. fuel color is light yellow and fuel is ignited. Product fuel was analysis by GC/MS, and Chromatogram analysis compounds carbon range showed C_3 to C_{27}. Fuel can use internal combustion engine because fuel has short chain to long chain hydrocarbon compounds.

Keywords: food container, waste plastic, conversion, fuel, GC/MS

Introduction

Modern societies are over dependent on petroleum for fuels and for raw material in many industries. In the world, about 42% of this fuel is consumed to produce energy, 45% on transportation, 4% for plastic production, 4% as feedstock for the petrochemical industry, and 5% in other applications [1]. Hence, efforts have to be undertaken to find alternative means to substitute petroleum for energy [1]. The treatment of wastes has become one of the most important concerns of modern society. The conventional solution of landfilling is becoming too expensive and of questionable desirability for many localities. The destruction of wastes by incineration is becoming more prevalent, but this practice is often expensive also and generates problems with unacceptable emissions. Recycling is the best alternative to landfilling because it is the most environmentally friendly way [2]. Nowadays, plastics are one of the most used materials due to their characteristics. Basically, four methods for the elimination of plastics can be distinguished: mechanical recycling, landfilling, incineration, and chemical recycling, [3-6] although they present several disadvantages. In one way, mechanical recycling (or secondary recycling) can only be applied to thermoplastic materials;[5] in the case of landfilling, the space is limited and most of the plastic wastes are resistant to environmental degradation;[5,6] incineration (or quaternary recycling) is an interesting alternative because of the energy production but less attractive from an environmental point of view.[3,5,6] Finally, chemical recycling (or tertiary recycling) implies the conversion of polymers into more valuable chemicals or fuels.[3-5] In this type of recycling method, pyrolysis is included as an interesting alternative for the elimination of plastics. [7] Several authors [8-10] studied the polyethylene pyrolysis process using different reactors and experimental conditions. The most used reactors were of the fluidized bed and the fixed bed types. Most of the studies focused on the effect of experimental conditions (reaction

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temperature and time) on product yield and composition; others[11-14] characterized extensively the products obtained in the polyethylene (PE) pyrolysis.

A promising solution to the waste plastics is feedstock recycling where the polymers are thermally and catalytically converted into useful products that can be used as fuel oil [15–20]. A maximum of 52 wt. % total conversion of high-density polyethylene (HDPE) was achieved using the most efficient zeolite, Ti–Al–beta(X) as a catalyst among the other applied zeolites [15]. One of these studies is focused on the pyrolysis of mixture of polymers other than HDPE i.e. LDPE and ethylene-vinyl acetate (EVA) copolymer [16]. Another study is concerned with only thermogravimetric analysis (TGA) of HDPE [17]. In another research work, HDPE was co-pyrolyzed in an autoclave micro-reactor with polypropylene and polystyrene where a maximum total conversion of 89.8% was obtained with about 40% liquid yield [18]. The same experimental setup was used in another study where a mixture of HDPE, LDPE and PP was degraded and amaximum total percent conversion of 95% was obtained at a pressure of 500 psi [19]. Total percent conversion in the range of 43.6–57.3% was obtained from catalytic degradation of HDPE and 78.4–86.9% total conversion was achieved with coprocessing of HDPE, petroleum residue and catalyst using the same autoclave micro-reactor [20]. All of these studies are mainly focused on the total percent conversion and efficiency of different catalysts and different reaction systems. None of these works include study about the evaluation of the liquid products as fuel oil by performing different fuel tests. [21]

The thermal degradation of LDPE has been widely studied.[22-26] Among the volatile products obtained in the pyrolysis of this polymer, C_3-C_5 olefins are the most valuable products since they are the basic building blocks for the manufacturing of petrochemical products, and their demand is steadily increasing. [27] Furthermore, light olefins such as ethylene and propylene are raw materials for the production of polymers and alkylbenzenes. [28,29] Other valuable products present in the volatile compounds generated during LDPE pyrolysis are propane and butane, which are very useful products that constitute a nonrenewable source of energy. On the other hand, the condensable products generated contain valuable gasoline-range hydrocarbons. [30] All these compounds have interesting industrial applications. These valuable compounds can be compared with those obtained in the thermal cracking of petroleum. [31] In this process, low-value heavy oils are converted into more valuable products like gasoline, light cycle oil, and lighter products. [31-34]

Materials and Method

Black color food container waste plastic was collected from Natural State Research office. Collected container surface was food particle and wash with liquid detergent. Then hard shape waste plastics cut into small pieces. Sample was use 125 gm for liquefaction process. This experiment was two step processes one was muffle furnace and another step was condensation process by using glass reactor. Small pieces black color hard shape waste plastic was place into crucible and crucible was placed into muffle furnace (Figure 1). Muffle furnace temperature was 400 ºC and temperature ramping rate was 20 ºC per minute. For experimental purpose was used muffle furnace, crucible with cover, glass reactor with temperature controller, condensation unit, fuel collation container, fuel purification device, gas cleaning liquid solution, Teflon bag, and residue collection container. Muffle furnace start from room temperature and temperature raised 20 ºC per minute up to 400 ºC. Temperature was holding 10 minute at temperature 400 ºC. The temperature was goes down at 150 ºC then muffle furnace door was open and liquid waste plastic slurry was transferred into glass reactor manually process. During muffle furnace process sample was volatile 5.7 gm from 125 gm initial sample. Muffle furnace sample volatile percentage was 4.56%. Muffle furnace waste plastic liquefaction process was set up under fume hood because volatile smoke can absorbed by HEPA filter. 4.56% volatile gas is usable gas it can collect and keep into storage because this gas has methane,

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ethane, propane and butane. Transferred liquid slurry was heated up at low temperature 150 ºC to until 420 ºC. Liquid slurry was heated up and produced vapor then vapor was condenses at the end liquid fuel was collected. Whole condensation process was under fume hood because environmental safety. Condensation process some light gas was escape from collection device because light gas has negative boiling point temperature. Light gas can make liquid in normal temperature because our condensation process was normal room temperature. Light gas was passed into liquid alkali solution to remove contamination. Then light gas was stored into Teflon bag for future usage. Fuel was clean into filter paper and store into another container. Fuel density was determining 0.76g/ml. total conversion rate was 84.86% and residue was leftover 15.14% because experimental purpose glass reactor was use. If steeliness steel reactor process is use it can reduce residual part. Condensation process liquid fuel was 89.3 gm (71.44%), light gas was 11.07 gm (8.86%), and residue was 18.93 gm (15.14%). Residue was collected after finished the whole experimental procedure.

