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Municipal Waste Plastic Conversion into Different Category of Liquid Hydrocarbon Fuel

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1. Introduction

Plastics were first invented in 1860, but have only been widely used in the last 30 years. Plastics are light, durable, modifiable and hygienic. Plastics are made up of long chain of molecules called polymers. Polymers are made when naturally occurring substances such as crude oil or petroleum are transformed into other substances with completely different properties. These polymers can then be made into granules, powders and liquids, becoming raw materials for plastic products. Worldwide plastics production increases 80 million tons every year. Global production and consumption of plastics have increased, from less than 5 million tons in the year 1950 to 260 million tons in the year 2007. Of those over one third is being used for packaging, while rest is used for other sectors. Plastic production has increased by more than 500% over the past 30 years. Per capita consumption of plastics will increase by more than 50% during the next decades. In the Western Europe total annual household waste generation is approximately 500 kg per capita and 750 kg per capita in the United States; 12% of this total waste is plastics. The global total waste plastic generation is estimated to be over 210 million tons per year. US alone generate 48 million tons per year (Stat data from EPA). The growth in plastics use is due to their beneficial characteristics; 21st century Economic growth making them even more suitable for a wide variety of applications, such as: food and product packaging, car manufacturing, agricultural use, housing products and etc. Because of good safety and hygiene properties for food packaging, excellent thermal and electrical insulation properties, plastics are more desirable among consumers. Low production cost, lower energy consumption and CO\textsubscript{2} emissions during production of plastics are relatively lower than making alternative materials, such as glass, metals and etc. Yet for all their advantages, plastics have a considerable downside in terms of their environmental impact. Plastic production requires large amounts of resources, primarily fossil fuels and 8% of the world’s annual oil production is used in the production of plastics. Potentially harmful chemicals are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment and their impact on human health and environment is currently uncertain. Worldwide municipal sites like shops or malls had the largest proportion of plastic rubbish items. Ocean soup swirling the debris of plastics trash in the Pacific Ocean has now grown to a size that is twice as large as the continental US. In 2006, 11.5 million of tons of plastics were wasted in the landfill. These types of disposal of the waste plastics release toxic gas; which has negative impact on environment.
Most plastics are non-biodegradable and they take long time to break down in landfill, estimated to be more than a century. Plastic waste also has a detrimental impact on wild life; plastic waste in the oceans is estimated to cause the death of more than a million seabirds and more than 100,000 marine mammals every year (UN Environmental Program Estimate). Along with this hundreds of thousands of sea turtles, whales and other marine mammals die every year eating discarded waste plastic bags mistaken for food. Setting up intermediate treatment plants for waste plastic, such as: plastic incineration, recycle, or obtaining the landfill for reclamation is difficult. The types of the waste plastics are LDPE, HDPE, PP, PS, PVC, PETE, PLA and etc. The problems of waste plastics can’t be solved by landfilling or incineration, because the safety deposits are expensive and incineration stimulates the growing emission of harmful greenhouse gases, e.g. COx, NOx, SOx and etc. By using NSR’s new technology we can convert all types of waste plastics into liquid hydrocarbon fuel by setting temperature profile 370 degree C to 420 degree C, we can resolve all waste plastic problems including land, ocean, river and greenhouse effects. Many of researcher and experts have done a lot of research and work on waste plastics; some of the thesis’s are on thermal degradation process [1-10], pyrolysis process [11-20] and catalytic conversion process [21-30]. Producing fuels can be alternative of heating oil, gasoline, naphtha, aviation, diesel and fuel oil. We also produce light gaseous (natural gas) hydrocarbon compound (C1-C4), such as: methane, ethane, propane and butane. This process is profitable because it requires less production cost per gallon. We can produce individual plastic to fuel, mixed waste plastic to fuel and that produced fuel can make different category fuels by using further fractional distillation process. This NSR technology will not only reduce the production cost of fuel, but it will also reduce 9% of foreign oil dependency, create more electricity and new jobs all over the world. To mitigate the present world market demand, we can substitute this method as a potential source of new renewable energy.

