

Transforming Fuel from Municipal Waste Plastic using Nickel Silica {Ni (SiO₂)} Catalyst

Moinuddin Sarker*, Mohammad Mamunor Rashid and Muhammad Sadikur Rahman

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

*E-mail: msarker@naturalstateresearch.com

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ABSTRACT

Plastics in general have many advantages and disadvantages. Due to plastics lightweight and durability its practice is very efficient in all sectors of the world. Plastics are initially produced from petroleum which derives from crude oil. However, once plastics are discarded after use, they end up in land and ocean creating many sorts of environmental and health related problems because the waste plastics do not bio-degrade. Since they derive from petroleum, so when the plastics become abundant the natural source becomes lost. To remove these waste plastics from landfill requires huge amount of money and land. The scientific societies in the world today are conducting research to find alternate ways to the current limited energy source. The particular experiment explained in this paper discusses the utilization of waste plastics into liquid hydrocarbon fuel using nickel silica catalyst. Since, waste plastics are available at disposal; it becomes feasible for raw materials for the fuel production process. The process utilized thermal degradation with catalytic process at temperature 50-400 °C under atmospheric pressure in present of oxygen. The produced liquid hydrocarbon fuel is tested and proven to be compatible with all types of internal combustion engines such as transportation vehicles and generators.

Key words: fuel, waste plastic, catalyst, thermal degradation, transforming, GC/MS.

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INTRODUCTION

Polymers are becoming a necessity in modern life in many Western countries. Their discovery and subsequent utilization meant that by the mid 1960s total world consumption of thermoplastics alone was 13 million tonnes with an increasing number of applications being found for these materials, today the demand for the main commodity thermoplastics is more than 70 million tonnes [1]. Although a significant amount of the thermoplastics are utilized in products with a long life span, the majority are used in short term applications such as packaging. Thus, the quantity of thermoplastics found in waste is increasing correspondingly. Plastic waste can originate from a multitude of sources. The major areas of waste creation are from the distribution industries representing 21.7% of all plastic waste [2] and municipal solid waste (MSW) which accounts for 60.4 % [2]. Waste plastics contribute to great environmental and social problems due to the loss of natural resources, environmental pollution, depletion of landfill space on the one hand and demands of environmentally-oriented society on the other hand. Production of plastics in the world amounted to about 230–250 million tones in 2005 (only in the EU to about 45–50 million tones) [3, 4]. Similar data may be given for other developed countries, the USA, Japan and China. In Japan, the consumption of plastics amounted to more than 10 million tones/per year in 2004 [5] and in China rose from 23 (in 2000) to 31.2 million metric tons in 2003, with an average annual growth rate of 11.8% [6]. In Poland, plastics consumption (without chemical fibers) exceeded 1.67 million tons in 2007 and over 75% of them were polyolefins.

The consumption of plastics per capita differs very much in the world even in developed countries; in Europe the consumption of plastics was about 24–150 kg/person in the years 2003–2005 while 10 years earlier the average consumption in the EU had been about 50–60 kg/person [2, 6]; in Poland it was about 45 kg/person in 2007 [7]. The amount of post-consumer plastics was estimated for 22–25 million tones only in EU, in 2005 [4, 8]. They represent only 7–9% of total wastes in terms of mass but 30% in terms of volume (in household wastes). Their amount has been increasing 6–7% year by year and will be increasing due to low consumption of plastics in developing countries [3, 9, 10]. The main part (over 70% by mass) of household waste plastics stream are polyolefins (LDPE, HDPE, LLDPE, PP), and polystyrene (PS).

At present, it is almost impossible to dispose of waste plastics by landfill due to the law, high costs, and higher ecological consciousness of people. However, there are also some technological and economic constrains that limit the full and efficient recycling of plastic wastes into useful products, e.g. contaminated waste plastics can be only partly recycled into new products and reuse of packaging containers is limited by the collection systems. Mechanical recycling that probably is the best way of reclaiming plastics refers to the processes which involve sorting,

shredding or melting and re-granulation. It may be applied only for the same type and clean plastics. Up to the present moment, energy recovery by incineration has seemed to be the second attractive option for waste plastics utilization that takes advantage of the high energy content of plastics and reducing the garbage volumes by over 90%. However, sometimes, it was questioned due to the lack of raw materials recovery, the low thermodynamic efficiency, the possible emission of toxic gaseous compounds and necessity of purification of flue gases that is difficult and expensive. Even though, current technologies would conform the emission requirements, incineration arouses almost always public resistance and objections [4, 11, 12].

