BIOINFO Renewable & Sustainable Energy
ISSN: 2249-1694 & E-ISSN: 2249-1708, Volume 2, Issue 1, 2012, pp.-05-11.
Available online at http://www.bioinfo.in/contents.php?id=299

HEAVY OIL PRODUCED FROM MUNICIPAL MIXED WASTE PLASTICS BY FRACTIONAL DISTILLATION PROCESS

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Received: April 27, 2012; Accepted: May 10, 2012

Abstract- Waste plastics found in our landfill are renewable energy sources that are capable of producing energy. After plastics are used and discarded, they become a problem for the environment and ecosystem they are very troublesome to get rid off. Waste plastics are non-biodegradable so, they occupy landfill for a long period of time. When waste plastic come in contact with light and starts photo degrading, it starts releasing harmful compounds like carbon monoxide, nitrogen sulfide and sulfur dioxide in the environment. USA alone generate 48 million ton of waste plastics per year. The developed a thermal degradation method to convert waste plastics into liquid hydrocarbon fuel energy. The technology plans to collect waste plastics from municipalities for the fuel production process. It will not only help the municipality to save a lot of money but it will also help the environment at the same time. The fuel can be produced at low cost, since the resource is already at disposal. The technology produced heavy fuel is capable of operating of internal combustion engines including ship, heavy generator and so on. The technology will be able create many jobs to the locals, once the commercialization plant is established .
Key words- Heavy oil, thermal, waste plastics, fractional distillation, GC/MS, Fuel

Citation: Moinuddin Sarker, et al. (2012) Heavy Oil Produced from Municipal Mixed Waste Plastics by Fractional Distillation Process. BIOINFO Renewable & Sustainable Energy, ISSN: 2249-1694 & E-ISSN: 2249-1708, Volume 2, Issue 1, pp.-05-11.

Introduction

The developed economies use oil much more intensively than the developing economies. United States and Canada consumptions equal almost 3 gallons per day per capita. The United States and Canada use oil more for transportation than for heat and power [1]. Canada's thirst for energy continues unabated into the 21st Century. Despite growing concerns about greenhouse gas emissions, as well as climate change and air quality, petroleum products remain key to satisfying that demand [2]. These petroleum products include heavy fuel oil, a highly polluting low-grade fuel of tar-like consistency. It is composed mostly of carbon, hydrogen, sulphur and other impurities such as ash, metals and water [2]. In Canada, no significant shift from the combustion of hydrocarbons toward more benign and renewable energy sources such as hydro -electricity has occurred during the past 15 years. Currently, more than one-third (37.6%) of our total energy demand is still met by refined petroleum products, one of which is heavy fuel oil. This ratio has not changed since 1990. However, some progress has been made in the case of heavy fuel oil. There has been a small decline in its overall use as an energy source [2].

The sector most dependent on heavy fuel oil is marine transportation, where it accounts for more than 60% of energy consumed. The rest comes from diesel fuel. This sector is also the only major user that increased its consumption during this 15-year period. More than half of consumption occurred in British Columbia [2]. While not one of the main energy sources nationally, heavy fuel oil is still an important fuel source for some industries. This low-grade carbon and sulphur-intensive petroleum product is burned in quantity for thermal-electric power generation, for heating boilers and furnaces in some manufacturing industries, and petroleum refining industry. It is also used to power large commercial marine vessels and heat some large, usually older commercial, institutional and multiple residential buildings [2]. HFO is used mainly to produce electricity, to fire boilers and blast furnaces in industry, notably the pulp and paper industry. Even though world, like many people in many other industrialized countries, are concerned about increases in greenhouse gas emissions, consumption of energy keeps rising in their country. Demands from all major energy sources such as petroleum products, natural gas and electricity- produced mainly from the combustion of fossil fuels and from nuclear and hydro sources-have all increased in recent decades [2].

Heavy fuel oil (HFO) is a black, low-grade fuel of tar-like consistency. It is composed mostly of carbon, hydrogen, sulphur and other impurities such as ash, metals, and water. HFO is obtained from the petroleum distillation process after other lighter petroleum products such as gasoline and kerosene have been distilled off. Heavy fuel oil is a by-product or residue-along with asphalt-of the distillation process [2]. Day by day natural resources for energy demand is decreasing contrary in whole world energy demand is increasing. Natural State Research, Inc. developed their own process to produce Heavy Fuel oil from varieties of abundant waste plastics. Waste Plastics sources would be major City, Municipality and house hold resources. Many sources of waste plastics are concluded HDPE (High Density Polyethylene), LDPE (Low Density Polyethylene), PP (Polypropylene), PS (Polystyrene), PETE (Polyethylene Terepthalate), PVC (Polyvinyl Chloride) etc. Municipal waste plastic represents about 8 wt% of the municipal solid waste and it generally consists of mixture of different kind of plastics: 40.5 wt% HDPE and LDPE,19.6 wt% PP, 11.9 wt% PS/EPS, 10.7 wt% PVC, 8.1 wt% PET, and about 5 wt% ABS and 4.2 wt% other polymers[3].

