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Research Article

Thermal and Catalytic Treatment of PVC and HDPE Mixture to Fuel using $NaHCO_3$

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Abstract

Thermal and catalytic degradation was performing with polyvinyl chloride (PVC) waste plastic and high density polyethylene (HDPE) mixture using Sodium Bicarbonate ($NaHCO_3$). Raw materials HDPE sample was use 50 gm and PVC sample was use 25 gm by weight. 3% $NaHCO_3$ was use as a catalyst to remove chlorine content and experiment was performed under laboratory fume hood. Experimental temperature range was 150 ºC to 400 ºC and Pyrex glass reactor was use for this experiment. Produce fuel density is 0.77 gm/ml and conversion rate was 70.8% liquid and including light gas. Produce fuel was analysis by Gas Chromatography and Mass Spectrometer (GC/MS Cluras 500) and GC/MS obtain results showed carbon chain C_3-C_{26}. Produce fuel can be use feed stock refinery as a feed.

Keywords: high density polyethylene, polyvinyl chloride, thermal, fuel, catalyst, $NaHCO_3$

1. Introduction

Plastics consumption has drastically increased in the last few decades. Annual consumption of plastics in Occidental Europe is about 60 million tons, yielding almost 23 million tons of plastic wastes per year [1]. At present, in Europe, about 50% of the annually generated plastic wastes are valorized, 60% by incineration with energy recovery and about 40% by recycling. Most of the recycled plastics are mechanically recycled, while less than 1% is chemically recycled [1]. Pyrolysis may be an alternative for increasing the chemical recycling percentage and an opportunity to obtain valuable liquid fuels from plastic wastes [2]. The presence of some PVC in real streams of municipal plastic wastes is still very common. Due to the low consumption of PVC in commodity applications, it is a minority product which is not recovered in the industrial separation and classification plants and therefore usually forms part of the rejected streams of such plants [3, 4]. The objectives of this paper are on the one hand to study and compare several dechlorination methods in the Thermal degradation of PVC containing plastic wastes, and on the other hand to analyze the influence of these methods not only on the chlorine content of the thermal degradation products but also on the characteristics of such products. There are many references in the literature about the thermal decomposition of PVC since it is a polymer which produces hydrogen chloride (HCl) when it is moderately heated, creating toxic and corrosive conditions. Consequently its sustainability has been under discussion for many years [5] and for this reason the thermal behavior and pyrolysis kinetics of both virgin and waste PVC, either alone or mixed with other plastics, have been widely studied and discussed by many authors [6–13]. Liquefaction of waste plastics has been attracting great attention as a key technology to solve environmental protection problems. It has been reported that thermal cracking or acid catalyzed cracking could produce liquid product from plastics, such as polypropylene or polyethylene. However, results to date have produced oils which are waxy and of a very bad quality and, thus, are useful for very limited purposes [14]. The present authors have already reported a new coal-derived disposable catalyst developed for residual oils cracking to produce high quality distillates [15].

2. Materials

Polyvinyl chloride waste plastic and high density polyethylene waste plastic were collected from local city. Collected waste plastic was wash and dried then cut into small pieces for reactor setup. $NaHCO_3$ was collected from VWR.com Company. A high density waste plastic was white color milk container and polyvinyl chloride waste plastic was transparent pipe. Both waste plastic cut into small pieces and size was 1-2 inch. Polyvinyl chloride waste plastic has chlorine content with hydrocarbon mixture and high density polyethylene waste plastic has only long chain hydrocarbon compounds. $NaHCO_3$ was use for chlorine removing and forming as a NaCl salt.