MATERIALS AND METHODS

Raw Sample Collection

Waste plastic collection from local supermarkets, grocery stores and offices. In particular the waste plastic were white color milk containers, coffee cups, black and white color shopping bags, black and white color food containers, white color food plates etc.

Raw Sample Preparation

After collection, the waste plastic samples were separated out from foreign particle such as dust, paper, food particle and etc. Then the waste plastics were washed with liquid detergent. Washed waste plastics were put into lab floor for air dry. Dried waste plastic were cut into sample pieces using a grinder machine. Sample sizes are usually 2-3 mm. These grounded waste plastics were placed into the reactor chamber prior to the experimental procedure.

Pre-Sample Analysis

Before the plastics are put into the reactor they are pre-analyzed using GC/MS with pyroprobe, FT-IR (Spectrum-100), TGA (Pyris-1). GC/MS and pyroprobe analysis indicates different hydrocarbon chain compound with different retention time in the waste plastics. The pre-analysis of the raw plastic's hydrocarbon chain compounds indicate mostly double bond compounds. A FT-IR spectrum is showing various types of functional groups are present in the waste plastics. TGA indicates the type of onset temperature needed for melting the waste plastics for conversion into fuel.

Process Description

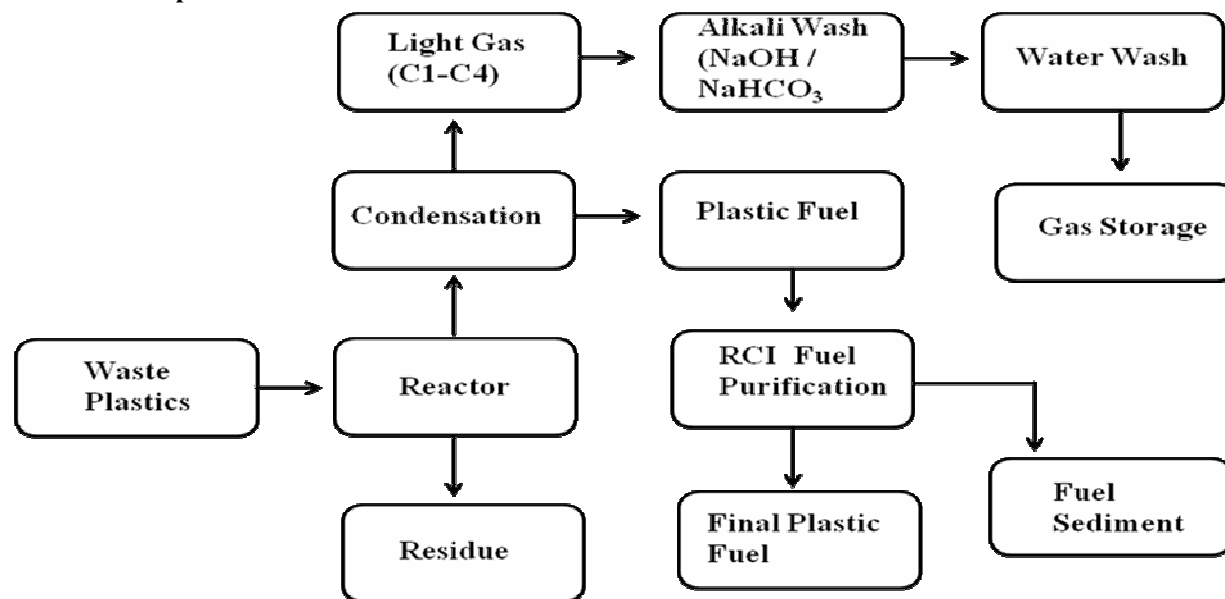


Fig. -1: Waste plastic to fuel production process by using nickel silica {Ni (SiO₂)} catalyst

A thermal degradation with catalytic process at temperature 50-400 °C under atmospheric pressure is utilized to convert the waste plastic into fuel. Sample used were 4 types of mix waste plastics, high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP) and polystyrene (PS). 500 gm -1 kilogram of the plastics were used for the experimental purpose. Reactor temperature range can go up to 500 °C. 20 % of each

LDPE-4, 20% HDPE-2, 35% PP-5 and 25% PS-6 used and 10% Ni (SiO₂) catalyst was used to conduct the experiment. Waste plastic grinded sample were put into reactor chamber with Ni(SiO₂) catalyst. Heating starts from 50°C temperature to up to 400 °C. When waste plastic starts to melt due to increasing the temperature the melted waste plastic turns into liquid and the condensed liquid turns into vapor. The vapor then passes through a condenser unit and it turns into a liquid form plastic fuel (See fig.1).