2. Experimental section

2.1 Waste plastics properties

A plastic has physical and chemical properties. Different types of plastics displayed distinguishable characteristics and properties. Many kinds of plastics are appeared like LDPE, HDPE, PP, PS, PVC &PETE etc. Several individual plastics properties are elaborated in shortly, that’s given below in Table-1, Table-2, Table-3 and Table-4.

| Quantity            | Value         | Units           |
|---------------------|---------------|-----------------|
| Thermal expansion   | 110 - 130     | e-6/K           |
| Thermal conductivity| 0.46 - 0.52   | W/m.K           |
| Specific heat       | 1800 - 2700   | J/kg.K          |
| Melting temperature | 108 - 134     | °C              |
| Glass temperature   | -110 - -110   | °C              |
| Service temperature | -30 - 85      | °C              |
| Density             | 940 - 965     | kg/m³           |
| Resistivity         | 5e+17 - 1e+21 | Ohm.mm²/m       |
| Shrinkage           | 2 - 4         | %               |
| Water absorption    | 0.01 - 0.01   | %               |

Table 1. HDPE-2 Plastic Properties
2.2 Pre analysis of Gas Chromatography & Mass Spectrometer (GC/MS) analysis
Before starting the fuel production experiment, we have analyzed each of the individual raw waste plastics. Types of analyzed raw waste plastics are following, HDPE-2 (High Density Polyethylene), LDPE-4 (Low Density Polyethylene), PP-5 (Polypropylene) and PS-6 (Polystyrene).
Fig. 1. GC/MS Chromatogram of HDPE-2 Raw Waste Plastic

| Retention Time | Compound Name          | Formula | Retention Time | Compound Name          | Formula |
|----------------|------------------------|---------|----------------|------------------------|---------|
| 2.14           | Propane                | C₃H₈    | 22.62          | Tetradecane            | C₁₄H₂₀  |
| 2.23           | 3-Butyn-1-ol           | C₄H₆O   | 24.57          | 1,13-Tetradecadiene    | C₁₄H₂₆  |
| 17.61          | Dodecane               | C₁₂H₂₆  | 40.94          | 1,19-Eicosadiene       | C₂₀H₃₈  |
| 19.78          | 1,13-Tetradecadiene   | C₁₄H₂₆  | 41.02          | 1-Docosene             | C₂₂H₄₄  |
| 20.00          | 1-Tridecene            | C₁₃H₂₆  | 42.48          | 1-Docosene             | C₂₂H₄₄  |
| 20.19          | Tridecane              | C₁₃H₂₈  | 43.89          | 1-Tetracosanol         | C₂₄H₅₀O |
| 22.24          | 1,13-Tetradecadiene   | C₁₄H₂₆  | 45.28          | 9-Tricosene, (Z)-      | C₂₃H₄₆  |
| 22.45          | Cyclotetradecane       | C₁₄H₂₈  | 46.76          | 17-Pentatriacontene    | C₃₅H₇₀  |

Table 4. GC/MS Compound List of HDPE-2 Waste Plastic
Fig. 2. GC/MS Chromatogram of LDPE-4 Raw Waste Plastic

| Retention Time (Minutes) | Compound Name     | Formula | Retention Time (Minutes) | Compound Name     | Formula |
|-------------------------|-------------------|---------|--------------------------|-------------------|---------|
| 2.11                    | Propane           | C₃H₈    | 17.13                    | 1,11-Dodecadiene  | C₁₂H₂₂  |
| 2.19                    | Cyclopropyl carbinol | C₄H₈O  | 17.37                    | Cyclododecane     | C₁₂H₂₄  |
| 11.44                   | 1,9-Decadiene     | C₁₀H₁₈  | 33.62                    | 1-Nonadecene      | C₁₉H₃₈  |
| 11.73                   | Cyclodecane       | C₁₀H₂₀  | 35.87                    | 1,19-Eicosadiene  | C₂₀H₃₈  |
| 11.95                   | Decane            | C₁₀H₂₂  | 35.87                    | 1-Heneicosyl formate | C₂₂H₄₄O₂ |
| 14.35                   | 1,10-Undecadiene | C₁₁H₂₀  | 36.08                    | 1-Undecene        | C₂₂H₄₆O  |
| 14.61                   | Undecane          | C₁₁H₂₄  | 42.76                    | 1-Docosanol       | C₂₃H₄₆   |
| 14.84                   |                   |         |                          | 9-Tricosene, (Z)  |         |

Table 5. GC/MS Chromatogram Compound list of LDPE-4 Raw Waste Plastic
Fig. 3. GC/MS Chromatogram of PP-5 Raw Waste Plastic