3. Process Description

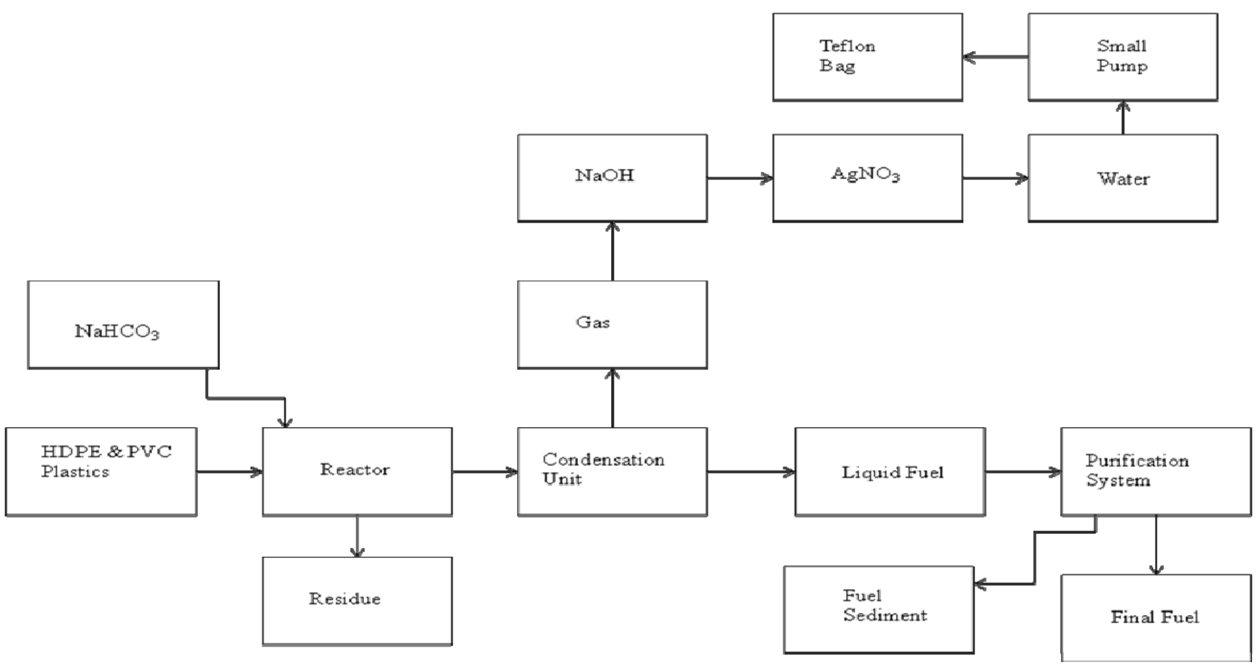

Figure 1: PVC and HDPE waste plastic mixture to fuel production process using $NaHCO_3$

Polyvinyl chloride 25 gm and high density polyethylene 50 gm waste plastics mixture and 3% sodium bicarbonate was place into reactor chamber for liquefaction process (Figure 1). Reactor chamber was place into heat mental then condensation unit was setup, collection container was set up with condensation unit, fuel purification system was setup with collection unit one end and other end was final fuel collection container, fuel sediment was collected from purification unit to sediment container, light gas was collected from condensation unit and light gas was passed through NaOH liquid solution and solution normality was 0.25 N, then light gas passed with $AgNO_3$ solution and solution normality was 0.25 N, then light gas was passed in to clean water system at the end setup small pump with Teflon bag. Polyvinyl chloride waste plastic has chlorine content and chlorine content is 56% by weight and also polyvinyl waste plastic has additives. A high density polyetyelene waste plastic has long chain hydrocarbon compounds with additives. Manufactures are adding additives based on plastics hardness, softness and their requirement. Plastics are made from petroleum and petroleum comes from crude oil. After finish setup experiential procedure properly then temperature ranges start 150 ºC to 400 ºC. Temperature was monitored by variac meter for production quality. 3% $NaHCO_3$ was use as a catalyst and accelerate the reaction. PVC waste plastic has chlorine content and $NaHCO_3$ can react with chlorine content and forming as a sodium chloride salt. PVC and HDPE waste plastic to fuel production process can produce some HCl acid because PVC chlorine and hydrocarbon hydrogen can react and produce HCl. Sometimes temperature was decrease and increased for good quality product. In this process light gas was generated and light gas was mix with chlorine content. Light gas was purified by NaOH solution then $AgNO_3$ solution at the end gas was transferred with clean water to removed chemical properties or impurities. Light gas Chlorine content with NaOH can produce NaCl and light gas with $AgNO_3$ can produce Ag_2Cl_2. Finally light gas can come out as chlorine free those light gas transferred into Teflon bag using small pump system. The process main goal was percentage calculations from PVC and HDPE mixture to fuel production percentage. Produced fuel was filtered using purification system and collected final fuel and fuel sediment during production period. Fuel density is 0.77 gm/ml and mass balance calculation showed from 75 gm mixture to liquid fuel 40.8 gm, light gas generated 12.3 gm and left over residue was 21.9 gm. Sodium Bicarbonate recovers under consideration, light gas and solid black residue analysis is under consideration.