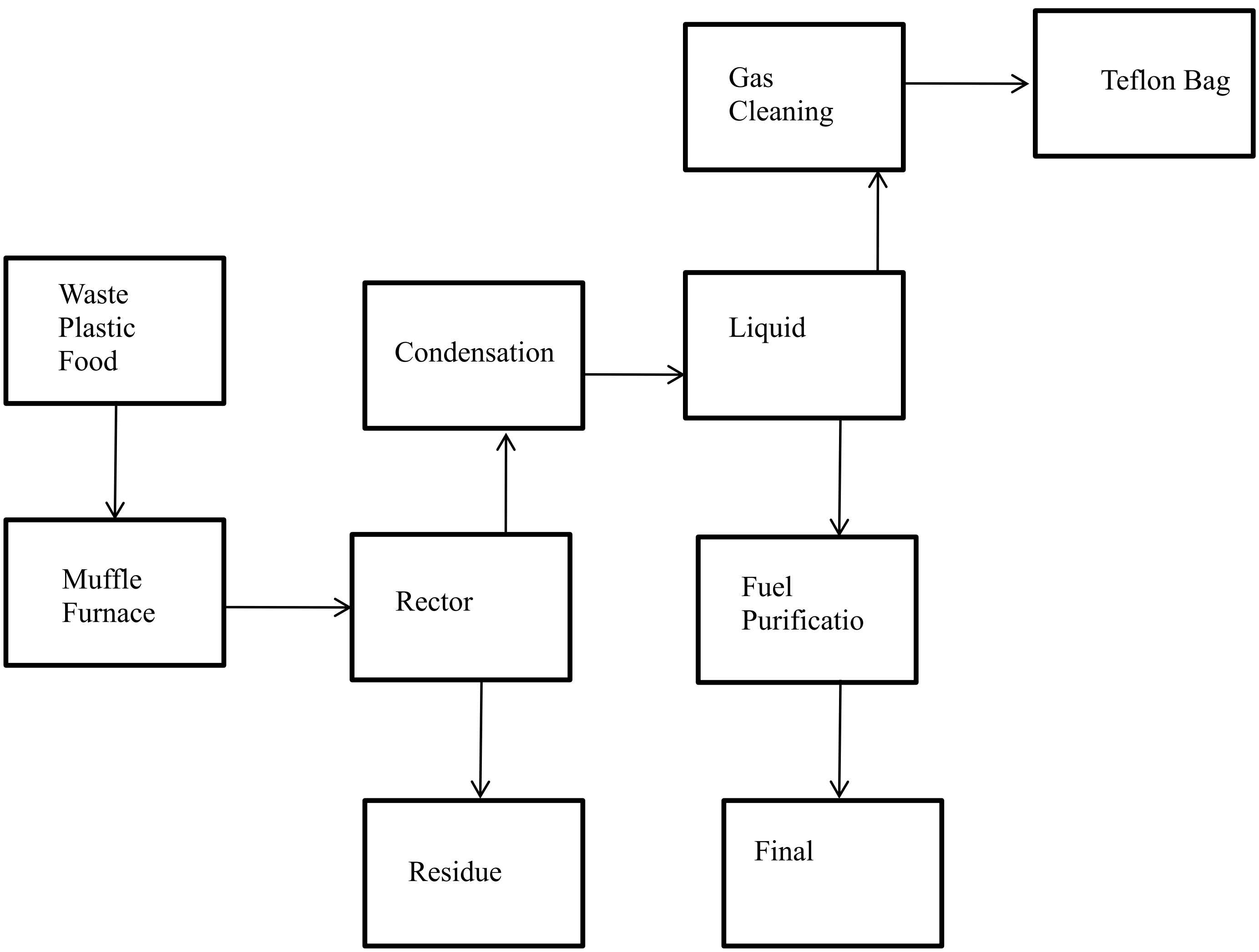

Figure 1: Waste plastic food container into fuel production process

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Result and Discussion

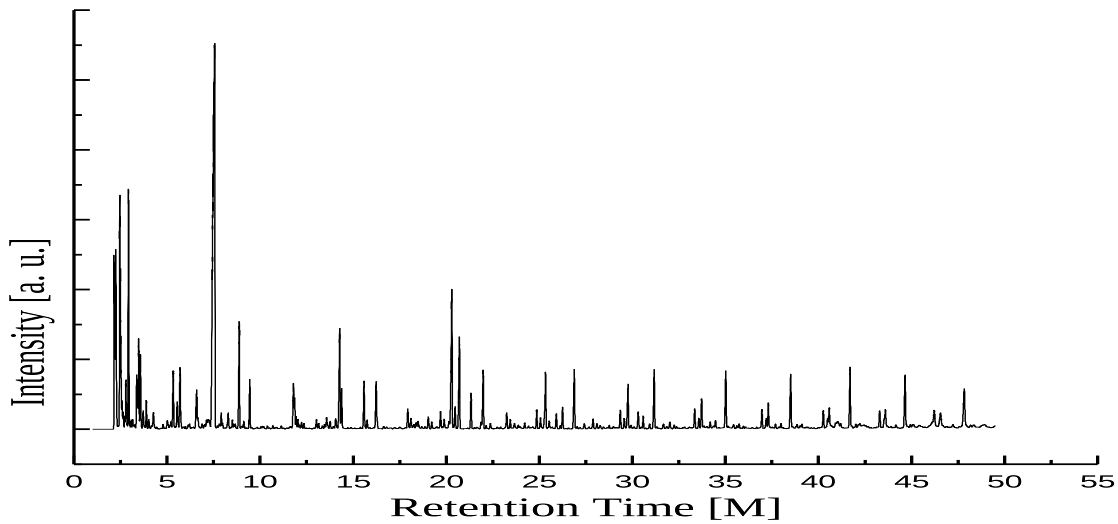

Figure 2: GC/MS chromatogram of raw materials of food container

Table 1: GC/MS chromatogram compounds list of raw materials of food container

Number of Peak	Retention Time (min.)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	2.16	42	Cyclopropane	C_3H_6	42	49.4	18854
2	2.25	41	2-Butene, (E)-	C_4H_8	56	22.7	105
3	2.46	41	1-Butanol, 3-methyl-	$C_5H_{12}O$	88	23.5	151656
4	2.51	55	Cyclopropane, 1,2-dimethyl-, cis-	C_5H_{10}	70	16.5	19070
5	2.58	67	1,4-Pentadiene	C_5H_8	68	35.7	114494
6	2.79	41	1-Pentanol, 2-methyl-	$C_6H_{14}O$	102	13.5	19924
7	2.93	55	3-Hexene, (Z)-	C_6H_{12}	84	17.5	114381
8	3.15	67	3-Hexyne	C_6H_{10}	82	10.5	19282
9	3.37	67	1,3-Pentadiene, 2-methyl-, (E)-	C_6H_{10}	82	13.3	113652
10	3.47	56	1-Pentene, 2,4-dimethyl-	C_7H_{14}	98	45.7	114435
11	3.57	81	2,4-Dimethyl 1,4-pentadiene	C_7H_{12}	96	51.2	114468
12	3.71	69	2-Hexene, 3-methyl-, (Z)-	C_7H_{14}	98	13.7	114046
13	3.88	81	1,5-Hexadiene, 2-methyl-	C_7H_{12}	96	57.4	114394
14	4.02	56	1-Hexene, 2-methyl-	C_7H_{14}	98	17.9	114433
15	4.27	81	3,5-	C_7H_{12}	96	12.9	113640