The waste plastic to fuel yield rate is 87% and its density is 0.80 g./ml. Ni (SiO₂). The nickel catalyst reaction is monitored. It was observed that it is only accelerating the degradation process but is not alternating or creating any reaction with the waste plastics. During plastic conversion into fuel all vapor are not able to turn into liquid fuel and being released out as a light gas (C₁-C₄) because this gas's boiling point is minus (- °C) temperature. A NaOH/NaHCO₃ solution with alkali wash is used to clean the light gas. The light gas is 8% of the total production process. The produced plastic fuel passes through RCI fuel purification unit and due to the centrifugal force the fuel is cleaned of water and sediments. Activated carbon is used to remove color dye from waste plastics because during plastic production period plastic industries use up to 3% additive for different shape of model. About 5% solid residue recovered from the production process. Experimental took about 5 hour and 30 minutes.

RESULTS AND DISCUSSION

A FT-IR spectrum-100 (Perkin Elmer) analysis spectrum of the produced fuel is shown in fig.2 and table1. NaCl cell is used for analysis with scan number took 32, resolution 4 cm⁻¹ and spectrum range of 4000-400 cm⁻¹. Form analysis of produce sample we noticed that in different wave number different types of functional group is appearing in the spectrum. Also in different band on spectrum field various number of distinct wave number is present. In wave number 3621.10 (cm⁻¹), compound is free OH, consequently wave number 2949.62 (cm⁻¹), 2729.43 (cm⁻¹) and 2671.38 (cm⁻¹) compound is C-CH₃, wave number 2209.89 (cm⁻¹), compound is C-C=C-CH then consecutively wave number 1871.17 (cm⁻¹), 1814.75 (cm⁻¹), 1798.94 (cm⁻¹), 1741.96 (cm⁻¹), 1641.81 (cm⁻¹) and 1631.05 (cm⁻¹) compound is Non-Conjugated, wave number 1604.18 (cm⁻¹) compound is Conjugated and uniquely wave number 1440.24 (cm⁻¹), compound is CH₂, wave number 1376.69 (cm⁻¹), compound is CH₃, wave number 1029.99 (cm⁻¹), compound is Secondary Cyclic Alcohol. In addition wave number 989.98 (cm⁻¹), 907.37 (cm⁻¹) compound is -CH=CH₂, wave number 728.40 (cm⁻¹), 699.65 (cm⁻¹) and 676.28 (cm⁻¹) compound is -CH=CH- (cis) as well. Energy values are calculated for each functional group such as functional group C-CH₃, calculated energy value is 5.42x10⁻²⁰ J, following way functional group C-C=C-H energy value is 4.38x10⁻²⁰ J, functional group CH₃, energy value is 2.86x10⁻²⁰ J. Subsequently functional group CH₂, energy value is 2.73x10⁻²⁰ J and functional group -CH=CH₂, energy value is 1.80x10⁻²⁰J, functional group -CH=CH-(cis), calculated energy value is 1.45x10⁻²⁰ J respectively.

Table-1: FT-IR spectra functional group of waste plastic to fuel

Number of Wave	Wave Number (cm ⁻¹)	Functional Group	Number of Wave	Wave Number (cm ⁻¹)	Functional Group
3	3621.10	Free OH	17	1631.05	Non-Conjugated
4	2949.62	C-CH ₃	18	1604.18	Conjugated
5	2729.43	C-CH ₃	21	1440.24	CH ₂
6	2671.38	C-CH ₃	22	1376.69	CH ₃
9	2209.89	C-C= -C-CH	27	1029.99	Sec. Cyclic Alcohol
12	1871.17	Non-Conjugated	28	989.98	-CH=CH ₂
13	1814.75	Non-Conjugated	29	907.37	-CH=CH ₂
14	1798.94	Non-Conjugated	33	728.40	-CH=CH- (cis)
15	1741.96	Non-Conjugated	34	699.65	-CH=CH- (cis)
16	1641.81	Non-Conjugated	35	676.28	-CH=CH- (cis)

Obtained fuel analysis purposes GC column was used (Perkin Elmer elite-5MS length 30 meter, 0.25 mm ID, 0.5um df , maximum program temperature 350 °C and minimum bleed at 330 °C (cat.# N9316284) and also it can be used -60 °C. Capillary column internal silica coating of viscous liquid such as carbowax or wall bonded organic materials.) For Perkin Elmer GC/MS operation carrier gas as Helium was used. GC methods initial temperature is 40 °C and initial hold for 1 minute. Temperature ramping rate is 10°C/minutes up to 325 °C and hold for 15 minutes at 325 °C. Total experiment run time is 44.50 minutes. MS method setup for sample analysis MS scan time 1 to 44.50 minutes and mass detection 35- 528 EI+ centroid. Internal scan time is 0.15 second. Mass detection is creating m/z ratio. From GC/MS analysis (shown fig.3 and table 2) we found the starting compound C₅ with retention time