4. Result and Discussion

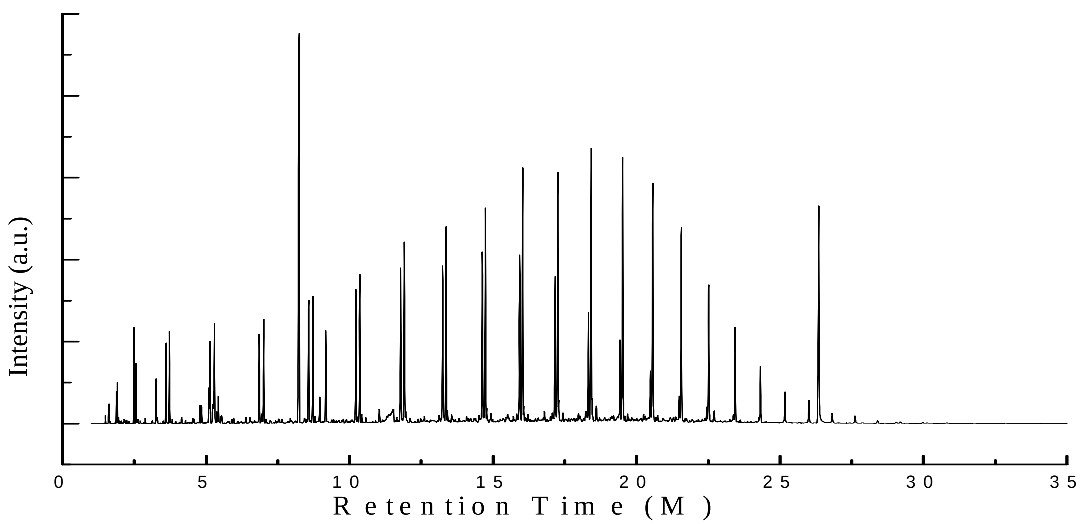

Figure 2: GC/MS Chromatogram of PVC and HDPE waste plastic mixture to fuel

Table 1: GC/MS Chromatogram compound list of PVC and HDPE waste plastic mixture to fuel

Number of Peak	Retention Time (min.)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.49	41	Propane	C_3H_8	44	54.5	18863
2	1.61	43	Butane	C_4H_{10}	58	74.9	18940
3	1.67	41	2-Butene, (E)-	C_4H_8	56	23.7	105
4	1.87	42	Cyclopropane, ethyl-	C_5H_{10}	70	22.2	114410
5	1.91	43	Pentane	C_5H_{12}	72	85.4	114462
6	1.95	55	2-Pentene, (E)-	C_5H_{10}	70	16.6	291780
7	1.99	55	Cyclopropane, 1,1-dimethyl-	C_5H_{10}	70	19.2	114476
8	2.05	67	1,4-Pentadiene	C_5H_8	68	23.0	114494
9	2.17	57	Propane, 2-chloro-2-methyl-	C_4H_9Cl	92	78.3	107667
10	2.24	67	Bicyclo[2.1.0]pentane	C_5H_8	68	20.5	192491
11	2.32	42	1-Pentanol	$C_5H_{12}O$	88	14.6	291529
12	2.43	57	Pentane, 3-methyl-	C_6H_{14}	86	21.6	565
13	2.49	41	1-Hexene	C_6H_{12}	84	31.8	500
14	2.56	57	Hexane	C_6H_{14}	86	85.6	61280
15	2.62	55	3-Hexene, (E)-	C_6H_{12}	84	20.5	19325
16	2.88	56	Cyclopentane, methyl-	C_6H_{12}	84	66.5	114428
17	3.13	67	Cyclopentene, 1-methyl-	C_6H_{10}	82	12.8	107747
18	3.26	78	Benzene	C_6H_6	78	67.5	114388
19	3.30	41	Butane, 2-chloro-2-methyl-	$C_5H_{11}Cl$	106	47.9	58840
20	3.60	41	1-Heptene	C_7H_{14}	98	40.5	107734
21	3.72	43	Heptane	C_7H_{16}	100	71.9	61276
22	3.82	55	2-Heptene, (E)-	C_7H_{14}	98	20.0	932
23	4.15	83	Cyclohexane, methyl-	C_7H_{14}	98	66.1	118503
24	4.29	69	Cyclopentane, ethyl-	C_7H_{14}	98	37.6	940
25	4.37	81	Cyclopropane, trimethylmethylene-	C_7H_{12}	96	10.7	63085
26	4.46	55	Isopropylcyclobutane	C_7H_{14}	98	14.7	113634
27	4.53	81	Cyclopentene, 4,4-dimethyl-	C_7H_{12}	96	8.22	38642
28	4.59	67	Ethanone, 1-(1,2,2,3-tetramethylcyclopentyl)-, (1R-cis)-	$C_{11}H_{20}O$	168	4.00	186082
29	4.71	43	1-Hexene, 3,5,5-trimethyl-	C_9H_{18}	126	7.57	61478
30	4.79	91	Toluene	C_7H_8	92	36.8	291301
31	4.84	43	Heptane, 3-methyl-	C_8H_{18}	114	14.2	34428
32	4.94	67	7-Methylbicyclo[4.2.0]octane	C_9H_{16}	124	10.9	210902
33	5.09	70	Heptane, 3-methylene-	C_8H_{16}	112	53.4	288517
34	5.14	55	1-Octene	C_8H_{16}	112	19.4	1604
35	5.23	55	3-Heptene, 3-methyl-	C_8H_{16}	112	43.2	113088