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			Dimethylcyclopentene				
16	4.78	81	1,4-Hexadiene, 4-methyl-	C_7H_{12}	96	20.3	113135
17	5.02	79	1-Cyclohexene-1-methanol	$C_7H_{12}O$	112	14.0	52048
18	5.21	41	1-Heptene, 2-methyl-	C_8H_{16}	112	10.3	107268
19	5.34	69	2-Heptene, 4-methyl-, (E)-	C_8H_{16}	112	30.1	113478
20	5.54	43	cis-3-Methylcyclohexanol	$C_7H_{14}O$	114	9.13	113806
21	5.70	95	1,5-Hexadiene, 2,5-dimethyl-	C_8H_{14}	110	12.7	162753
22	5.99	56	4-Methyl-1,4-heptadiene	C_8H_{14}	110	9.26	113473
23	6.21	95	Cyclopentene, 1,2,3-trimethyl-	C_8H_{14}	110	25.5	113461
24	6.59	69	3-Heptene, 2,6-dimethyl-	C_9H_{18}	126	17.6	113946
25	6.65	69	2,3-Dimethyl-3-heptene, (Z)-	C_9H_{18}	126	14.0	232149
26	6.88	43	Hexane, 3-ethyl-	C_8H_{18}	114	30.1	113940
27	7.46	70	2,4-Dimethyl-1-heptene	C_9H_{18}	126	63.2	113516
28	7.56	41	2,4-Dimethyl-1-heptene	C_9H_{18}	126	24.1	113516
29	7.81	109	Cyclohexane, 1,3-dimethyl-2-methylene-, trans-	C_9H_{16}	124	21.3	113520
30	7.92	69	Cyclohexane, 1,3,5-trimethyl-, (1α,3α,5α)-	C_9H_{18}	126	28.1	114126
31	7.98	95	1,3-Hexadiene, 2,5-dimethyl-	C_8H_{14}	110	22.5	61715
32	8.10	95	1,4-Hexadiene, 2,3-dimethyl-	C_8H_{14}	110	7.65	1482
33	8.28	67	Cyclohexene, 3,3,5-trimethyl-	C_9H_{16}	124	43.1	114765
34	8.42	41	cis,cis-4,6-Octadienol	$C_8H_{14}O$	126	99.72	250522
35	8.67	56	1-Octene, 2-methyl-	C_9H_{18}	126	12.2	227609
36	8.88	43	2,3,3-Trimethyl-1-hexene	C_9H_{18}	126	12.8	113521
37	9.13	83	Bicyclo[3.1.1]heptan-2-one, 6,6-dimethyl-, (1R)-	$C_9H_{14}O$	138	28.9	108460
38	9.45	82	1,6-Octadiene, 2,5-dimethyl-, (E)-	$C_{10}H_{18}$	138	10.8	62075
39	11.14	81	Cyclopentane, 1-methyl-3-(2-methyl-2-propenyl)-	$C_{10}H_{18}$	138	6.26	149979
40	11.63	81	2,4-Dodecadienal, (E,E)-	$C_{12}H_{20}O$	180	13.8	53578
41	11.79	69	Nonane, 2-methyl-3-methylene-	$C_{11}H_{22}$	154	11.9	61011
42	11.85	69	Nonane, 2-methyl-3-methylene-	$C_{11}H_{22}$	154	6.95	61011
43	11.93	69	Cyclohexane, 1,1-dimethyl-2-propyl-	$C_{11}H_{22}$	154	9.76	69817
44	13.03	57	1-Nonene, 4,6,8-	$C_{12}H_{24}$	168	11.5	6413

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			trimethyl-				
45	12.12	57	1-Decene, 4-methyl-	$C_{11}H_{22}$	154	4.48	150275
46	12.23	43	Decane, 4-methyl-	$C_{11}H_{24}$	156	7.97	113875
47	12.36	71	Octane, 3,5-dimethyl-	$C_{10}H_{22}$	142	8.05	114062
48	13.03	69	2-Undecanethiol, 2-methyl-	$C_{12}H_{26}S$	202	4.66	9094
49	13.34	55	Cyclopropanemethanol, 2-methyl-2-(4-methyl-3-pentenyl)-	$C_{11}H_{20}O$	168	8.47	185050
50	13.46	57	2-Piperidinone, N-[4-bromo-n-butyl]-	$C_9H_{16}BrNO$	233	6.59	251632
51	13.58	69	3-Tetradecyne	$C_{14}H_{26}$	194	5.77	62725
52	13.76	69	3-Tridecene	$C_{13}H_{24}$	180	4.19	142644
53	13.94	69	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl-, [1R-(1α,2α,5α)]-	$C_{10}H_{18}$	138	4.89	140998
54	14.06	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	11.1	113757
55	14.27	69	Cyclooctane, 1,4-dimethyl-, trans-	$C_{10}H_{20}$	140	4.46	61408
56	15.59	83	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	3.30	114065
57	15.75	69	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	11.3	114065
58	16.23	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	25.3	113757
59	17.94	69	3-Tetradecene, (Z)-	$C_{14}H_{28}$	196	4.24	62806
60	18.10	69	3-Tetradecene, (E)-	$C_{14}H_{28}$	196	4.44	139981
61	18.26	69	1-Octadecyne	$C_{18}H_{34}$	250	6.82	233010
62	18.38	57	1-Nonene, 4,6,8-trimethyl-	$C_{12}H_{24}$	168	13.0	6413
63	18.47	69	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	4.79	114065
64	18.68	71	Dodecane, 2,6,10-trimethyl-	$C_{15}H_{32}$	212	5.96	68892
65	18.87	55	Oxirane, dodecyl-	$C_{14}H_{28}O$	212	10.0	290804
66	19.04	69	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	4.60	114065
67	19.22	69	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	3.83	114065
68	19.69	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	21.9	113757
69	19.89	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	23.4	113757
70	20.30	69	1-Nonadecene	$C_{19}H_{38}$	266	4.31	113626

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71	20.47	69	1-Nonadecene	$C_{19}H_{38}$	266	4.00	113626
72	20.71	69	1-Nonadecene	$C_{19}H_{38}$	266	4.08	113626
73	21.33	69	1-Octanol, 2-butyl-	$C_{12}H_{26}O$	186	4.56	114639
74	21.87	43	3-Octadecene, (E)-	$C_{18}H_{36}$	252	4.30	62811
75	21.99	69	Cyclododecanemethanol	$C_{13}H_{26}O$	198	5.86	108275
76	22.15	69	Cyclododecanemethanol	$C_{13}H_{26}O$	198	6.00	108275
77	22.37	69	(R)-(-)-(Z)-14-Methyl-8-hexadecen-1-ol	$C_{17}H_{34}O$	254	4.70	98702
78	23.25	63	Isotridecanol-	$C_{13}H_{28}O$	200	3.44	298499
79	23.44	69	2-Decene, 7-methyl-, (Z)-	$C_{11}H_{22}$	154	4.21	61984
80	23.66	71	1-Decanol, 2-hexyl-	$C_{16}H_{34}O$	242	5.50	113815
81	23.88	69	1-Nonadecene	$C_{19}H_{38}$	266	4.70	113626
82	24.22	69	3-Eicosene, (E)-	$C_{20}H_{40}$	280	4.33	62838
83	24.87	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	6.35	113757
84	25.33	69	1-Docosene	$C_{22}H_{44}$	308	4.79	113878
85	25.53	69	2-Hexyl-1-octanol	$C_{14}H_{30}O$	214	4.45	113807
86	25.92	69	3-Eicosene, (E)-	$C_{20}H_{40}$	280	4.34	62838
87	26.13	69	1-Decanol, 2-hexyl-	$C_{16}H_{34}O$	242	4.94	113815
88	26.25	69	1-Docosene	$C_{22}H_{44}$	308	4.34	113878
89	26.87	69	1,19-Eicosadiene	$C_{20}H_{38}$	278	5.83	158339
90	27.89	69	3-Eicosene, (E)-	$C_{20}H_{40}$	280	7.03	62838
91	29.36	69	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	$C_{15}H_{30}O$	226	8.71	31254
92	29.76	69	1-Docosene	$C_{22}H_{44}$	308	3.37	113878
93	30.32	69	1-Nonadecene	$C_{19}H_{38}$	266	4.59	107568
94	30.58	69	1-Nonadecene	$C_{19}H_{38}$	266	3.84	113626
95	30.93	69	1-Heptadecene	$C_{17}H_{34}$	238	3.83	233150
96	31.18	69	1,22-Docosanediol	$C_{22}H_{46}O_2$	342	6.01	142886
97	31.68	69	Cyclododecanemethanol	$C_{13}H_{26}O$	198	8.97	108275
98	32.01	69	1-Hexadecanol, 3,7,11,15-tetramethyl-	$C_{20}H_{42}O$	298	5.15	194527
99	33.35	69	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	$C_{15}H_{30}O$	226	9.22	31254
100	33.72	69	Cyclotetradecane, 1,7,11-trimethyl-4-(1-methylethyl)-	$C_{20}H_{40}$	280	5.22	13489
101	34.19	69	3-Eicosene, (E)-	$C_{20}H_{40}$	280	5.06	62838
102	35.02	69	11,13-Dimethyl-12-tetradecen-1-ol acetate	$C_{18}H_{34}O_2$	282	6.74	130810
103	36.96	69	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	11.2	75831
104	37.30	69	Cyclotetradecane, 1,7,11-trimethyl-4-(1-methylethyl)-	$C_{20}H_{40}$	280	13.4	13489
105	38.51	69	Dodecane, 1-cyclopentyl-4-(3-	$C_{25}H_{48}$	348	7.16	15853