Table 6. GC/MS Chromatogram Compound List of PP-5 Raw Waste Plastic

| Retention Time (Minutes) | Compound Name                          | Formula  | Retention Time (Minutes) | Compound Name                          | Formula  |
|--------------------------|----------------------------------------|----------|--------------------------|----------------------------------------|----------|
| 2.13                     | Cyclopropane                            | C3H6     | 12.29                    | Decane, 4-methyl-2-Dodecene, (E)-1-Hexadecanol, 3,7,11,15-tetramethyl-1-Heneicosyl formate | C11H24   |
| 2.26                     | 1-Butyne                                | C4H6     | 14.18                    |                                        | C12H24   |
| 9.36                     | 1,6-Octadiene, 2,5-dimethyl-, (E)-      | C10H18   | 26.35                    |                                        | C20H42O  |
| 11.71                    | Nonane, 2-methyl-3-methylene-1-Ethyl-2,2,6-trimethylcyclohexane | C11H22   | 31.52                    | 1-Nonadecanol                          | C19H40O  |
| 11.78                    |                                        | C11H22   | 32.51                    |                                        | C19H40O  |
| 12.17                    | Nonane, 2,6-dimethyl-                   | C11H24   | 33.98                    | 1,22-Docosanediol                      | C22H46O2 |
Table 7. GC/MS Chromatogram of PS-6 Raw Waste Plastic Compound List

| Retention Time (Minutes) | Compound Name                          | Formula | Retention Time (Minutes) | Compound Name                          | Formula               |
|--------------------------|----------------------------------------|---------|--------------------------|----------------------------------------|-----------------------|
| 2.17                     | Cyclopropane                            | C3H6    | 24.78                    | 1,1'-Biphenyl, 3-methyl-                | C13H12               |
| 2.24                     | Methylene cyclopropane                   | C4H6    | 25.64                    | 1,2-Diphenyleethylene                  | C14H12               |
| 5.52                     | Toluene                                 | C7H8    | 27.30                    | 1,2-Diphenylcyclopropane               | C15H14               |
| 20.09                    | Methanonaphthalene, 1,4-dihydro-        | C11H10  | 37.35                    | Naphthalene, 1-(phenylmethyl)-         | C17H14               |
| 20.28                    | Benzocycloheptatriene                   | C11H10  | 37.63                    | p-Terphenyl                            | C18H14               |
| 20.67                    | Naphthalene, 1-methyl-                  | C11H10  | 38.79                    | Fluoranthene, 2-methyl-                | C17H12               |
| 22.32                    | Biphenyl                                | C12H10  | 39.83                    | Benzene, 1,1′-[1-(ethylthio)propyldiene]bis-Benzene, 1,1′,1″-(1,2,3,4-butanetetrayl)tetrakis- | C17H20S C28H26       |
| 23.52                    | Diphenylmethane                         | C13H12  | 40.13                    |                                        |                       |

Fig. 4. GC/MS Chromatogram of PS-6 Raw Waste Plastic
Individual raw waste plastics of GCMS pre-analysis in accordance with their numerous retention times many compound are found, some of them are mentioned shortly. In HDPE-2 raw waste plastics on retention time 2.14, compound is Propane \((\text{C}_3\text{H}_8)\), on retention time 22.45, compound is Cyclotetradecane and finally on retention time 46.76 obtained compound is Pentatriacotene \((\text{C}_{35}\text{H}_{70})\) [Shown above Fig.1 and Table-4]. In LDPE-4 raw waste plastics on retention time 2.11, compound is Propane \((\text{C}_3\text{H}_8)\), on retention time 14.84, compound is Undecane \((\text{C}_{11}\text{H}_{24})\) and finally on retention time 47.91 obtained compound is 9-Tricosene \((\text{Z})-(\text{C}_{23}\text{H}_{46})\) [Shown above Fig.2 and Table-5]. In PP-5 initially on retention time 2.13 compound is Cyclopropane \((\text{C}_3\text{H}_6)\) and finally on retention time 33.98 obtained compound is 1, 22-Docosanediol \((\text{C}_{22}\text{H}_{46}\text{O}_2)\) [Shown above Fig.3 and Table-6]. Accordingly in PS-6 on retention time 2.17 found compound is Cyclopropane and eventually on retention time 40.13 obtained compound is Benzene, \(1,1',1''',1''''-(1,2,3,4-\text{butanetetrayl})\)tetraakis[Shown above Fig.4 and Table-7].