36	5.29	43	Octane	C_8H_{18}	114	36.6	61242
37	5.38	55	2-Octene, (Z)-	C_8H_{16}	112	19.3	113889
38	5.43	70	2-Heptene, 3-methyl-	C_8H_{16}	112	18.0	149374
39	5.52	55	2-Octene, (Z)-	C_8H_{16}	112	26.2	113889
40	5.55	67	5-Bromo-1-hexene	$C_6H_{11}Br$	162	28.5	113158
41	5.90	41	1,4-Heptadiene, 3-methyl-	C_8H_{14}	110	7.58	1484
42	5.96	83	Cyclohexane, ethyl-	C_8H_{16}	112	55.9	113476
43	6.11	67	Cyclopentene, 1-propyl-	C_8H_{14}	110	11.7	142659
44	6.23	81	1-Nonyne	C_9H_{16}	124	11.1	20577
45	6.31	81	2,4-Octadiene	C_8H_{14}	110	26.5	113458
46	6.39	91	Ethylbenzene	C_8H_{10}	106	38.9	114918
47	6.53	81	Cyclohexene, 1,2-dimethyl-	C_8H_{14}	110	13.3	113912
48	6.86	56	1-Nonene	C_9H_{18}	126	21.9	107756
49	6.95	91	p-Xylene	C_8H_{10}	106	27.9	113952
50	7.01	43	Nonane	C_9H_{20}	128	36.1	249212
51	7.09	55	cis-2-Nonene	C_9H_{18}	126	16.5	113508
52	8.24	55	Heptane, 3-chloro-3-methyl-	$C_8H_{17}Cl$	148	71.3	114670
53	8.58	55	1-Decene	$C_{10}H_{20}$	140	18.5	107686
54	8.73	57	Decane	$C_{10}H_{22}$	142	42.1	291484
55	8.97	57	Heptane, 3-(chloromethyl)-	$C_8H_{17}Cl$	148	65.5	35077
56	9.18	57	1-Hexanol, 2-ethyl-	$C_8H_{18}O$	130	58.9	114109
57	10.23	55	1-Undecene	$C_{11}H_{22}$	154	7.70	5022
58	10.36	57	Undecane	$C_{11}H_{24}$	156	36.5	107774
59	10.42	55	3-Undecene, (Z)-	$C_{11}H_{22}$	154	10.7	142598
60	11.04	43	Acetic acid, 2-ethylhexyl ester	$C_{10}H_{20}O_2$	172	18.7	227968
61	11.52	105	Benzenecarboxylic acid	$C_7H_6O_2$	122	19.0	227847
62	11.78	55	1-Dodecene	$C_{12}H_{24}$	168	17.1	107688
63	11.91	57	Dodecane	$C_{12}H_{26}$	170	35.8	291499
64	11.96	55	3-Dodecene, (E)-	$C_{12}H_{24}$	168	11.0	70642
65	13.25	55	1-Tridecene	$C_{13}H_{26}$	182	19.8	107768
66	13.37	57	Tridecane	$C_{13}H_{28}$	184	47.3	107767
67	13.41	55	5-Tridecene, (E)-	$C_{13}H_{26}$	182	10.8	142619
68	13.56	55	2-Trifluoroacetoxytridecane	$C_{15}H_{27}F_3O_2$	296	4.39	245471
69	14.63	55	1-Tetradecene	$C_{14}H_{28}$	196	7.00	69725
70	14.74	57	Tetradecane	$C_{14}H_{30}$	198	44.2	113925
71	14.78	55	7-Tetradecene	$C_{14}H_{28}$	196	7.70	70643
72	14.92	55	7-Tetradecene	$C_{14}H_{28}$	196	8.28	70643
73	15.93	55	1-Pentadecene	$C_{15}H_{30}$	210	8.59	69726
74	16.04	57	Pentadecane	$C_{15}H_{32}$	212	38.9	107761
75	17.16	55	1-Hexadecene	$C_{16}H_{32}$	224	9.41	69727
76	17.26	57	Hexadecane	$C_{16}H_{34}$	226	41.5	114191
77	17.43	55	Cyclododecane, ethyl-	$C_{14}H_{28}$	196	5.50	61040