Experimental Section

Materials

To setting up experiment we collected different types of raw waste plastics from many sources like city, municipality and domestic resources including HDPE, LDPE, PP, PS, PETE and PVC. Among them HDPE, LDPE, PP and PS are sorting out separately then washed, cleaned and dried out properly. Subsequently we identified them as a polymer by initial analyzing by FTIR (Fourier Transform Infra-red Spectroscopy) and TGA (Thermo gravimetric Analyzer). FT-IR was used for functional group band energy determine for raw materials and TGA was used for raw material liquefaction temperature (onset temperature) determine.

Sample Preparation

Washed, cleaned and dried out sample were manually shredded by scissors according to small square sizes (2.3 square. inch each side). Again shredded samples are grinded by grinding machine. After grinding sample turns into small pellet sizes 2-3 mm.

Experimental Process

To preceding experimental procedure one 3000 ml round bottom empty boiling flask weighing out and recorded. Then 1000 gm sample were taken weighing by rough balance. Subsequently that grinded sample filled into the boiling flask with proper shielding. Filled boiling flask was set up into the 3000 ml heat mantle with neck stopper. 70 º angle and condenser upper path joined using by apeizon grease, each condenser joint tighten by clump, variac meter connected to regulate temperature range and one 1000 ml collection flask set up with condenser lower path to collect heavy fuel. Whole boiling flask upper body was insulated by aluminum foil paper. Ultimately related wire and connection were connected to the electric port properly and confirmed, as well as experiment started. Condensation process was expedited in the under laboratory fume hood. Initial state of experiment set temperature was at 90% variac (1% variac = 4.5 °C) that's 405°C for quick melting waste plastic. It takes like half an hour to melt. After melting temperature was decreases to lower temperature range depends on experiment thermal circumstances. Sometimes noticed that boiling flask inside vapor accumulated and on this situation temperature were decrease to lower range to control vapor pressure. Similarly other time temperature was increased to high temperature to get expected vapor. Vapor traveling through the condenser path and due condenser inside surface touch into vapor then vapor turns into liquid fuel. Produced liquid fuel deposited into the collection flask rapidly as a dropping wise. When condensation was complete experiment were allowed to cool down for half an hour. After cool down experiment fuel was collected 920 g fuel from the experiment then by graduated cylinder measured volume is 1200 ml and calculated density is 0.77 g/ml. Obtained fuel is named as a Plastic fuel.

To perform fractional distillation process to produce heavy oil was utilize plastic fuel obtained by above mentioned process. Fractional distillation process has been conducted according to the laboratory scale. Plastic fuel was called also heating fuel. During the experiment time taken the weight of 1000 ml boiling flask (Glass Reactor), and all the related weight and function recorded in the experimental log book for further computation. Subsequently fuel took into the boiling flask, after that we put filled boiling flask in 1000 ml heat mantle as well as connected variac meter with heat mantle. Attached distillation adapter, clump joint, condenser and collection flask using high temperature apiezon grease and insulated by aluminum foil paper. Then experiment was investigating finally that every step of experimental procedure followed properly. Initially was run the experiment at low temperature that's 40 ºC to starting up the experiment. Gradually raised up temperature and once condensation started, produced vapor traveling through the condenser , after that due to cooling air system in the inside hood condenser inside vapor turns into liquid fuel and its continuing up to at 260 ºC, produced fuel is mixture of several category of fuel such as Gasoline, Naphtha, Aviation and Diesel. We collected them separately into fuel NFPA approved container. Subsequently again we started to raised up temperature from 261 ºC to 340 ºC. At this stage during the condensation period mentioned temperature range (at 261 ºC to 340 ºC) produced fuel was Heavy Oil. In the laboratory stage from each 700 ml of experiment we can collect 150 ml of Heavy oil; density is 0.84 g/ml.

Results and Discussion

Analytical Procedure

Perkin Elmer, GCMS Clarus-500 (Gas Chromatography and Mass Spectrometer) was use to analysis purposes. GC Method programs set up are point out here, that's elaborated below. Initial temperature was 40 ºC for 1 minute. Ramping Rate: 10 ºC/ minute, Highest Temperature: 325 ºC, Hold at 325 ºC for 15 minute, Run Time: 44.50 minute, Sample Inject Volume: 0.5µL, Carrier Gas: Helium (He). In MS Method Set up Solvent delay was 1 Minute. Mass detection: start at 35 m/z, End at 528 m/z. Ionization Mode: EI+, Data: Centroid. Scan Time: 0.25 s and Inter Scan delay: 0.15s. Perkin Elmer GC Capillary Column Used.Elite-5MS Length, 30 meter, Inner Diameter 0.25, 0.5umdf, Maximum Program Temperature at 350 ºC and Minimum Bleed at 330 ºC. A f -

ter all program set up sample analyzed by GCMS. From GCMS analysis in versus of retention time following types of hydrocarbon compounds are appeared. Perkin Elmer FT-IR (Fourier Transform Infra-red Spectroscopy), Spectrum-100, was employed to analysis purposes. FT-IR Program set up are elaborated, before sample run ,Visible ray range were 4000-400 cm^{-1}, used NaCl cell is 0.05mm,Taken Scan Number, 32 and Resolution number, 4. Perkin Elmer TGA was used for solid sample analysis and carrier gas was helium and program temperature was 25-800 ºC and temperature rate was 15ºC/ min and isothermal was 50 ºC for 1 minutes.