1.91 and compound name is cyclopropane, ethyl- (C_5H_{10}), molecular weight 70 and trace mass 42. We used 4 types of waste plastic for the experiment. Among four (4) types, polystyrene has benzene related compounds. When the polystyrene is mixed with other long chain hydrocarbon compound of waste plastics in presence of heat and pressure it forms Benzene compound (C_6H_6) and molecular weight of 78. GC/MS detects at retention time 4.87 and trace mass 41, compound is Toluene (C_7H_8) and molecular weight is 92. Ethylbenzene (C_8H_{10}) compound derived at retention time 6.49 and trace mass 91, molecular weight 106. Styrene (C_8H_8) molecular weight is 104. Retention time 8.57 and trace mass 117, compounds is α -Methylstyrene (C_9H_{10}) and molecular weight is 118. Heptacosane ($C_{27}H_{56}$) long chain hydrocarbon compound found at retention time 25.23 minutes and trace mass 57 and this compound molecular weight is 380. From GC/MS analysis we found most of the compounds are aliphatic and olefin compound. The compounds start at shorter hydrocarbon chain carbon number C_5 and increase as boiling point range increases up to hydrocarbon chain compound carbon number C_{27} . In the detailed hydrocarbon analysis of Gas Chromatography and Mass Spectrometer various hydrocarbon compounds are appeared in the analysis some of the compound are described in according to the retention time trace masses. Earlier phase of the analysis index in accordance with retention time and trace mass such as retention time 2.36 and trace mass 43, compound is Pentane-2-methyl- (C_6H_{14}), retention time 2.68 and trace mass 41, compound is 2-Butene,2,3-Methyl- (C_6H_{12}), retention time 3.11 and trace mass 56, compound is 1-Pentene,2,4-Dimethyl- (C_7H_{14}), retention time 3.66 and trace mass 41, compound is 1-Heptene (C_7H_{14}), retention time 4.83 and trace mass 43, compound is Heptane,4-methyl- (C_8H_{18}), retention time 5.21 and trace mass 41, compound is 1-Octene (C_8H_{16}), retention time 6.07 and trace mass 70, compound is 2,4-Dimethyl-1-heptene (C_9H_{18}), retention time 7.04 and trace mass 51, compound is styrene (C_8H_8), retention time 8.65 and trace mass 41, compound is 1-Decene ($C_{10}H_{20}$), retention time 8.99 and trace mass 43, compound is Nonane,2,6-dimethyl- ($C_{11}H_{24}$), retention time 9.79 and trace mass 83 2-Decene,2,4-dimethyl- ($C_{12}H_{24}$), retention time 10.92 and trace mass 83, compound is 9-Eicosyne ($C_{20}H_{38}$), retention time 11.42 and trace mass 91, compound is Benzene, pentyl- ($C_{11}H_{16}$), retention time 11.98 and trace mass 43, compound is Dodecane ($C_{12}H_{26}$), retention time 12.68 and trace mass 43, compound is Decane,2,3,5,8-Tetramethyl- ($C_{14}H_{30}$), retention time 13.46 and trace mass 43, compound is 1-Nonene,4,6,8-trimethyl- ($C_{12}H_{24}$) etc.