2.3 Sample preparation

We take municipal mixed waste plastics or any other source of mixed waste plastics; we initially sort out the foreign particles, clean the waste plastics and clean wash them with detergent. After clean up all waste plastics spread in the open air for air dry. When dried out we shred them by scissors, now shredded plastics are grinded by grinding machine. Grinded samples structure are granular form small particles and that easy to put into the reactor. In our laboratory facility we can utilize 400g to 3kg of grinding sample for any experimental purposes.

3. Process description

3.1 Individual plastic to fuel production process

The process has been conducted in small scales with individual plastics in laboratory, on various waste plastics types; High-density polyethylene (HDPE, code 2), low-density polyethylene (LDPE, code 4), polypropylene (PP, code 5) and polystyrene (PS, code 6). These plastic types were investigated singly. For small-scale laboratory process the weight of input waste plastics ranges from 400 grams to 3kg. These waste plastics are collected, optionally sorted, cleaned of contaminants, and shredded into small pieces prior to the thermal liquefaction process. The process of converting the waste plastic to alternative energy begins with heating the solid plastic with or without the presence of cracking catalyst to form liquid slurry (thermal liquefaction in the range of 370-420 °C), condensing the vapor with standard condensing column to form liquid hydrocarbon fuel termed “NSR fuel”. Preliminary tests on the produced NSR fuel have shown that it is a mixture of various hydrocarbons range. The produced fuel density varies based on individual plastic types. In equivalent to obtaining the liquid hydrocarbon fuel we also receive light gaseous hydrocarbon compounds \((\text{C}_1-\text{C}_4)\) which resembles natural gas. Further fractional distillation based on different temperature is producing different category fuels; such as heating oil, gasoline, Naphtha (chemical), Aviation, Diesel and Fuel Oil. Experiment diagram given below in Fig.5.

3.2 Mixed waste plastic to fuel production process

Mixed waste plastics to fuel production process performed in the laboratory on various waste plastics types; High-density polyethylene (HDPE, code 2), low-density polyethylene
Municipal Waste Plastic Conversion into Different Category of Liquid Hydrocarbon Fuel

Fig. 5. Individual & Waste Plastic to Fuel Production Process Diagram

(LDPE, code 4), polypropylene (PP, code 5) and polystyrene (PS, code 6). These processes were investigated with mixture of several plastics such as HDPE-2, LDPE-4, and PP-5 & PS-6. These waste plastics are collected, optionally sorted, cleaned of contaminants, and shredded into small pieces prior to the thermal degradation process. The experiment could be randomly mixture of waste plastics or proportional ratio mixture of waste plastics. For small-scale laboratory process the weight of input waste plastics ranges from 300 grams to 3kg. In the laboratory processes our present reactor chamber capacity is 2-3 kg. We put 2 kg of grinding sample into the reactor chamber to expedite the experiment process. At the starting point of experiment reactor temperature set up at 350 ºC for quick melting, after melted temperature maintained manually from “reactor temperature profile menu option” by increasing and decreasing depending to the rate of reaction. The optimum temperature (steady & more fuel production state) is 305 ºC. From 2kg of waste plastics obtained fuel amount is 2 liter 600 ml (2600 ml), fuel density is 0.76 g/ml. We defined the fuel as heating oil named “NSR fuel”. The experiment additionally produced light gases Methane, Ethane, Propane and Butane as well as few amount of carbon ashes as a remaining residue. These light gases would be the alternative source of natural gases. Mixed waste plastic to produced fuel preliminary test indicated that the hydrocarbon compound range from C₃ to C₂₇.

3.3 Fractional distillation process

Fractional distillation process has been conducted according to the laboratory scale. We measured 700 ml of NSR fuel called heating fuel and took the weight of 1000 ml boiling flask (Glass Reactor). Subsequently fuel poured 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 with high temperature apiezon grease and insulated by aluminum foil paper. Initially we ran the experiment at 40 ºC to collect gasoline grade, after gasoline collection subsequently we raised the temperature to 110 ºC for
naphtha (Chemical), 180 ºC for aviation fuel, 260 º C for diesel fuel and eventually at 340 ºC we found fuel oil. At the end of the experiment remaining residual fuel was less, approximately amount 10-15 ml. Out of 700 ml NSR fuel we collected 125 ml of gasoline; density is 0.72 g/ml, 150 ml of naphtha; density is 0.73, 200 ml of aviation fuel; density is 0.74, 150 ml of diesel fuel; density is 0.80 g/ml and 50-60 ml of fuel oil; density is 0.84.