78	18.33	55	E-14-Hexadecenal	$C_{16}H_{30}O$	238	7.96	130980
79	18.42	57	Heptadecane	$C_{17}H_{36}$	240	34.1	107308
80	19.43	55	E-15-Heptadecenal	$C_{17}H_{32}O$	252	7.41	130979
81	19.52	57	Octadecane	$C_{18}H_{38}$	254	19.3	57273
82	20.48	55	9-Nonadecene	$C_{19}H_{38}$	266	11.8	113627
83	20.56	57	Nonadecane	$C_{19}H_{40}$	268	28.8	114098
84	21.49	55	5-Eicosene, (E)-	$C_{20}H_{40}$	280	8.08	62816
85	21.57	57	Eicosane	$C_{20}H_{42}$	282	30.2	290513
86	22.45	55	10-Heneicosene (c,t)	$C_{21}H_{42}$	294	11.1	113073
87	22.52	57	Heneicosane	$C_{21}H_{44}$	296	29.8	107569
88	22.71	149	1,2-Benzenedicarboxylic acid, mono(2-ethylhexyl) ester	$C_{16}H_{22}O_4$	278	48.3	75949
89	23.38	55	1-Docosene	$C_{22}H_{44}$	308	14.1	113878
90	23.44	57	Heneicosane	$C_{21}H_{44}$	296	13.3	107569
91	24.32	57	Heneicosane	$C_{21}H_{44}$	296	10.5	107569
92	25.18	57	Tetracosane	$C_{24}H_{50}$	338	16.6	34731
93	26.01	57	Heneicosane	$C_{21}H_{44}$	296	6.74	107569
94	26.35	149	1,2-Benzenedicarboxylic acid, mono(2-ethylhexyl) ester	$C_{16}H_{22}O_4$	278	31.9	291384
95	26.81	57	Hexacosane	$C_{26}H_{54}$	366	12.8	107147