Pre-analysis Result

Table 1- Raw materials TGA analysis result

Plastics Name	Sample weight (mg)	On set temperature (ºC)	Inflection temperature (ºC)
LDPE	3.132	421.53	457.11
HDPE	3.044	420.65	430.98
PS	2.575	326.62	364.88
PP	2.952	359.63	403.72

Experimental purposes were used four types of raw waste plastics such as LDPE, HDPE, PP and PS as well. Those plastics are analyzed by TGA (Thermogravimetric Analyzer) in order to determined onset temperature of each individual plastic (table 1). To expedite the TGA experiment of LDPE, plastic sample was taken 3.3132 g and found Onset Temperature is 421.53 °C and Inflection Temperature is 457.11°C. HDPE plastic sample was taken 3.3132 g and found Onset Temperature is 420.65 °C and Inflection Temperature is 430.98°C. PP plastic sample was taken 2.575 g and found Onset Temperature is 326.62 °C and Inflection Temperature is 364.88°C. Eventually PS plastic sample was taken 2.952 g and found Onset Temperature is 359.63 °C and Inflection Temperature is 403.72°C. TGA Onset average temperature of all plastics is 382.10°C. TGA used 25°C to 800 °C temperature ranges to melt and volatile the solid sample in order to derived onset temperature of each raw plastic; between the temperature ranges TGA mostly used 550 °C highest temperature range to volatile the plastic sample. After done the TGA experiment in the crucible 5% LDPE residue are remained and rest of 95% are converted to volatile gases, for HDPE 4% residue are remained in the crucible and rest of 96% are already converted to volatile gases, for PP 4% residue are remained in the crucible and 96% sample are converted to volatile gases and ultimately for PS 7% residue are remained in the crucible and 93% sample are converted to volatile gases as well. Based on onset temperature of each plastics determined that at what temperature conversion of liquefaction process would be expedited as well as also giving clue that how much percentage of product conversion rate would be probably occur and how much residue yield percentage would be in the particular experiment.

LDPE (Figure blue color chromatogram) following types of wave numbers and functional groups appeared. In accordance to the wave number such as wave number 2949.39 cm^{-1}, 2917.42 cm^{-1}, 2866.47 cm^{-1} and 2838.30 cm^{-1}, investigated functional group is C -CH_3, wave number 1743.81 cm^{-1}, functional group is Non-Conjugated and end of the spectrum phase wave number 1455.81 cm^{-1}, 1375.47 cm^{-1} and 1358.81 cm^{-1}, functional group is CH_3 etc. PP (Figure red color chromatogram) following types of wave numbers and functional groups appeared. In accordance to the wave number such as wave number 2949.94 cm^{-1}, 2917.66 cm^{-1}, 2867.11 cm^{-1} and 2838.32 cm^{-1}, investigated functional group is C -CH_3, wave number 1743.99 cm^{-1}, functional group is Non-Conjugated and also on the spectrum phase wave number 1454.48 cm^{-1}, 1375.74 cm^{-1} and 1359.00 cm^{-1}, functional group is CH_3 as well as at the end phase of the spectrum wave number 721.33 cm^{-1}, functional group is -CH=CH-(cis) etc. PS (Figure green color chromatogram) following types of wave numbers and functional groups appeared. In accordance to the wave number such as wave number 3059.62 cm^{-1} and 3025.15 cm^{-1}, investigated functional group is =C-H, wave number 2921.91 cm^{-1} and 2850.69 cm^{-1}, investigated functional group is C-CH_3, wave number 1869.56 cm^{-1}, 1801.91 cm^{-1}, 1743.82 cm^{-1},1600.85 cm^{-1} functional group is Non-Conjugated and also on the spectrum phase wave number 1451.61 cm^{-1} and 1371.06 cm^{-1} , functional group is CH_3, wave number 1027.74 cm^{-1} functional group is Acetates, wave number 964.20 cm^{-1} , functional group is -CH=CH-(trans), wave number 905.91 cm^{-1} , functional group is -CH=CH_2 , and at the end phase of the spectrum wave number 748.40 cm^{-1}, functional group is -CH=CH-(cis) etc.

Liquid Fuel Analysis

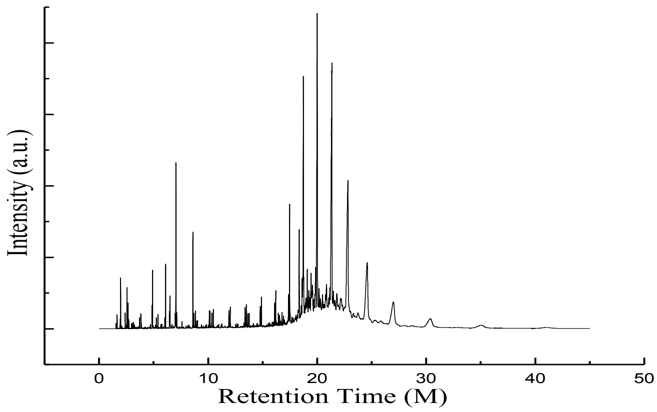

Fig. 2- GC/MS Chromatogram of Mixed Waste Plastics Fuel to 5th Fractional Fuel (Heavy Oil)