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			cyclopentylpropyl)-				
106	40.26	69	Dodecane, 1-cyclopentyl-4-(3-cyclopentylpropyl)-	$C_{25}H_{48}$	348	10.7	15853
107	40.58	69	9-Hexacosene	$C_{26}H_{52}$	364	5.01	113632
108	41.70	69	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	11.3	75831
109	43.28	69	Cyclotetradecane, 1,7,11-trimethyl-4-(1-methylethyl)-	$C_{20}H_{40}$	280	9.75	13489
110	44.65	69	Dodecane, 1-cyclopentyl-4-(3-cyclopentylpropyl)-	$C_{25}H_{48}$	348	10.9	15853
111	46.22	69	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	6.43	75831
112	46.55	69	1-Tricosene	$C_{23}H_{46}$	322	4.75	189272
113	47.82	69	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	8.71	75831

Before experimental process setup initial materials was analysis by GC/MS with pyroprobe. Solid sample was run into GC/MS and GC/MS chromatogram provided us compounds structure (Figure 2 and table 1). All compounds were determined from GC/MS chromatogram and library was followed Perkin Elmer NIST library. GC/MS chromatogram solid waste plastic sample to compounds was determination based on peak retention time (M) and trace mass (m/z). Analysis data table (Table 1) showed that most of the compounds are double bonded hydrocarbon compounds. GC/MS chromatogram showed that peak intensity is not high enough. But an initial raw material has short chain hydrocarbon compounds to long chain hydrocarbon compounds including alkane, alkene and alkyl group. Chromatogram compounds ranges determine C_3 to C_{26}. Initial materials analysis result showed initial solid materials has oxygen content compounds, alcoholic compounds, halogen content compounds, nitrogen content compounds and sulfur content compounds. This analysis main goal was initial materials compounds types determination and what types of waste plastic. Because initial materials was none coded black color food container waste plastic. Some compounds are showed in this section based on retention time (m) and trace mass (m/z) and IUPAC name wise. Initial compound is Cyclopropane (C_3H_6) (t=2.16, m/z=42) then 3-methyl-1-Butanol ($C_5H_{12}O$) (t=2.46, m/z=41), (E)-2-methyl-1,3-Pentadiene (C_6H_{10}) (t=3.37, m/z=67), 4-methyl-1,4-Hexadiene (C_7H_{12}) (t=4.78, m/z=81), (E)-4-methyl-2-Heptene (C_8H_{16}) (t=5.34, m/z=69), 4-heptadiene4-Methyl-1 (C_8H_{14}) (t=5.99, m/z=56), trans-1,3-dimethyl-2-methylene-Cyclohexane (C_9H_{16}) (t=7.81, m/z=109), 2,5-dimethyl-1,3-Hexadiene (C_8H_{14}) (t=7.98, m/z=95), (E)-2,5-dimethyl-1,6-Octadiene ($C_{10}H_{18}$) (t=9.45, m/z=82), 2-methyl-3-methylene- Nonane ($C_{11}H_{22}$) (T=11.85, m/z=69), 3,5-dimethyl- Octane ($C_{10}H_{22}$) (t=12.36, m/z=71), N-[4-bromo-n-butyl]- 2-Piperidinone ($C_9H_{16}BrNO$) (t=13.46, m/z=57), trans-1,4-dimethyl-Cyclooctane ($C_{10}H_{20}$) (t=14.27, m/z=69), (Z)-3-Tetradecene ($C_{14}H_{28}$) (t=17.94, m/z=69), 3,7,11-trimethyl-1-Dodecanol ($C_{15}H_{32}O$) (t=18.47, m/z=69), dodecyl- Oxirane ($C_{14}H_{28}O$) (t=18.87, m/z=55), 1-Nonadecene ($C_{19}H_{38}$) (t=20.30, m/z=69), (E)-3-Octadecene ($C_{18}H_{36}$) (t=21.87, m/z=43), 2-hexyl-1-Decanol ($C_{16}H_{34}O$) (T=23.66, m/z=71), 2-Hexyl-1-octanol ($C_{14}H_{30}O$) (t=25.53, m/z=69), 2-hexyl-1-Decanol ($C_{16}H_{34}O$) (T=26.13, m/z=69), (E)-3-Eicosene ($C_{20}H_{40}$) (t=27.89, m/z=69), 1-Docosene ($C_{22}H_{44}$) (t=29.76, m/z=69), 3,7,11,15-tetramethyl-1-Hexadecanol ($C_{20}H_{42}O$) (t=32.01, m/z=69), 11,13-Dimethyl-12-tetradecen-1-ol acetate ($C_{18}H_{34}O_2$) (t=35.02, m/z=69), 1-cyclopentyl-4-(3-cyclopentylpropyl)- Dodecane ($C_{25}H_{48}$) (t=38.51, m/z=69), 9-Hexacosene ($C_{26}H_{52}$) (t=40.58, m/z=69), 1-Tricosene ($C_{23}H_{46}$) (t=46.55, m/z=69), and so on. Plastic has different types of additives and additives percentages are differ based on plastic production. Additives is not coming out fuel production because our waste plastic to fuel product temperature 420 ºC. Different kinds of metal are using for additive we know metal melting point

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higher then production temperature. Whatever metal part is coming with production period is negligible or less the 1 ppm.