### 4. Fuel production yield percentage

After all experiment done on behalf of each experiment we calculated the yield percentages of fuel production, light gases and residue. In addition described the physical properties of each fuel such as fuel density, specific gravity, fuel color and fuel appearance respectively. Similarly, individual fuel production yield percentages & properties are given below in Table 8 (a) & 9 (a) and Mixed Waste Plastics to fuel Yield percentages & properties are also given below in Table 8(b) & 9 (b).

| Waste Plastic Name | Fuel Yield % | Light Gas % | Residue % |
|--------------------|--------------|-------------|-----------|
| HDPE-2             | 89.354       | 5.345       | 5.299     |
| LDPE-4             | 87.972       | 5.806       | 6.221     |
| PP-5               | 91.981       | 2.073       | 5.944     |
| PS-6               | 85.331       | 4.995       | 9.674     |

Table 8. (a): Individual Fuel Production Yield Percentage

| Sample Name     | Fuel  Yield % | Light Gas % | Residue % |
|-----------------|---------------|-------------|-----------|
| HDPE,LDPE,PP&PS | 90            | 5           | 5         |

Table 8. (b): Mixed Waste Plastic to Fuel Yield Percentage

| Name of Waste Plastic Fuel | Fuel Density gm/ml | Specific Gravity | Fuel Color                  | Fuel Appearance                          |
|---------------------------|--------------------|------------------|-----------------------------|------------------------------------------|
| LDPE-4                    | 0.771              | 0.7702           | Yellow, light transparent   | Little bit wax and ash content           |
| HDPE-2                    | 0.782              | 0.7812           | Yellow, no transparent      | Wax, cloudy and little bit ash content   |
| PP-5                      | 0.759              | 0.7582           | Light brown, light transparent | Little bit wax and ash content |
| PS-6                      | 0.916              | 0.9150           | Light yellow, not transparent | Wax, cloudy and little bit ash content |

Table 9. (a): Individual Plastic to Fuel Properties

| Name of Fuel                  | Density g/ml | Specific Gravity | Fuel Color       | Fuel     |
|-------------------------------|--------------|------------------|------------------|----------|
| Mixed Plastic to Fuel         | 0.775        | 0.7742           | Yellow light transparent | Ash contain present |

Table 9. (b): Mixed Waste Plastic to Fuel Properties
4.1 Fuel analysis and result discussion
4.2 Gas Chromatography and Mass Spectrometer (GC/MS) analysis

Analysis of Individual waste plastics (HDPE-2, LDPE-4, PP-5, and PS-6) to individual fuel:

![Graph showing retention time vs. intensity](image)

**Fig. 6. GC/MS Chromatogram of HDPE-2 Waste Plastic to Fuel**

| Retention Time (Minutes) | Compound Name                  | Formula | Retention Time (Minutes) | Compound Name                  | Formula |
|--------------------------|--------------------------------|---------|--------------------------|--------------------------------|---------|
| 1.56                     | Propane                        | C₃H₈    | 12.18                    | Cyclopentane, hexyl             | C₁₁H₂₂  |
| 1.66                     | 2-Butene, (E)-                 | C₄H₈    | 12.92                    | 1-Dodecene                     | C₁₂H₂₄  |
| 1.68                     | Butane                         | C₄H₁₀   | 13.05                    | Dodecane                       | C₁₂H₂₆  |
| 1.96                     | Cyclopropane, 1,2-dimethyl-, cis-| C₅H₁₀  | 13.76                    | Cyclododecane                  | C₁₂H₂₄  |
| 9.65                     | 1-Decene                       | C₁₀H₂₀  | 27.98                    | 1-Docosene                     | C₂₂H₄₄  |
| 9.80                     | Decane                         | C₁₀H₂₂  | 28.09                    | Tetracosane                    | C₂₄H₅₀  |
| 11.35                    | 1-Undecene                     | C₁₁H₂₂  | 30.24                    | 1-Docosene                     | C₂₂H₄₄  |
| 11.49                    | Undecane                       | C₁₁H₂₄  | 30.38                    | Octacosane                     | C₂₈H₅₈  |