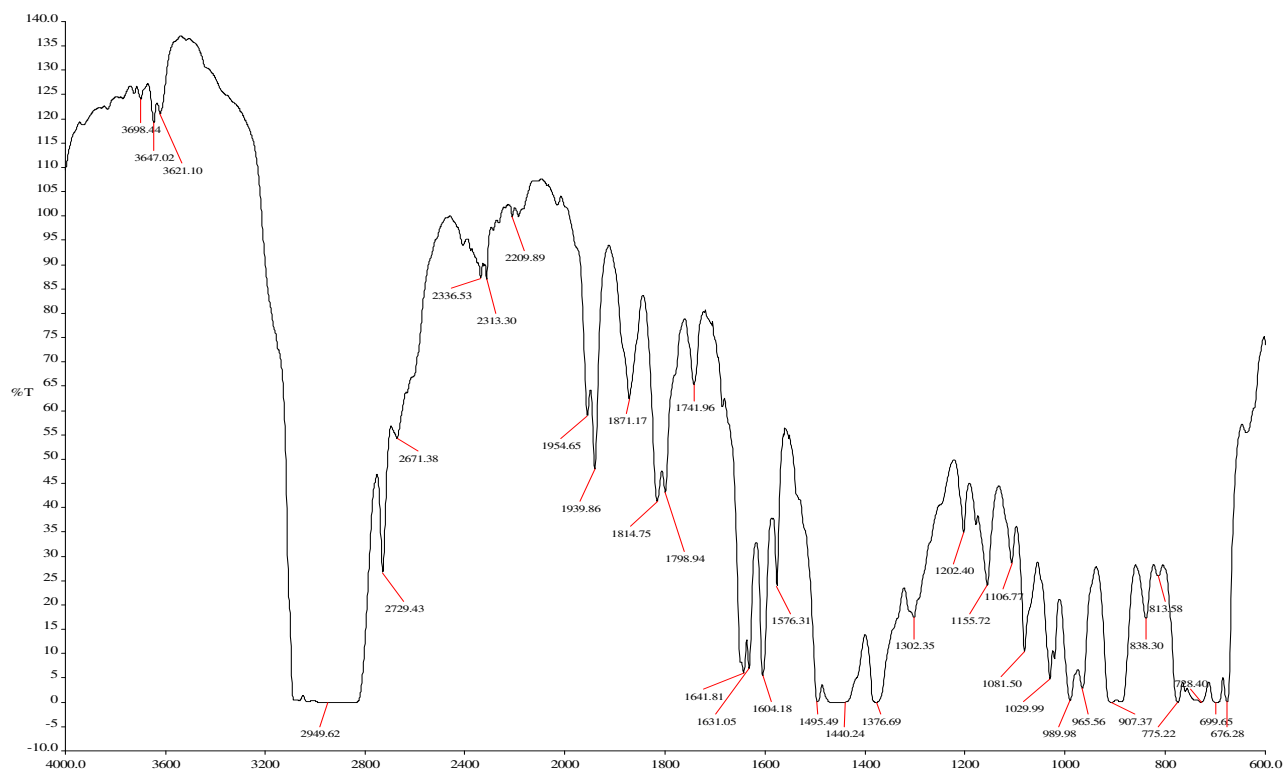


Fig.-2: FT-IR spectra of waste plastic to fuel

At the end phase of the analysis index at retention time 14.80 and trace mass 57, compound is Tetradecane ($C_{14}H_{30}$), retention time 15.99 and trace mass 41, compound is 1-Pentadecane ($C_{15}H_{30}$), retention time 16.77 and trace mass 43,

compound is Isotridecanol- (C₁₃H₂₈O), retention time 18.93 and trace mass 91, compound is Benzene, 1,1'-(2-butene-1,4-diyl) bis-(Benzene, 1,1'-(2-butene-1,4-diyl) bis-(C₁₆H₁₆), retention time 19.57 and trace mass 57, compound is Octadecane (C₁₈H₃₈), retention time 20.62 and trace mass 57, compound is Nonadecane (C₁₉H₄₀), retention time 21.76 and trace mass 204, compound is 2-Phenylnaphthalene (C₁₆H₁₂), retention time 22.97 and trace mass 218, compound is 9-Phenyl-5H-benzocycloheptene (C₁₇H₁₄), retention time 25.87 and trace mass 91, compound is (2,3-Diphenylcyclopropyl) methyl phenyl sulfoxide, trans-(C₂₂H₂₀OS) and ultimately retention time 26.07 and trace mass 57, compound is Tetracosane (C₂₄H₅₀) etc. In the analysis noticed that some oxygen and sulfur compound are produced because during reaction in the reactor sulfur and oxygen compound are formed and trace amounts of compounds are mixed with fuel as well. Differential Scanning Calorimeter (Perkin Elmer, DSC) used to measure the boiling (Fig.4) and enthalpy value of the produced fuel. DSC analysis uses N₂ gas as a carrier gas and a 50 micro ml aluminum sample pan. Program temperature range starts from 10 °C to 400 °C and at a ramping rate of 10 °C per minute. Total sample run time was 39 minutes. From this analysis we found some information for this produced fuel onset temperature is 92.71 °C, peak 162.09 °C, peak height 14.2957 mW, enthalpy Delta H value is 9690.5868 J/g.