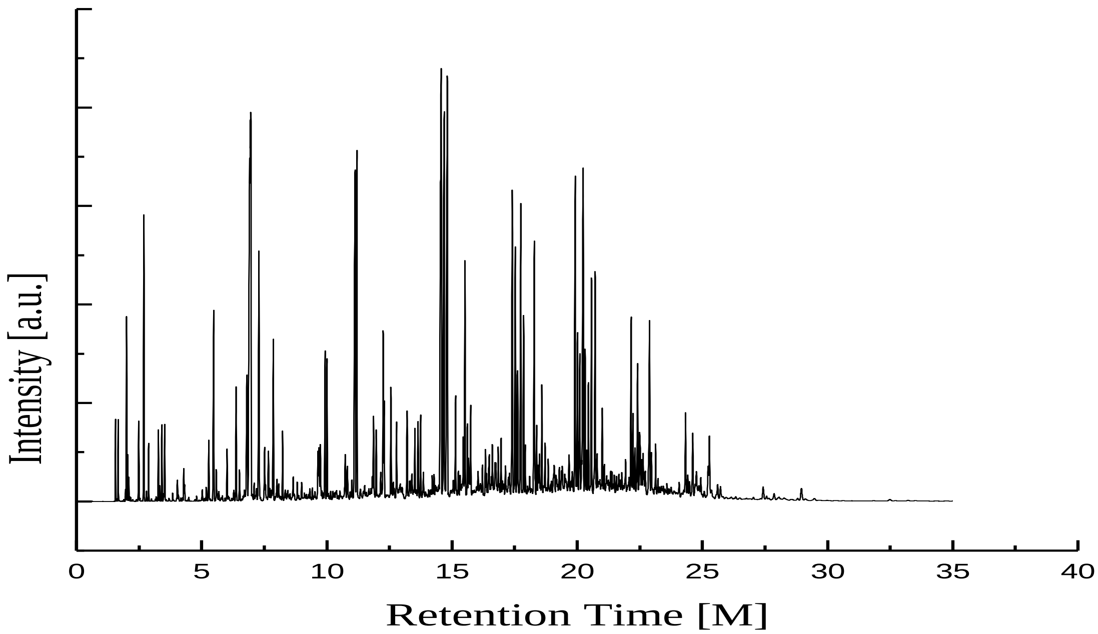

Figure 3: GC/MS chromatogram of product fuel

Table 2: GC/MS chromatogram compounds list of product fuel

Number of Peak	Retention Time (min.)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.56	39	Cyclopropane	C_3H_6	42	56.0	18854
2	1.66	41	1-Propene, 2-methyl-	C_4H_8	56	26.4	18910
3	1.96	42	Cyclopropane, ethyl-	C_5H_{10}	70	21.1	114410
4	2.00	72	Pentane	C_5H_{12}	72	23.8	291244
5	2.05	55	2-Pentene, (E)-	C_5H_{10}	70	15.9	291780
6	2.48	43	Pentane, 2-methyl-	C_6H_{14}	86	62.5	61279
7	2.69	42	2-Hexene, (Z)-	C_6H_{12}	84	12.5	114458
8	2.79	57	Hexane	C_6H_{14}	86	84.0	61280
9	2.88	41	2-Pentene, 2-methyl-	C_6H_{12}	84	12.2	230826
10	2.99	67	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	11.6	113646
11	3.19	56	Cyclopentane, methyl-	C_6H_{12}	84	44.3	114428
12	3.27	67	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	10.8	113646
13	3.33	67	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	14.3	113646
14	3.41	56	1-Pentene, 2,4-dimethyl-	C_7H_{14}	98	49.5	37343
15	3.48	55	1-Hexene, 3-methyl-	C_7H_{14}	98	25.4	231713
16	3.52	81	2,4-Dimethyl 1,4-pentadiene	C_7H_{12}	96	44.1	114468

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17	3.69	81	Cyclopropane, trimethylmethylene-	C_7H_{12}	96	7.69	63085
18	3.84	43	Hexane, 3-methyl-	C_7H_{16}	100	67.2	113081
19	4.03	56	1-Hexene, 2-methyl-	C_7H_{14}	98	37.9	156226
20	4.07	56	Cyclopentane, 1,3-dimethyl-	C_7H_{14}	98	20.8	151129
21	4.16	57	3-Pentanone	$C_5H_{10}O$	86	79.5	114666
22	4.23	41	2-Heptene	C_7H_{14}	98	19.1	113119
23	4.29	81	1,3-Pentadiene, 2,4-dimethyl-	C_7H_{12}	96	29.9	114450
24	4.32	81	Cyclopentene, 4,4-dimethyl-	C_7H_{12}	96	14.9	38642
25	4.43	69	2-Hexene, 3-methyl-, (Z)-	C_7H_{14}	98	21.9	114046
26	4.49	81	1,4-Hexadiene, 2-methyl-	C_7H_{12}	96	10.1	840
27	4.73	95	1,4-Pentadiene, 2,3,3-trimethyl-	C_8H_{14}	110	14.4	154036
28	4.80	81	1,3-Pentadiene, 2,3-dimethyl-	C_7H_{12}	96	11.0	150967
29	4.90	69	3-Penten-2-one	C_5H_8O	84	37.5	515
30	5.02	70	Cyclopentane, 1,2,4-trimethyl-	C_8H_{16}	112	27.7	152127
31	5.19	56	2,4-Dimethyl-1-hexene	C_8H_{16}	112	57.3	227584
32	5.28	69	3-Heptene, 4-methyl-	C_8H_{16}	112	28.2	149383
33	5.48	70	Heptane, 4-methyl-	C_8H_{18}	114	64.2	107267
34	5.58	95	1,5-Hexadiene, 2,5-dimethyl-	C_8H_{14}	110	46.0	162753
35	5.69	70	Cyclopentane, 1,2,4-trimethyl-, (1α,2α,4β)-	C_8H_{16}	112	25.8	1610
36	6.02	95	4-Methyl-1,3-heptadiene (c,t)	C_8H_{14}	110	13.1	113091
37	6.29	69	1-Hexene, 3,3-dimethyl-	C_8H_{16}	112	8.68	227594
38	6.38	83	Cyclopentane, 1,1,3,4-tetramethyl-, cis-	C_9H_{18}	126	16.7	27589
39	6.51	43	Heptane, 2,4-dimethyl-	C_9H_{20}	128	46.3	155382
40	6.81	111	Cyclohexane, 1,3,5-trimethyl-, (1α,3α,5α)-	C_9H_{18}	126	41.0	2479
41	6.92	70	2,4-Dimethyl-1-heptene	C_9H_{18}	126	25.9	113516
42	6.94	70	cis-2-Nonene	C_9H_{18}	126	10.2	227608
43	6.96	42	Oxirane, 2,2'-(1,4-butanediyl)bis-	$C_8H_{14}O_2$	142	6.09	108137
44	7.09	95	1,3-Heptadiene, 5,5-dimethyl-	C_9H_{16}	124	45.5	142726
45	7.29	69	Cyclohexane, 1,3,5-trimethyl-, (1α,3α,5β)-	C_9H_{18}	126	19.8	2480
46	7.51	109	Cyclohexene, 3,3,5-	C_9H_{16}	124	43.1	114765