**Table 10. GC/MS Chromatogram Compound List of HDPE-2 Waste Plastic to Fuel**
Fig. 7. GC/MS Chromatogram of LDPE-4 Waste Plastic to Fuel

| Retention Time (Minutes) | Compound Name                  | Compound Formula | Retention Time (Minutes) | Compound Name       | Compound Formula |
|--------------------------|--------------------------------|------------------|--------------------------|---------------------|------------------|
| 1.55                     | Cyclopropane                   | C₃H₆             | 12.92                    | 1-Dodecene          | C₁₂H₂₄           |
| 1.68                     | Butane                         | C₄H₁₀            | 13.06                    | Dodecane            | C₁₂H₂₆           |
| 1.96                     | 2-Pentene, (E)-                | C₅H₁₀            | 13.76                    | Cyclododecane       | C₁₂H₂₄           |
| 1.99                     | Pentane                        | C₅H₁₂            | 14.40                    | 1-Tridecene         | C₁₃H₂₆           |
| 10.48                    | Cyclodecane                    | C₁₀H₂₀           | 24.88                    | Heneicosane         | C₂₁H₄₄           |
| 10.89                    | Cyclohexene, 3- (2- methylpropyl)- | C₁₀H₁₈        | 26.31                    | Heneicosane         | C₂₁H₄₄           |
| 11.35                    | 1-Undecene                     | C₁₁H₂₂           | 28.09                    | Tetracosane         | C₂₄H₅₀           |
| 11.49                    | Undecane                       | C₁₁H₂₄           | 33.21                    | Octacosane          | C₂₈H₅₈           |

Table 11. GC/MS Chromatogram Compound List of LDPE-4 Waste Plastic to Fuel
Fig. 8. GC/MS Chromatogram of PP-5 Waste Plastic to Fuel

| Retention Time (Minute) | Compound Name                  | Formula | Retention Time (Minute) | Compound Name                  | Formula   |
|-------------------------|--------------------------------|---------|-------------------------|--------------------------------|-----------|
| 1.55                    | Cyclopropane                   | C₃H₆    | 11.13                   | Cyclooctane, 1,4-dimethyl-, cis-| C₁₀H₂₀    |
| 1.66                    | 1-Propene, 2-methyl-            | C₄H₈    | 11.20                   | 1-Tetradecene                  | C₁₄H₂₈    |
| 1.99                    | Pentane                        | C₅H₁₂   | 11.86                   | 1-Dodecanol, 3,7,11-trimethyl-(2,4,6-trimethylcyclohexyl) methanol | C₁₃H₂₈O   |
| 2.48                    | Pentane, 2-methyl-              | C₆H₁₄   | 12.25                   | Dodecan, 1-cyclopentyl-4-(3-cyclopentylpropyl)-Cyclotetradecane | C₂₃H₄₈    |
| 9.64                    | Nonane, 2-methyl-3-methylene-3-undecene, (Z)- | C₁₁H₂₂ | 23.13                   | 1,7,11-trimethyl-4-(1-methylethyl) Dodecan, 1-cyclopentyl-4-(3-cyclopentylpropyl) | C₂₀H₄₀ |
| 9.74                    | 3-Decene, 2,2-dimethyl- (E)-    | C₁₂H₂₄  | 25.72                   |                                | C₂₃H₄₈    |
| 9.92                    | Octane, 3,3-dimethyl-           | C₁₀H₂₂  | 28.95                   |                                |           |
| 10.73                   |                                |         |                         |                                |           |

Table 12. GC/MS Chromatogram Compound List of PP-5 Waste Plastic to Fuel
Table 13. GC/MS Chromatogram Compound List of PS-6 Waste Plastic to Fuel

| Retention Time (Minute) | Compound Name       | Formula | Retention Time (Minute) | Compound Name                       | Formula |
|-------------------------|---------------------|---------|-------------------------|-------------------------------------|---------|
| 3.65                    | 1,5-Hexadiyne       | C₆H₆    | 17.68                   |-Benzene, 1,1’-(1,2-ethanediyl)bis- | C₁₄H₁₄  |
|                         |                     |         |                         | Benzene, 1,1’-(1-methyl-1,2-ethanediyl)bis- | C₁₅H₁₆ |
| 5.54                    | Toluene             | C₇H₈    | 18.03                   | Benzene, 1,1’-(1,3-propanediyl)bis- | C₁₅H₁₆  |
| 7.94                    | Styrene             | C₈H₈    | 19.30                   | Naphthalene, 1-phenyl-o-Terphenyl   | C₁₆H₁₂  |
| 11.00                   | Acetophenone        | C₈H₈O   | 21.61                   | 2-Phenylnaphthalene 9-Phenyl-5H-benzocycloheptene | C₁₇H₁₄ |
| 13.07                   | Naphthalene         | C₁₀H₈   | 21.81                   | o-Terphenyl                      | C₁₈H₁₄  |
| 15.84                   | Biphenyl            | C₁₂H₁₀  | 22.83                   |                                      | C₁₆H₁₂  |
| 16.51                   | Diphenylmethane     | C₁₃H₁₂  | 24.14                   |                                      | C₁₇H₁₄  |
| 17.22                   | Benzene, 1,1’-ethylidenebis- | C₁₄H₁₄ | 24.67                   | p-Terphenyl                      | C₁₈H₁₄  |