PVC and HDPE waste plastics mixture to fuel was analysis by using GC/MS and detected some compounds based on retention time (M) and trace mass (m/z) (Figure 2 and Table 1). Produce fuel GC/MS analysis result showed hydrocarbon compounds mixture with halogen contain, oxygen contain, alcoholic contain, aromatic derivative and aliphatic group alkane and alkene. GC/MS analysis result starting compounds Propane (C_3H_8) (t=1.49, m/z=41) and final compound was Hexacosane ($C_{26}H_{54}$) (t=26.81, m/z=57). Fuel large peak compounds detected by GC/MS 3-chloro-3-methyl-Heptane ($C_8H_{17}Cl$) (t=8.24, m/z=55). GC/MS analysis compounds table showed produce fuel has some chlorinated compounds, and chlorine content fuel can use for feed stock refinery as a feed. Fuel was ignited and fuel color was light yellow. Perkin Elmer GC/MS compounds detection library was followed NIST library. Some compounds are elaborated from above analysis table with retention time versus trace mass, compounds molecular weight and probability percentage such as Butane (C_4H_{10}) (t=1.61, m/z=43) Compound molecular weight 58 and probability 74.9 %, Pentane (C_5H_{12}) (t=1.91, m/z=43) Compound molecular weight 72 and probability 85.4 %, 2-chloro-2-methyl- Propane (C_4H_9Cl) (t=2.17, m/z=57) Compound molecular weight 92 and probability 78.3 %, Hexane (C_6H_{14}) (t=2.56, m/z=57) Compound molecular weight 86 and probability 85.6 %, Benzene (C_6H_6) (t=3.26, m/z=78) Compound molecular weight 78 and probability 67.5 %, methyl-Cyclohexane (C_7H_{14}) (t=4.15, m/z=83) Compound molecular weight 98 and probability 66.1 %, 4,4-dimethyl-Cyclopentene (C_7H_{12}) (t=4.53, m/z=81) Compound molecular weight 96 and probability 8.22 %, Toluene (C_7H_8) (t=4.79, m/z=91) Compound molecular weight 92 and probability 36.8 %, 3-methyl-3-Heptene (C_8H_{16}) (t=5.23, m/z=55) Compound molecular weight 112 and probability 43.2%, 5-Bromo-1-hexene ($C_6H_{11}Br$) (t=5.55, m/z=67) Compound molecular weight 162 and probability 28.5 %, Ethylbenzene (C_8H_{10}) (t=6.39, m/z=91) Compound molecular weight 106 and probability 38.9 %, p-Xylene (C_8H_{10}) (t=6.95, m/z=91) Compound molecular weight

106 and probability 27.9 %, 2-ethyl-1-Hexanol ($C_8H_{18}O$) (t=9.18, m/z=57) Compound molecular weight 130 and probability 58.9 %, Benzenecarboxylic acid ($C_7H_6O_2$) (t=11.52, m/z=105) Compound molecular weight 122 and probability 19.0 %, (E)- 5-Tridecene ($C_{13}H_{26}$) (t=13.41, m/z=55) Compound molecular weight 182 and probability 10.8 %, Tetradecane ($C_{14}H_{30}$) (t=14.74, m/z=57) Compound molecular weight 198 and probability 44.2 %, 1-Hexadecene ($C_{16}H_{32}$) (t=17.16, m/z=55) Compound molecular weight 224 and probability 9.41 %, Heptadecane ($C_{17}H_{36}$) (t=18.42, m/z=57) Compound molecular weight 240 and probability 34.1 %, Octadecane ($C_{18}H_{38}$) (t=19.52, m/z=57) Compound molecular weight 254 and probability 19.3 %, Nonadecane ($C_{19}H_{40}$) (t=20.56, m/z=57) Compound molecular weight 268 and probability 28.8 %, Heneicosane ($C_{21}H_{44}$) (t=22.52, m/z=57) Compound molecular weight 296 and probability 29.8 %, Tetracosane ($C_{24}H_{50}$) (t=25.18, m/z=57) Compound molecular weight 338 and probability 16.6 %. HDPE and PVC mixture to fuel has chlorine content compounds and chlorine have to remove from fuel before run combustion engines further refinery process.

5. Conclusion

Catalytic degradation of PVC and HDPE waste plastic mixture to fuel production process observed that during fuel production period huge amount of gas was generated inside glass reactor. Fuel production was monitored with precaution because chlorinated gas is harmful for human body. Gas was condensed with standard condensation system and produced liquid fuel with light gas. Fuel analysis result showed C_3-C_{26} carbon compounds including other different types of compounds. Produce fuel has aromatics derivative such as benzene, Toluene, Ethylbenzene, p-Xylene. Fuel odor was chlorinated and it was ignited. PVC and HDPE mixture can produce fuel using sodium bicarbonate and solve the PVC and HDPE waste plastic problem from environmental. Fuel can be use for refinery process and feed for power plant.

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