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			trimethyl-				
47	7.67	109	Cyclohexene, 3,3,5-trimethyl-	C_9H_{16}	124	48.0	114765
48	7.72	56	1-Octene, 2-methyl-	C_9H_{18}	126	30.5	155943
49	7.86	83	2,3,3-Trimethyl-1-hexene	C_9H_{18}	126	12.3	113521
50	8.01	83	2,6-Octadiene, 2,4-dimethyl-	$C_{10}H_{18}$	138	50.5	150595
51	8.08	83	Bicyclo[3.1.1]heptan-2-one, 6,6-dimethyl-, (1R)-	$C_9H_{14}O$	138	16.2	108460
52	8.23	82	1,6-Octadiene, 2,5-dimethyl-, (E)-	$C_{10}H_{18}$	138	10.6	62075
53	8.34	95	Cyclopentene, 1,4-dimethyl-5-(1-methylethyl)-	$C_{10}H_{18}$	138	18.1	60993
54	8.53	107	Cycloheptanol, 1-methyl-2-methylene-	$C_9H_{16}O$	140	11.0	163975
55	8.66	43	1-Octanol, 2,7-dimethyl-	$C_{10}H_{22}O$	158	5.11	61714
56	8.82	56	1-Octene, 2,6-dimethyl-	$C_{10}H_{20}$	140	7.56	150583
57	8.88	56	2-Methyl-1-nonene	$C_{10}H_{20}$	140	21.2	113561
58	9.00	43	2-Decene, (Z)-	$C_{10}H_{20}$	140	9.25	114151
59	9.10	57	Octane, 2,3-dimethyl-	$C_{10}H_{22}$	142	9.94	114135
60	9.18	95	Bicyclo[4.1.0]heptane, 3,7,7-trimethyl-, [1S-(1α,3β,6α)]-	$C_{10}H_{18}$	138	10.1	38894
61	9.28	55	2,4-Pentadien-1-ol, 3-pentyl-, (2Z)-	$C_{10}H_{18}O$	154	15.2	142197
62	9.32	55	Cyclopentane, 1-methyl-3-(2-methyl-2-propenyl)-	$C_{10}H_{18}$	138	32.5	149979
63	9.64	69	Nonane, 2-methyl-3-methylene-	$C_{11}H_{22}$	154	8.40	61011
64	9.74	69	3-Undecene, (Z)-	$C_{11}H_{22}$	154	6.40	142598
65	9.80	57	2-Piperidinone, N-[4-bromo-n-butyl]-	$C_9H_{16}BrNO$	233	3.89	251632
66	9.93	43	Octane, 3,3-dimethyl-	$C_{10}H_{22}$	142	10.7	114124
67	10.15	43	2-Decene, 7-methyl-, (Z)-	$C_{11}H_{22}$	154	5.28	61984
68	10.74	83	3-Decene, 2,2-dimethyl-, (E)-	$C_{12}H_{24}$	168	6.46	60857
69	10.82	83	2-Undecanethiol, 2-methyl-	$C_{12}H_{26}S$	202	5.42	9094
70	11.00	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	6.71	113757
71	11.13	69	Cyclooctane, 1,4-dimethyl-, cis-	$C_{10}H_{20}$	140	3.44	61409
72	11.21	111	1-Tetradecene	$C_{14}H_{28}$	196	3.86	230878

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73	11.82	69	1-Isopropyl-1,4,5-trimethylcyclohexane	$C_{12}H_{24}$	168	37.6	113584
74	11.97	69	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	9.59	114065
75	12.15	56	2-Undecene, 8-methyl-, (Z)-	$C_{12}H_{24}$	168	5.74	61832
76	12.25	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	13.3	113757
77	12.56	69	1-Isopropyl-1,4,5-trimethylcyclohexane	$C_{12}H_{24}$	168	34.5	113584
78	12.66	69	Ethanone, 1-(1,2,2,3-tetramethylcyclopentyl)-, (1R-cis)-	$C_{11}H_{20}O$	168	7.21	186082
79	12.79	69	Cyclohexane, 2,4-diethyl-1-methyl-	$C_{11}H_{22}$	154	20.3	61114
80	12.86	69	Cyclohexane, 1,1'-(oxydi-2,1-ethanediyl)bis[4-methyl-	$C_{18}H_{34}O$	266	6.28	12888
81	13.01	109	1,1,6,6-Tetramethylspiro[4.4]nonane	$C_{13}H_{24}$	180	29.4	190689
82	13.21	69	1-Isopropyl-1,4,5-trimethylcyclohexane	$C_{12}H_{24}$	168	24.1	113584
83	13.32	69	Phytol	$C_{20}H_{40}O$	296	12.7	157813
84	13.40	69	9-Undecenol, 2,10-dimethyl-	$C_{13}H_{26}O$	198	6.70	131860
85	13.51	71	Decane, 2,3,5,8-tetramethyl-	$C_{14}H_{30}$	198	9.06	149589
86	13.56	69	5-Tetradecene, (Z)-	$C_{14}H_{28}$	196	5.21	142626
87	13.64	71	Decane, 2,3,5,8-tetramethyl-	$C_{14}H_{30}$	198	9.63	149589
88	13.74	71	Dodecane, 2,6,10-trimethyl-	$C_{15}H_{32}$	212	6.40	68892
89	13.86	55	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	6.03	113757
90	13.94	69	2-Dodecen-1-yl(-)succinic anhydride	$C_{16}H_{26}O_3$	266	6.18	76110
91	14.28	83	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	2.83	114065
92	14.57	111	1-Nonadecene	$C_{19}H_{38}$	266	5.94	107568
93	14.81	41	1-Nonadecene	$C_{19}H_{38}$	266	5.80	107568
94	15.14	69	2-Isopropyl-5-methyl-1-heptanol	$C_{11}H_{24}O$	172	6.60	245029
95	15.45	69	9-Eicosene, (E)-	$C_{20}H_{40}$	280	4.21	62815
96	15.52	109	7-Octadecyne, 2-methyl-	$C_{19}H_{36}$	264	5.82	114518
97	15.62	69	(R)-(-)-(Z)-14-Methyl-8-hexadecen-1-ol	$C_{17}H_{34}O$	254	5.98	98702

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98	16.04	69	Z-11(13,13-Dimethyl)tetradecen-1-ol acetate	$C_{18}H_{34}O_2$	282	8.74	131363
99	16.22	69	2-Piperidinone, N-[4-bromo-n-butyl]-	$C_9H_{16}BrNO$	233	4.23	251632
100	16.33	69	Cyclopropanol, 1-(3,7-dimethyl-1-octenyl)-	$C_{13}H_{24}O$	196	8.14	55804
101	16.49	71	Decane, 2,3,5,8-tetramethyl-	$C_{14}H_{30}$	198	7.70	149589
102	17.13	69	11,13-Dimethyl-12-tetradecen-1-ol acetate	$C_{18}H_{34}O_2$	282	7.00	130810
103	17.41	69	Trichloroacetic acid, hexadecyl ester	$C_{18}H_{33}Cl_3O_2$	386	4.61	280518
104	17.74	57	2-Hexyl-1-octanol	$C_{14}H_{30}O$	214	4.47	113807
105	17.92	69	Acetic acid, 3,7,11,15-tetramethyl-hexadecyl ester	$C_{22}H_{44}O_2$	340	3.76	193630
106	18.28	69	Cyclododecanemethanol	$C_{13}H_{26}O$	198	4.77	108275
107	18.49	69	1-Isopropyl-1,4,5-trimethylcyclohexane	$C_{12}H_{24}$	168	9.66	113584
108	18.84	69	Cyclohexane, 1,3,5-trimethyl-2-octadecyl-	$C_{27}H_{54}$	378	6.59	16569
109	19.08	57	Dodecane, 2,6,10-trimethyl-	$C_{15}H_{32}$	212	5.54	68892
110	19.41	57	Tetradecane, 2,6,10-trimethyl-	$C_{17}H_{36}$	240	4.73	11556
111	19.50	83	2-Piperidinone, N-[4-bromo-n-butyl]-	$C_9H_{16}BrNO$	233	13.4	251632
112	19.67	69	11,13-Dimethyl-12-tetradecen-1-ol acetate	$C_{18}H_{34}O_2$	282	8.65	130810
113	19.92	71	1-Nonadecene	$C_{19}H_{38}$	266	5.45	107568
114	20.24	69	1-Nonadecene	$C_{19}H_{38}$	266	7.35	107568
115	20.71	69	1,22-Docosanediol	$C_{22}H_{46}O_2$	342	8.29	142886
116	21.93	96	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	5.92	75831
117	22.16	69	1-Hexadecanol, 3,7,11,15-tetramethyl-	$C_{20}H_{42}O$	298	7.47	194527
118	22.89	83	Oxirane, tetradecyl-	$C_{16}H_{32}O$	240	6.66	75831
119	23.13	69	Dodecane, 1-cyclopentyl-4-(3-cyclopentylpropyl)-	$C_{25}H_{48}$	348	8.31	15853
120	24.07	69	11-Dodecen-1-ol, 2,4,6-trimethyl-, (R,R,R)-	$C_{15}H_{30}O$	226	7.34	31254
121	24.33	69	1-Hexadecanol, 3,7,11,15-tetramethyl-	$C_{20}H_{42}O$	298	5.84	194527
122	25.28	69	Dodecane, 1-cyclopentyl-4-(3-cyclopentylpropyl)-	$C_{25}H_{48}$	348	9.70	15853