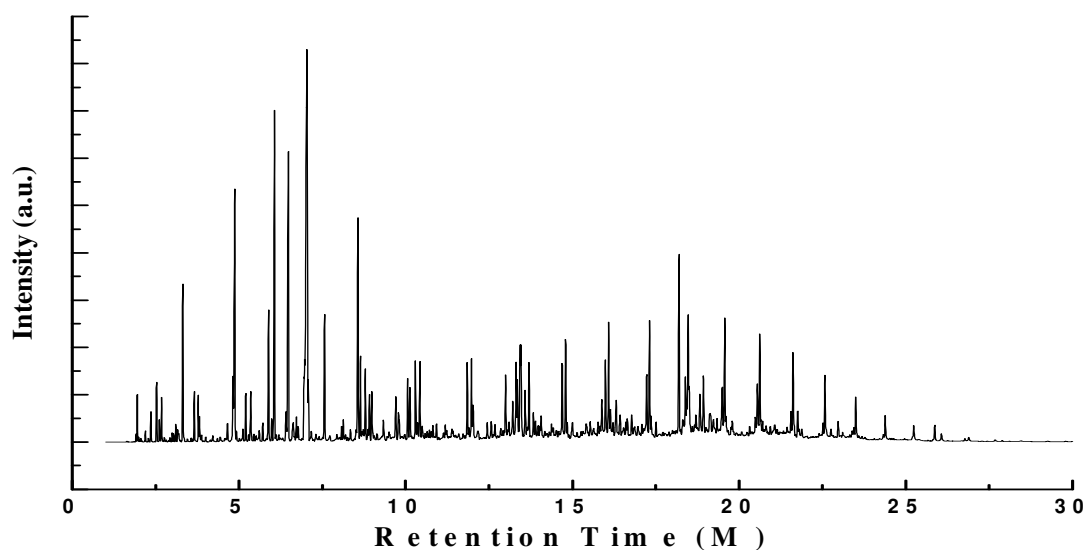


Fig.-3: GC/MS Chromatogram of waste plastic to fuel

Table-2: GC/MS Chromatogram compound list of waste plastic to fuel

Number of Peak	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight
1	1.91	42	Cyclopropane, ethyl-	C ₅ H ₁₀	70
2	1.95	43	Pentane	C ₅ H ₁₂	72
3	2.36	43	Pentane, 2-methyl-	C ₆ H ₁₄	86
4	2.54	41	1-Hexene	C ₆ H ₁₂	84
5	2.68	41	2-Butene, 2,3-dimethyl-	C ₆ H ₁₂	84
6	3.11	56	1-Pentene, 2,4-dimethyl-	C ₇ H ₁₄	98
7	3.32	78	Benzene	C ₆ H ₆	78
8	3.66	41	1-Heptene	C ₇ H ₁₄	98
9	3.78	43	Heptane	C ₇ H ₁₆	100
10	4.83	43	Heptane, 4-methyl-	C ₈ H ₁₈	114
11	4.87	92	Toluene	C ₇ H ₈	92

12	5.21	41	1-Octene	C ₈ H ₁₆	112
13	5.35	43	Octane	C ₈ H ₁₈	114
14	5.71	43	Heptane, 2,4-dimethyl-	C ₉ H ₂₀	128
15	5.89	83	2,3-Dimethyl-3-heptene	C ₉ H ₁₈	126
16	6.07	70	2,4-Dimethyl-1-heptene	C ₉ H ₁₈	126
17	6.49	91	Ethylbenzene	C ₈ H ₁₀	106
18	7.04	51	Styrene	C ₈ H ₈	104
19	7.56	105	Benzene, (1-methylethyl)-	C ₉ H ₁₂	120
20	8.08	91	Benzene, propyl-	C ₉ H ₁₂	120
21	8.13	57	Nonane, 4-methyl-	C ₁₀ H ₂₂	142
22	8.35	105	Benzene, 1-ethyl-3-methyl-	C ₉ H ₁₂	120
23	8.57	117	α -Methylstyrene	C ₉ H ₁₀	118
24	8.65	41	1-Decene	C ₁₀ H ₂₀	140
25	8.79	43	Decane	C ₁₀ H ₂₂	142
26	8.99	43	Nonane, 2,6-dimethyl-	C ₁₁ H ₂₄	156
27	9.29	55	2,6-Octadien-1-ol, 2,7-dimethyl-	C ₁₀ H ₁₈ O	154
28	9.33	117	1,3-Methanopentalene, 1,2,3,5-tetrahydro-	C ₉ H ₁₀	118
29	9.71	83	2-Undecanethiol, 2-methyl-	C ₁₂ H ₂₆ S	202
30	9.79	83	2-Decene, 2,4-dimethyl-	C ₁₂ H ₂₄	168
31	10.30	41	3-Undecene, (Z)-	C ₁₁ H ₂₂	154
32	10.43	57	Undecane	C ₁₁ H ₂₄	156
33	10.92	83	9-Eicosyne	C ₂₀ H ₃₈	278
34	11.19	69	1,12-Tridecadiene	C ₁₃ H ₂₄	180
35	11.39	130	4,7-Methano-1H-inden-1-ol, 3a,4,7,7a-tetrahydro-, acetate	C ₁₂ H ₁₄ O ₂	190
36	11.42	91	Benzene, pentyl-	C ₁₁ H ₁₆	148
37	11.85	41	1-Dodecene	C ₁₂ H ₂₄	168
38	11.98	43	Dodecane	C ₁₂ H ₂₆	170
39	12.45	43	Decane, 2,3,5,8-tetramethyl-	C ₁₄ H ₃₀	198
40	12.57	43	Dodecane, 2,6,10-trimethyl-	C ₁₅ H ₃₂	212
41	12.68	43	Decane, 2,3,5,8-tetramethyl-	C ₁₄ H ₃₀	198
42	13.00	83	3-Decene, 2,2-dimethyl-, (E)-	C ₁₂ H ₂₄	168
43	13.21	83	7-Tetradecene	C ₁₄ H ₂₈	196
44	13.31	41	3-Tridecene, (E)-	C ₁₃ H ₂₆	182
45	13.46	43	1-Nonene, 4,6,8-trimethyl-	C ₁₂ H ₂₄	168
46	14.69	41	4-Tetradecene, (E)-	C ₁₄ H ₂₈	196
47	14.80	57	Tetradecane	C ₁₄ H ₃₀	198
48	15.99	41	1-Pentadecene	C ₁₅ H ₃₀	210
49	16.09	57	Pentadecane	C ₁₅ H ₃₂	212
50	16.77	43	Isotridecanol-	C ₁₃ H ₂₈ O	200
51	17.23	41	1-Hexadecene	C ₁₆ H ₃₂	224
52	17.31	57	Hexadecane	C ₁₆ H ₃₄	226
53	18.20	92	Benzene, 1,1'-(1,3-propanediyl) bis-	C ₁₅ H ₁₆	196
54	18.47	57	Heptadecane	C ₁₇ H ₃₆	240