Gas Chromatography and Mass Spectrometer (GC/MS) analysis of mixed waste plastics to heavy fuel (fig.2 and table 2) in accordance with the various retention time and trace masses different types of hydrocarbon compound and benzene derivatives compounds are appeared in the analysis result index. Many compounds are emerged on the analysis carbon range C_3 to C_{27}. Based on the retention time and trace mass following hydrocarbon compounds as follows such as at the initial phase of the analysis at retention time 1.55 and trace mass 41, compound is Cyclopropane (C3H6), retention time 1.65 and trace mass 41, compound is 1-Propene, 2-methyl- (C4H8), retention time 1.72 and trace mass 41, compound is 2-Butene, (E)- (C_4H_8), retention time 1.98 and trace mass 43,compound is Pentane, (C_5H_{12}), retention time 2.02 and trace mass 55, compound is Cyclopropane, 1,2-dimethyl-, cis- (C_5H_{10}), retention time 2.56 and trace mass 56, compound is 1-Pentene, 2-methyl- (C_6H_{12}), retention time 2.72 and trace mass 41,compound is 2-Butene, 2,3-dimethyl- (C_6H_{12}), retention time

2.98 and trace mass 56,compound name is Cyclopentane, methyl (C_6H_{12}), retention time 3.04 and trace mass 67,compound name is 2,4-Hexadiene, (Z,Z)-(C_6H_{10}), retention time 3.39 and trace mass 41, compound is Oxirane, (1-methylbutyl)- ($C_7H_{14}O$), retention time 3.66 and trace mass 56, compound is 1-Hexene, 2-methyl- (C_7H_{14}), retention time 3.90 and trace mass 81, compound is 3,5-Dimethylcyclopentene (C_7H_{12}), retention time 4.71 and trace mass 43, compound is 1-Heptene, 4-methyl- ($C_{18}H_{16}$), retention time 4.96 and trace mass 81, compound is Cyclohexene, 3-methyl -- (C_7H_{12}), retention time 5.17 and trace mass 56, compound is 1-Heptene, 2-methyl- (C_8H_{16}), retention time 5.76 and trace mass 43, compound is Heptane, 2,4-dimethyl- (C_9H_{20}), retention time 6.99 and trace mass 43, compound is 1-Undecene, 8-methyl- ($C_{12}H_{24}$) etc. Also at retention time 7.60 and trace mass 105, compound is Benzene, (1-methylethyl) - (C_9H_{12}), retention time 8.96 and trace mass 43, compound is Nonane, 2, 6-dimethyl- ($C_{11}H_{24}$) etc. In the middle phases of the analysis index results in accordance with the retention time and trace masses various kinds of compounds are detected such as at retention time 10.87 and trace mass 43, compound is 1-Dodecanol, 3, 7, 11-trimethyl- ($C_{15}H_{32}O$), here also appearing that oxygenated compound are formed because in the glass reactor chamber much amount of steams are produced and also experiment executed in the presence of air. Retention time 12.64 and trace mass 57, compound is Decane, 2,3,5,8-tetramethyl- ($C_{14}H_{30}$), retention time 13.52 and trace mass 69, compound is 9-Eicosene, (E)- ($C_{20}H_{40}$), retention time 14.78 and trace mass 55, compound is 1-Tetradecene ($C_{14}H_{28}$), retention time 16.10 and trace mass 55, compound is 1-Pentadecene ($C_{15}H_{30}$), at retention time 17.38 and trace mass 55, compound is 1-Hexadecene ($C_{16}H_{32}$), benzene compounds are formed because when raw polystyrene are made benzene are added into the reactants. Retention time 18.35 (on third highest peak) and trace mass 92, compound is Benzene, 1,1'-(1,3-propanediyl)bis- ($C_{15}H_{16}$) etc. In the ultimate phase of the analysis index several compound are detected as according to their retention time and trace masses such as retention time 19.86 and trace mass 55, compound is E-7-Octadecene ($C_{18}H_{36}$), at the first highest peak on retention time 20.01 and trace mass 43, compound is Octadecane ($C_{18}H_{38}$), at the second highest peak on retention time 21.35 and trace mass 57, compound is Nonadecane ($C_{19}H_{40}$), retention time 22.82 and trace mass 57, compound is Eicosane ($C_{20}H_{42}$), retention time 24.58 and trace mass 57, compound is Heneicosane ($C_{21}H_{44}$), and eventually retention time 27.00 and trace mass 57, compound is Heptacosane ($C_{27}H_{56}$) etc. Mentioned that practically found on the spectrum some retention time are acquired at highest peak height and maximum retention times are gained at in the normal peak height.