123	25.72	69	Cyclotetradecane, 1,7,11-trimethyl-4-(1-methylethyl)-	$C_{20}H_{40}$	280	5.27	13489
124	27.43	69	1-Hexadecanol, 3,7,11,15-tetramethyl-	$C_{20}H_{42}O$	298	7.34	194527
125	28.95	69	Dodecane, 1-cyclopentyl-4-(3-cyclopentylpropyl)-	$C_{25}H_{48}$	348	8.69	15853

Black color food container to liquid fuel was analysis by using GC/MS with auto sample system and chromatogram and compounds table showed figure 3 and table 2. Liquid fuel chromatogram compounds was traced Perkin Elmer provide NIST library for GC/MS. Compounds was determination from fuel chromatogram based on peak retention time (M) and peak trace mass (m/z). Analysis was collected compounds from GC/MS chromatogram and it was not details compounds analysis. Analysis was collected compounds from GC/MS chromatogram high peak intensity compounds. Analysis compounds showed that liquid fuel has long chain hydrocarbon compounds including other type's compounds such as oxygen, alcoholic, halogen, nitrogen, sulfur combination. Because all of those compounds was included in the raw materials. In the raw materials most of the compounds was double bonded but in the liquid fuel most of the compounds are single bonded. Due to thermal degradation process long chain double bonded compounds break down in to short chain single bonded hydrocarbon compounds. Fuel analysis compounds table indicate that short chain hydrocarbon and long chain hydrocarbon compounds with methyl group. So far we know plastic raw materials molecular structure methyl group has polypropylene. This analysis data indicate that initial raw materials was polypropylene waste plastic but it was not coded. After fuel production and fuel analysis GC/MS chromatogram gives us carbon chain number C_3 to C_{27}. Initial compound is Cyclopropane (C_3H_6) (t=1.56, m/z=39), the various of compounds are elaborated in this section from fuel compounds table based on retention time, trace mass and GC/MS probability percentage such as Pentane (C_5H_{12}) (t=2.00, m/z=72) and probability percentage is 23.8 %, Hexane (C_6H_{14}) (t=2.79, m/z=57) and probability percentage is 84.0%, methyl-Cyclopentane (C_6H_{12}) (t=3.19, m/z=56) and probability percentage is 44.3%, 2,4-dimethyl-1-Pentene (C_7H_{14}) (t=3.41, m/z=56) and probability percentage is 49.5%, 3-methyl-Hexane (C_7H_{16}) (t=3.84, m/z=43) and probability percentage is 67.2%, 3-Pentanone ($C_5H_{10}O$) (T=4.16, m/z=57) and probability percentage is 79.5%, (Z)- 3-methyl-2-Hexene (C_7H_{14}) (t=4.43, m/z=69) and probability percentage is 21.9%, 1,2,4-trimethyl-Cyclopentane (C_8H_{16}) (t=5.02, m/z=70) and probability percentage is 27.7%, 2,5-dimethyl-1,5-Hexadiene (C_8H_{14}) (t=5.58, m/z=95) and probability percentage is 46.0%, 2,4-dimethyl-Heptane (C_9H_{20}) (t=6.51, m/z=43) and probability percentage is 46.3%, 5,5-dimethyl-1,3-Heptadiene (C_9H_{16}) (t=7.09, m/z=95) and probability percentage is 45.5%, 3,3,5-trimethyl-Cyclohexene (C_9H_{16}) (t=7.67, m/z=109) and probability percentage is 48.0%, 2,4-dimethyl-2,6-Octadiene ($C_{10}H_{18}$) (t=8.01, m/z=83) and probability percentage is 50.5%, 1,4-dimethyl-5-(1-methylethyl)-Cyclopentene ($C_{10}H_{18}$) (t=8.34, m/z=95) and probability percentage is 18.1%, 2-Methyl-1-nonene ($C_{10}H_{20}$) (t=8.88, m/z=56) and probability percentage is 21.2%, 2-methyl-3-methylene-Nonane ($C_{11}H_{22}$) (t=9.64, m/z=69) and probability percentage is 8.40%, 2-methyl-2-Undecanethiol ($C_{12}H_{26}S$) (t=10.82, m/z=83) and probability percentage is 5.42%, 1-Tetradecene ($C_{14}H_{28}$) (t=11.21, m/z=111) and probability percentage is 3.86%, (1R-cis)-1-(1,2,2,3-tetramethylcyclopentyl)-Ethanone ($C_{11}H_{20}O$) (t=12.66, m/z=69) and probability percentage is 7.21%, 1-Isopropyl-1,4,5-trimethylcyclohexane ($C_{12}H_{24}$) (t=13.21, m/z=69) and probability percentage is 24.1%, 2,3,5,8-tetramethyl-Decane ($C_{14}H_{30}$) (t=13.64, m/z=71) and probability percentage is 9.63%, 3,7,11-trimethyl-1-Dodecanol ($C_{15}H_{32}O$) (t=14.28, m/z=83) and probability percentage is 2.83%, 2-methyl-7-Octadecyne ($C_{19}H_{36}$) (t=15.52, m/z=109) and probability percentage is 5.82%, 1-(3,7-dimethyl-1-octenyl)-

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Cyclopropanol ($C_{13}H_{24}O$) (t=16.33, m/z=69) and probability percentage is 8.14%, Acetic acid, 3,7,11,15-tetramethyl-hexadecyl ester ($C_{22}H_{44}O_2$) (t=17.92, m/z=69) and probability percentage is 3.76%, 1,3,5-trimethyl-2-octadecyl-Cyclohexane ($C_{27}H_{54}$) (t=18.84, m/z=69) and probability percentage is 6.59 %, N-[4-bromo-n-butyl]-2-Piperidinone ($C_9H_{16}BrNO$) (t=19.50, m/z=83) and probability percentage is 13.4%, 1-Nonadecene ($C_{19}H_{38}$) (t=20.24, m/z=69) and probability percentage is 7.35%, 3,7,11,15-tetramethyl-1-Hexadecanol ($C_{20}H_{42}O$) (t=22.16, m/z=69) and probability percentage is 7.47%, 1-cyclopentyl-4-(3-cyclopentylpropyl)-Dodecane ($C_{25}H_{48}$) (t=25.28, m/z=69) and probability percentage is 9.70%. Product fuel has more compounds in to chromatogram with small peak intensity. But largest compounds carbon number was C_{27}. Fuel is ignited and fuel color is light yellow and it can use for internal combustion engine.