55	18.82	83	1-Nonadecanol	C ₁₉ H ₄₀ O	284
56	18.93	91	Benzene, 1,1'-(2-butene-1,4-diyl) bis-	C ₁₆ H ₁₆	208
57	19.14	69	tert-Hexadecanethiol	C ₁₆ H ₃₄ S	258
58	19.50	55	E-7-Octadecene	C ₁₈ H ₃₆	252
59	19.57	57	Octadecane	C ₁₈ H ₃₈	254
60	20.55	203	Pyrene, 4,5-dihydro-	C ₁₆ H ₁₂	204
61	20.62	57	Nonadecane	C ₁₉ H ₄₀	268
62	21.55	55	1-Docosene	C ₂₂ H ₄₄	308
63	21.61	57	Eicosane	C ₂₀ H ₄₂	282
64	21.76	204	2-Phenyl-naphthalene	C ₁₆ H ₁₂	204
65	22.58	57	Heneicosane	C ₂₁ H ₄₄	296
66	22.97	218	9-Phenyl-5H-benzocycloheptene	C ₁₇ H ₁₄	218
67	25.23	57	Heptacosane	C ₂₇ H ₅₆	380
68	25.87	91	(2,3-Diphenylcyclopropyl) methyl phenyl sulfoxide, trans-	C ₂₂ H ₂₀ OS	332
69	26.07	57	Tetracosane	C ₂₄ H ₅₀	338