Table 3- Mixed Waste Plastics Fuel to 5th Fractional Fuel (Heavy Oil) FT-IR Functional Group List

Band Peak Number	Wave Number (cm-1)	Functional Group Name	Band Peak Number	Wave Number (cm-1)	Functional Group Name
1	2923.45	CH_2	9	991.95	Secondary Cyclic Alcohol
2	2853.06	CH_2	10	964.93	-CH=CH- (trans)
3	1746.10	Non-Conjugated	11	908.97	-CH=CH2
4	1641.30	Non-Conjugated	12	888.68	C=CH2
5	1602.35	Non-Conjugated	13	720.09	-CH=CH- (cis)
6	1464.70	CH_2	14	698.20	-CH=CH- (cis)
7	1377.43	CH_3			

From FT-IR (spectrum 100) analyses of heavy fuel (fig. 3 and table 3) in accordance with the different wave number different types of functional groups are appeared. In according to wave number on the spectrum such as wave number 2923.45 cm^{-1}, functional group is CH_3, wave number 2853.06 cm^{-1} functional group is CH_2, wave number 1746.10 cm^{-1}, 1641.30 cm^{-1} and 1602.35 cm^{-1} functional group is Non-Conjugated, wave number 1464.70 cm^{-1} and 1377.43 cm^{-1} functional group is CH_2 / CH_3 etc. In the end of the spectrum phase wave number 991.95 cm^{-1}, functional group is $-CH=CH_2$, wave number 964.93 cm^{-1}, functional group is -CH=CH-(trans), wave number 908.97 cm^{-1}, functional group is $-CH=CH_2$, wave number 888.68 cm^{-1}, functional group is $C=CH_2$ and ultimately wave number 720.09 cm^{-1} and 698.20 cm^{-1}, functional group is CH=CH-(cis) as well. Energy values are calculated, using formula is E=hυ, Where h=Planks Constant, h $=6.626\times10^{-34}$ J, υ= Frequency in Hertz (sec^{-1}), Where υ=c/λ, c=Speed of light, where, $c=3\times10^{10}$ 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 such as for 2923.45 (cm^{-1}) calculated energy, $E=5.80\times10^{-20}$ J. Similarly, wave number 1746.10 (cm^{-1}) energy, $E=3.46\times10^{-20}$ J, wave number 1377.43 (cm^{-1}) energy, $E = 2.73\times10^{-20}$ J and eventually wave number 991.95 (cm^{-1}) functional group is 1.97×10^{-20} J respectively.

Some ASTM test was conducted from 3rd party of produces fuel and ASTM test was such as API Gravity at 60 ºF (ASTM D287), Density (ASTM D1298), Relative Density (Elevated temp) (ASTM D4052), Flash Point Test (ASTM D93_B), Pour Point Test (ASTM D97), Sediment Content (ASTM D473), Sulfur Content (ASTM D4294), Viscosity - Kinematic at 40 & 100 ºC (ASTM D445), Water Content (ASTM D95), Appearance or Haze (ASTM D4176), Cetane Index (Calculation Only) (ASTM D976), Cloud Point (ASTM D2500), Color (ASTM D1500), Copper Corrosion (ASTM D130), Distillation (ASTM D86), Oxidation Stability (ASTM D2274), pH Value (ASTM D1293), Btu value gal or lb (ASTM D240).

Conclusion

In batch process laboratory scale heavy oil produced by fractional distillation process was two step. Initially municipal mixed waste plastics grinded sample was converted in to liquid hydrocarbon fuel and the experiment were executed without any catalyst. Produced plastic hydrocarbon fuel is mixture of several types of fuel such as gasoline, naphtha, aviation, diesel and heavy oil. 2nd step process was used for heavy oil first step plastic liquid hydrocarbon fuel was use to set up fractional distillation process. In the 2nd step experiment light fuel were gradually extracted by their temperature profile e.g. gasoline (at 40-65 ºC) naphtha (at 110-135 ºC), aviation fuel (at 180 -205 ºC), diesel fuel (at 260 -285 ºC) and finally between 260 ºC to 340 ºC temperature range obtained fuel was heavy oil. A thermal degradation process was applied to produce NSR Heavy Oil from waste plastic fuel. Fuel analysis result showed produced fuel has some aromatic compound and aliphatic compound because raw materials were LDPE, PP, HDPE and PS mixtures. This fuel could be used as feed stock refinery for further modification or it could be used as heating oil.

Acknowledgement The author acknowledges the support of Dr.

Karin Kaufman, the founder of Natural State Research, Inc. The author also acknowledges the valuable contributions NSR laboratory team members during the preparation of this manuscript.