Conclusion

Black color non coded food container waste plastic converted in to liquid fuel without using catalyst or chemical. Two step processes was applied in the experiment and fuel product density is 0.76 g/ml. fuel was analysis by GC/MS and hydrocarbon compounds determine form fuel C_3 to C_{27}. Analysis fuel result showed fuel has short and long chain hydrocarbon compounds. In this fuel no benzene group compounds and compounds long chain with branch chain compounds. Most of the single bonds compounds are present in the fuel. In the production process gas percentage was high because two step process. Residue percentages are determined based on plastic inside additive. All plastic manufacturing production additives percentage is not equal, some plastic production additives percentage are using high. According to research study usually plastic production additives are using 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, antistatic agent, and money more reagent. These types of additive are not affecting in the fuel product. Actually all additive are remain as a residue after fuel production finish. Based on this experiment present technology can convert all kinds of none coded waste plastic into liquid hydrocarbon fuel for internal combustion engine. By using this technology can resolve waste plastic problem from environment.

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Reference

[1] Paula A. Costa, Filomena J. Pinto, Ana. M. Ramos, Ibrahim K. Gulyurtlu, Isabel A. Cabrita, and Maria. S. Bernardo, Kinetic Evaluation of the Pyrolysis of Polyethylene Waste, Energy & Fuels 2007, 21, 2489-2498

[2] Shibai Ma, Jun Lu, and Jinsheng Gao, Study of the Low Temperature Pyrolysis of PVC, Energy & Fuels 2002, 16, 338-342

[3] Miskolczi, N.; Bartha, L.; Antal, F.; Dudas, Cs. Talanta 2005, 66, 1264-1271.

[4] Ucüar, S.; Karagoz, S.; Karayildirim, T.; Yanik, J. Polym. Degrad. Stab. 2002, 75, 161-171.

[5] De la Puente, G.; Sedran, U. Appl. Catal., B 1998, 19, 305-311.

[6] Yanik, J.; Uddin, Md. A.; Sakata, Y. Energy Fuels 2001, 15, 163- 69.

[7] Antonio Marcilla, AÄ ngela N. Garcia, and Maria del Remedio Hernandez, Thermal Degradation of LDPE-Vacuum Gas Oil Mixtures for Plastic Wastes Valorization, Energy & Fuels 2007, 21, 870-880

[8] Hernandez, M. R.; Garcia, A. N.; Gomez A.; Agullo, J.; Marcilla, A. Ind. Eng. Chem. Res. 2006, 45, 8770-8778.

[9] Hernandez, M. R.; Gomez A.; Garcia, A. N.; Agullo, J.; Marcilla. Appl. Catal. A: Gen. 2007, 317, 183-194.

[10] Mastral, J. F.; Berrueco, C.; Ceamanos, J. Energy Fuels 2006, 20, 1365-1371.

[11] Hernandez, M. R.; Garcia, A. N.; Marcilla, A. J. Anal. Appl. Pyrol. 2007, 78, 272-281.

[12] Sojak, L.; Kubinec, R.; Jurdakova, H.; Hajekova, E.; Bajus, M. J. Anal. Appl. Pyrol. 2007, 78, 387-399.

[13] Demirbas, A. Energy Sources 2005, 27, 1313-1319.

[14] Demirbas, A. J. Anal. Appl. Pyrol. 2004, 72, 97-102.

[15] J. Aguado, D.P. Serrano, J.M. Escola, E. Garagorri, J.A. Fernandez, Catalytic conversion of polyolefins into fuels over zeolite beta, Polym. Degrad. Stab. 69 (2000) 11–16.

[16] D.P. Serrano, J. Aguado, J.M. Escola, J.M. Rodriguez, L. Morselli, R. Orsi, Thermal and catalytic cracking of a LDPE–EVA copolymer mixture, J. Anal. Appl. Pyrol. 68–69 (2003) 481–494.

[17] C. Breen, P.M. Last, S. Taylor, P. Komadel, Synergic chemical analysis — the coupling of TG with FTIR, MS and GC–MS 2. Catalytic transformation of the gases evolved during the thermal decomposition of HDPE using acid-activated clays, Thermochim. Acta 363 (2000) 93–104.

[18] M.N. Siddiqui, H.H. Redhwi, Pyrolysis of mixed plastics for the recovery of useful products, Fuel Process. Technol. 90 (2009) 545–552.

[19] M.N. Siddiqui, Conversion of hazardous plastic wastes into useful chemical products, J. Hazard. Mater. 167 (2009) 735–742.

[20] M.N. Siddiqui, H.H. Redhwi, Catalytic coprocessing of waste plastics and petroleum residue into liquid fuel oils, J. Anal. Appl. Pyrol. 86 (2009) 141–147.

[21] M. Rasul Jan , Jasmin Shah, Hussain Gulab, Catalytic degradation of waste high-density polyethylene into fuel products using BaCO3 as a catalyst, Fuel Processing Technology, 2010, pp: 1-10, journal homepage: www.elsevi e r.com/locate/fuproc

[22] Aguado, J.; Serrano, D. P.; Escola, J. M.; Garagorri, E. Catal. Today 2002, 75, 257-262.

[23] Van Grieken, R.; Serrano, D. P.; Aguado, J.; Garcia, R.; Rojo, C. J. Anal. Appl. Pyrolysis 2001, 58-59, 127-142.

[24] Williams, P. T.; Williams, E. A. J. Anal. Appl. Pyrolysis 1999, 51, 107-126.

[25] Bagri, R.; Williams, P. T. J. Anal. Appl. Pyrolysis 2002, 63, 29- 41.

[26] Williams, E. A.; Williams, P. T. J. Anal. Appl. Pyrolysis 1997, 40-41, 347-363.

[27] Wallenstein, D.; Harding, R. H. Appl. Catal., A 2001, 214, 11-29.

[28] Bortonovsky, O.; Sazama, P.; Wichterlova, B. Appl. Catal., A 2005, 287, 203-213.

[29] Den Hollander, M. A.; Wissink, M.; Makke, M.; Moulijn, J. A. Appl. Catal., A 2002, 223, 85-102.

[30] Buekens, A. G.; Huang, H. Resour. ConserV. Recycl. 1998, 23, 163-181.

[31] EÄ rij, V.; Rasina M.; Rudin, M. Quimica y Tecnologia del Petroleo y del Gas; Mir: Moscow, 1988.

[32] Arandes, J. M.; Erena, J.; Azkoiti, M. J.; Olazar, M.; Bilbao, J. J. Anal. Appl. Pyrolysis 2003, 70, 747-760.

[33] Ng, S.; Yang, H.; Wang, J.; Zhu, Y.; Fairbridge, C.; Yui, S. Energy Fuels 2001, 15, 783-785.

[34] Atias, J. A.; De Lasa, H. Chem. Eng. Sci. 2004, 59, 5663-5669.