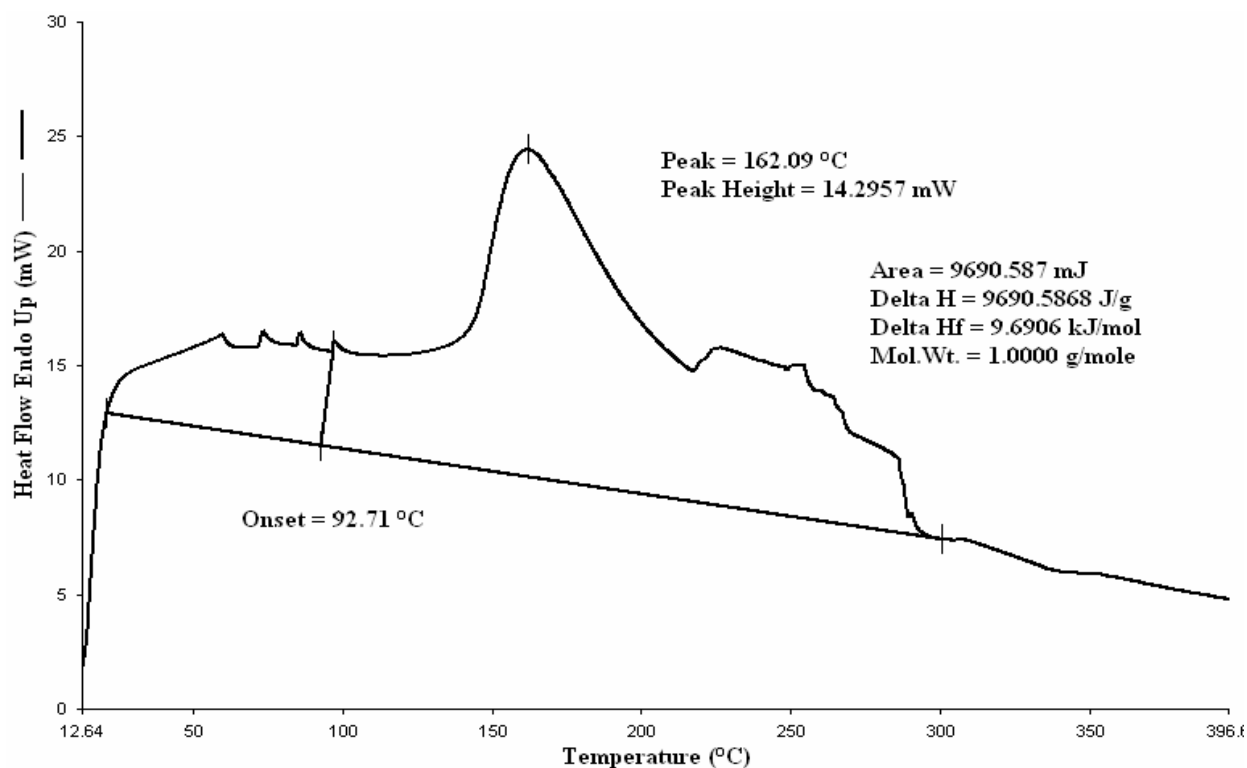


Fig.-4: DSC graph of waste plastic to fuel

CONCLUSION

In this experiment thermal degradation with nickel silica catalytic cracking of high and low density polyethylene, polypropylene and polystyrene mixture activity was observed. GC/MS analysis is showing first carbon peak at C₅. With Nickel Silica catalyst added to the production process almost 8% gas products were formed from HDPE, LDPE, PP and PS cracking with hydrocarbons (C₁-C₄) with a high proportion of olefins. In the polypropylene and polystyrene degradation, the order of activity is strongly modified compared to the low and high density polyethylene plastics. The product distribution of the polypropylene and polystyrene cracking over these catalysts is

qualitatively similar to those of HDPE and LDPE with liquid hydrocarbon mixtures as predominant products. Polypropylene has a $-CH_3$ group and polystyrene has a benzene ring compound. All analysis results show that mixture sample material with promising catalytic properties for the conversion of polymeric wastes into liquid feedstock for refinery. The maximum yield of the conversion fuel and the lowest residue obtained at 400 °C, which is also the temperature corresponding to the maximum cracking rate of polyolefin's. The produce fuel has a high concentration of aromatics, and the gases are mainly methane, ethane propylene and butanes.

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REFERENCES

1. Prospects for Plastics. Shell Briefing SC&c. Leaflet No. I, (1993)
2. APME. Plastics Recovery, in: Rrspective: Plastics Consumption and Rceovry in Western Europe 1989- 1991. Association of Plastics Manufacturers in Europe (APME), Brussels, (1991)
3. Scheirs J., Kaminski W.(Eds.). Feedstock recycling and pyrolysis of waste plastics: converting waste plastics into diesel and other fuels, Wiley series in polymer sciences. John Wiley & Sons, Ltd; (2006)
4. Aguado J., Serrano D. P., Escola M. J., Ind Eng Chem Res, **47(21)** (2008) 7982.
5. Nishino J., Itoh M., Fujiyoshi H., Uemichi Y., Fuel, **87** (2008) 3681.
6. Xiao R., Jin B., Zhou H., Zhong Z., Zhang M., Energy Convers Manage, **48** (2007) 778.
7. Statistical Yearbook of the Republic of Poland. GUS, Warsaw; (2008)
8. Spokas K., Waste Manage, **26** (2008) 473.
9. Williams P. T., Slaney E., Resour Conserv Recycl, **51** (2007) 754.
10. Achilles D. S., Roupakias C., Megalokonomosa P., Lappas A. A., Antonakou E. V., J Hazard Mater, **149** (2007) 536.
11. Stelmachowski M., Thermo-catalytic degradation of waste polymers , Polish Academy of Sciences (PAN), The Committee of Environmental Protection, Lodz; (2003). ISBN 83-86492-19-8.
12. Siddique R., Khatib J., Kaur I., Waste Manage, **28** (2008) 1835.

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