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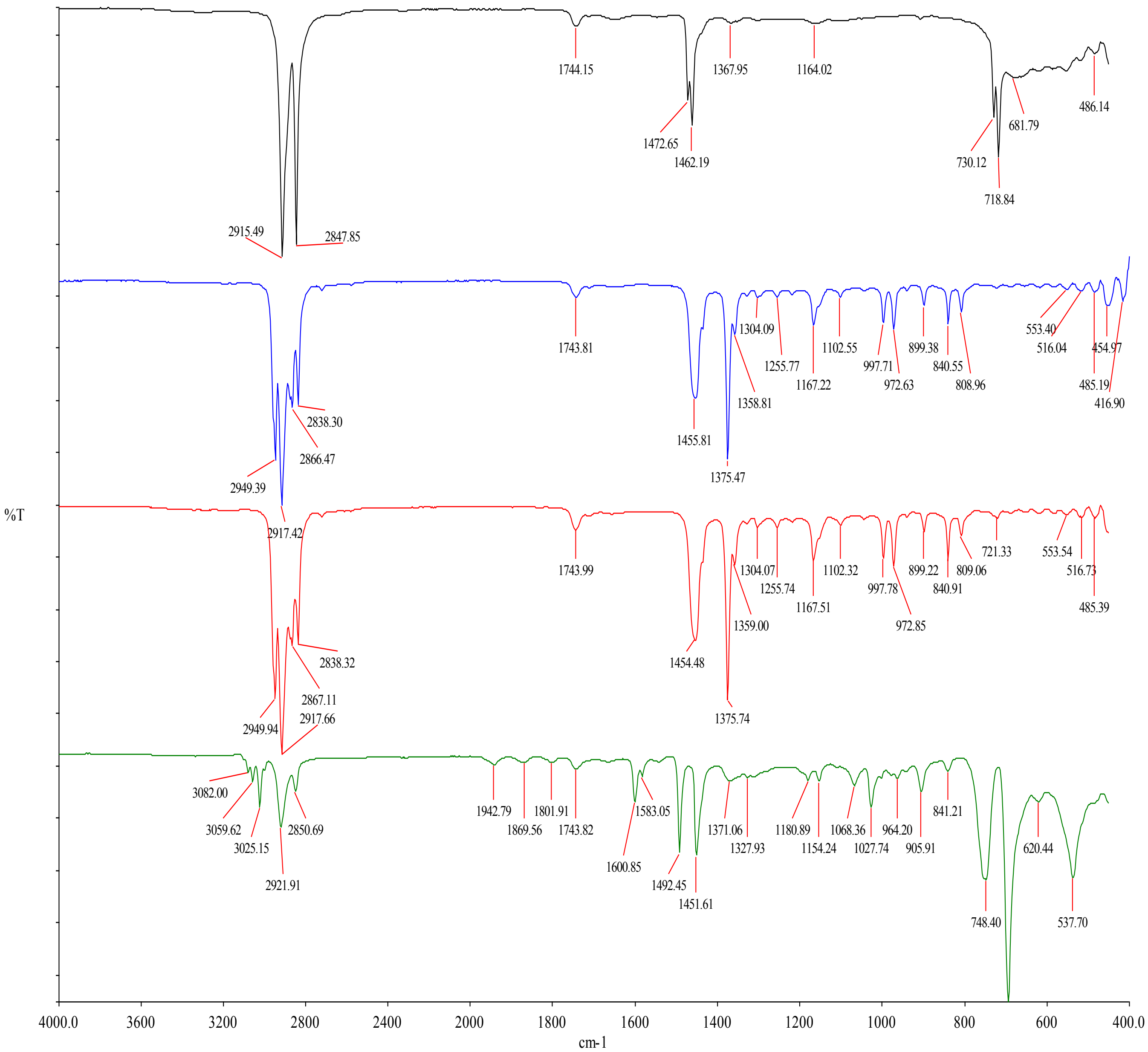

Fig. 1- FT-IT graph of four types of solid waste plastic

Table 2- GC/MS Chromatogram Compound list of Mixed Waste Plastics Fuel to Heavy Oil

Peak Number	Retention Time (M)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.55	41	Cyclopropane	C_3H_6	42	29.6	18854
2	1.65	41	1-Propene, 2-methyl-	C_4H_8	56	27.4	18910
3	1.72	41	2-Butene, (E)-	C_4H_8	56	25.1	105
4	1.81	43	Butane, 2-methyl-	C_5H_{12}	72	70.3	19107
5	1.94	42	1-Pentene	C_5H_{10}	70	24.1	19081
6	1.98	43	Pentane	C_5H_{12}	72	83.3	61286
7	2.02	55	Cyclopropane, 1,2-dimethyl-, cis-	C_5H_{10}	70	18.1	19070
8	2.39	43	Pentane, 2-methyl-	C_6H_{14}	86	65.0	61279
9	2.52	57	Pentane, 3-methyl-	C_6H_{14}	86	58.8	19375
10	2.56	56	1-Pentene, 2-methyl-	C_6H_{12}	84	35.9	495
11	2.65	57	Hexane	C_6H_{14}	86	85.7	61280
12	2.72	41	2-Butene, 2,3-dimethyl-	C_6H_{12}	84	11.8	289588
13	2.81	67	Cyclobutene, 3,3-dimethyl-	C_6H_{10}	82	10.4	62288
14	2.86	41	2-Pentene, 3-methyl-, (Z)-	C_6H_{12}	84	16.8	114483
15	2.98	56	Cyclopentane, methyl-	C_6H_{12}	84	67.1	114428
16	3.04	67	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	10.7	113646
17	3.09	67	2,4-Hexadiene, (Z,Z)-	C_6H_{10}	82	14.4	113646
18	3.24	81	2,4-Dimethyl 1,4-pentadiene	C_7H_{12}	96	36.3	114468
19	3.36	78	Benzene	C_6H_6	78	76.8	114388
20	3.39	41	Oxirane, (1-methylbutyl)-	$C_7H_{14}O$	114	11.7	49880
21	3.63	43	2-Pentanone	$C_5H_{10}O$	86	41.8	291264
22	3.66	56	1-Hexene, 2-methyl-	C_7H_{14}	98	27.1	231711
23	3.71	56	1-Heptene	C_7H_{14}	98	10.3	107734
24	3.83	43	Heptane	C_7H_{16}	100	79.8	61276
25	3.87	81	1,3-Pentadiene, 2,4-dimethyl-	C_7H_{12}	96	26.9	114450
26	3.90	81	3,5-Dimethylcyclopentene	C_7H_{12}	96	14.7	113640
27	4.71	43	1-Heptene, 4-methyl-	C_8H_{16}	112	11.9	113433
28	4.86	43	Heptane, 4-methyl-	C_8H_{18}	114	58.6	113916
29	4.90	91	Toluene	C_7H_8	92	64.3	291301
30	4.96	81	Cyclohexene, 3-methyl-	C_7H_{12}	96	9.73	236066
31	5.17	56	1-Heptene, 2-methyl-	C_8H_{16}	112	47.6	107268
32	5.25	55	1-Octene	C_8H_{16}	112	26.7	1604
33	5.34	95	1,4-Pentadiene, 2,3,3-trimethyl-	C_8H_{14}	110	9.62	154036
34	5.40	43	Octane	C_8H_{18}	114	54.8	229407
35	5.50	55	3-Octene, (Z)-	C_8H_{16}	112	6.29	227617
36	5.66	83	Cyclopentane, 1,1,3,4-tetramethyl-, cis-	C_9H_{18}	126	15.0	27589
37	5.76	43	Heptane, 2,4-dimethyl-	C_9H_{20}	128	23.8	155382
38	6.03	111	Cyclohexane, 1,3,5-trimethyl-	C_9H_{18}	126	37.9	114702
39	6.10	43	2,4-Dimethyl-1-heptene	C_9H_{18}	126	65.2	113516
40	6.46	69	Cyclohexane, 1,3,5-trimethyl-, (1α,3α,5β)-	C_9H_{18}	126	33.7	2480
41	6.51	91	Ethylbenzene	C_8H_{10}	106	61.5	114918
42	6.99	43	1-Undecene, 8-methyl-	$C_{12}H_{24}$	168	4.28	61823
43	7.05	78	Styrene	C_8H_8	104	42.8	291542
44	7.12	43	Nonane	C_9H_{20}	128	30.9	228006
45	7.60	105	Benzene, (1-methylethyl)-	C_9H_{12}	120	50.0	228742
46	8.13	91	Benzene, propyl-	C_9H_{12}	120	72.6	113930
47	8.18	57	Nonane, 4-methyl-	$C_{10}H_{22}$	142	29.1	3834
48	8.28	105	Benzaldehyde	C_7H_6O	106	53.6	291541
49	8.60	118	α-Methylstyrene	C_9H_{10}	118	36.6	229186
50	8.69	41	1-Decene	$C_{10}H_{20}$	140	8.95	118883
51	8.84	57	Decane	$C_{10}H_{22}$	142	34.9	291484
52	8.96	43	Nonane, 2,6-dimethyl-	$C_{11}H_{24}$	156	9.40	61438
53	9.38	117	Benzene, 1-propenyl-	C_9H_{10}	118	13.0	20403
54	9.55	56	Cyclohexane, 1,1-dimethyl-2-propyl-	$C_{11}H_{22}$	154	13.1	69817
55	9.76	43	2-Undecanethiol, 2-methyl-	$C_{12}H_{26}S$	202	5.29	9094
56	9.86	91	2-Cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl)-	$C_{10}H_{16}O$	152	19.1	114684
57	10.11	69	Cyclooctane, 1,4-dimethyl-, trans-	$C_{10}H_{20}$	140	3.52	61408
58	10.18	43	3-Tetradecene, (E)-	$C_{14}H_{28}$	196	2.65	142623
59	10.24	56	3-Undecene, (E)-	$C_{11}H_{22}$	154	6.36	60565
60	10.34	55	2-Undecene, (Z)-	$C_{11}H_{22}$	154	5.26	142596
61	10.48	57	Undecane	$C_{11}H_{24}$	156	32.3	107774
62	10.55	55	Z-10-Pentadecen-1-ol	$C_{15}H_{30}O$	226	3.51	245485
63	10.87	43	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$	228	5.44	114065
64	11.24	69	(2,4,6-Trimethylcyclohexyl) methanol	$C_{10}H_{20}O$	156	7.46	113757
65	11.91	55	3-Dodecene, (E)-	$C_{12}H_{24}$	168	6.98	70642
66	12.03	57	Dodecane	$C_{12}H_{26}$	170	31.7	291499
67	12.51	57	Tetradecane, 2,6,10-trimethyl-	$C_{17}H_{36}$	240	9.76	11556
68	12.64	57	Decane, 2,3,5,8-tetramethyl-	$C_{14}H_{30}$	198	12.2	149589
69	13.28	56	3-Tetradecene, (E)-	$C_{14}H_{28}$	196	4.37	139981

Table 2- Continue

70	13.39	55	1-Tridecene	$C_{13}H_{26}$	182	5.74	232738
71	13.50	57	Tridecane	$C_{13}H_{28}$	184	44.0	114282
72	13.52	69	9-Eicosene, (E)-	$C_{20}H_{40}$	280	3.0	62815
73	14.78	55	1-Tetradecene	$C_{14}H_{28}$	196	5.32	69725
74	14.88	57	Tetradecane	$C_{14}H_{30}$	198	30.3	113925
75	16.10	55	1-Pentadecene	$C_{15}H_{30}$	210	7.64	69726
76	16.20	57	Pentadecane	$C_{15}H_{32}$	212	31.2	107761
77	16.91	83	1-Docosanol	$C_{22}H_{46}O$	326	3.98	23377
78	17.38	55	1-Hexadecene	$C_{16}H_{32}$	224	6.85	118882
79	17.48	57	Hexadecane	$C_{16}H_{34}$	226	39.8	114191
80	18.35	92	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	91.4	229725
81	18.63	55	3-Heptadecene, (Z)-	$C_{17}H_{34}$	238	8.78	141673
82	18.73	71	Heptadecane	$C_{17}H_{36}$	240	37.5	107308
83	19.09	69	1-Nonadecanol	$C_{19}H_{40}O$	284	5.83	232931
84	19.86	55	E-7-Octadecene	$C_{18}H_{36}$	252	5.96	130920
85	20.01	43	Octadecane	$C_{18}H_{38}$	254	22.6	57273
86	20.85	83	1-Docosanol	$C_{22}H_{46}O$	326	7.51	23377
87	21.35	57	Nonadecane	$C_{19}H_{40}$	268	9.54	114098
88	22.82	57	Eicosane	$C_{20}H_{42}$	282	23.1	290513
89	24.58	57	Heneicosane	$C_{21}H_{44}$	296	22.6	107569
90	27.00	57	Heptacosane	$C_{27}H_{56}$	380	7.55	79427

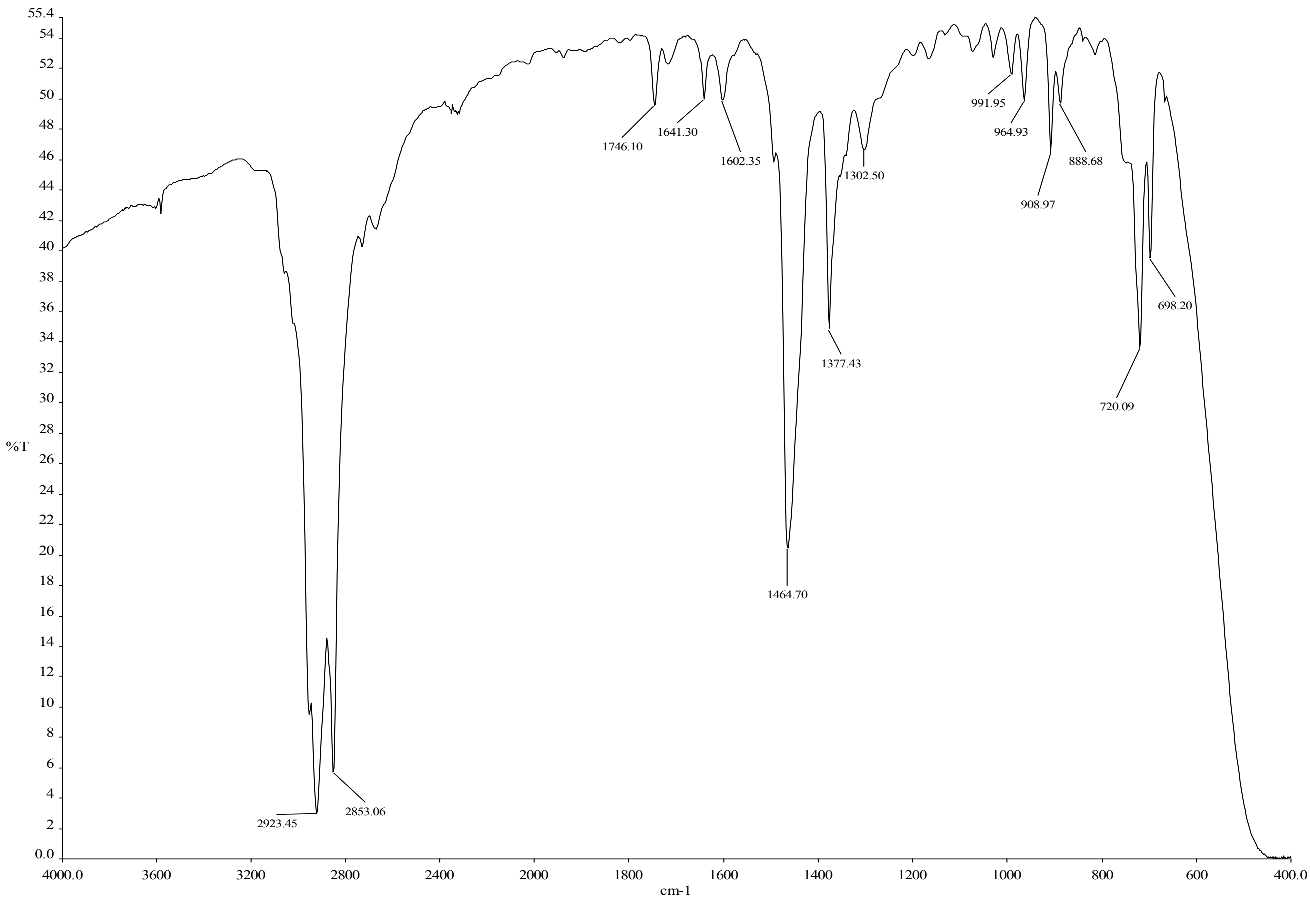

Fig. 3- FTIR Spectra of Mixed Waste Plastic Fuel to Heavy Fuel