Fig. 9. GC/MS Chromatogram of PS-6 Waste Plastic to Fuel

From GCMS analysis of Individual HDPE-2, LDPE-4, PP-5, and PS-6 fuel, in accordance with their numerous retention times many compounds are found, some of them are mentioned shortly. In HDPE-2 fuel at retention time 1.56, compound is Propane (C₃H₈), and finally at retention time 30.38 obtained compound is Octacosane (C₂₈H₅₈). [Shown above, Fig.6 & Table-10]. In LDPE-4 fuel at retention time 1.55, compound is Cyclopropane (C₆H₁₀), and finally at retention time 33.21 obtained compound is Octacosane (C₂₈H₅₈) [Shown above,
Fig.7 & Table-11]. In PP-5 initially at retention time 1.55 compound is Cyclopropane (C$_3$H$_6$) and finally at retention time 28.95 obtained compound is Dodecane,-1-Cyclopentyl-4-(3-Cyclopentylpropyl) (C$_{22}$H$_{46}$O$_2$) [Shown above, Fig.8 & Table-12]. Accordingly in PS-6 at retention time 3.65 found compound is 1, 5-Hexadiyne and eventually at retention time 24.67 obtained compound is p-Terphenyl (C$_{18}$H$_{14}$) [Shown above, Fig.9 & Table-13].

**Analysis of Mixed Waste Plastics to Fuel (Heating Oil):**

| Compound Name | Formula | Compound Name | Formula |
|---------------|---------|---------------|---------|
| Cyclopropane   | (C$_3$H$_6$) | Dodecane      | (C$_{12}$H$_{26}$) |
| 2-Butene, (E)-| (C$_4$H$_8$) | Decane, 2,3,5,8-| tetramethyl- |
| Pentane       | (C$_5$H$_{12}$) | 1-Tridecane   | (C$_{13}$H$_{26}$) |
| Pentane, 2-methyl- | (C$_6$H$_{14}$) | Tridecane     | (C$_{13}$H$_{28}$) |
| Cyclopropane, 1-| (C$_{11}$H$_{22}$) | Heneicosane   | (C$_{21}$H$_{44}$) |
| Undecane      | (C$_{11}$H$_{24}$) | Nonadecane    | (C$_{19}$H$_{40}$) |
| 1-Dodecanol, 3,7,11-| (C$_{15}$H$_{32}$ O) | Benzene, hexadecyl- | (C$_{22}$H$_{38}$) |
| 1-Dodecene    | (C$_{12}$H$_{24}$) | Heptacosane   | (C$_{27}$H$_{56}$) |

Table 14. GC/MS Chromatogram Compound List of Mixed Waste Plastic to Fuel (Heating Oil)

From GCMS analysis of NSR fuel (Called Heating Fuel) primarily we found long chain hydrocarbon of compound. In the GCMS data we have noticed that the obtained compounds are Cyclopropane (C$_3$H$_6$) to Heptacosane (C$_{27}$H$_{56}$) including long and short chain of hydrocarbon compound [Shown above, Fig.10 & Table-14].
GCMS Analysis of Mixed Waste Plastics to Fractional Distillation Fuel:

![GC/MS Chromatogram of Mixed Waste Plastic Fuel to 1st Fractional Fuel (Gasoline)](image)

Table 15. GC/MS Chromatogram compound list of Mixed Waste Plastic Fuel to 1st Fractional Fuel (Gasoline)

| Compound Name              | Formula  | Compound Name                  | Formula   |
|----------------------------|----------|--------------------------------|-----------|
| 1-Propene,2-methyl-         | (C4H8)   | Heptane                        | (C7H16)   |
| Butane                     | (C4H10)  | 1,4-hexadiene,4-methyl-        | (C7H12)   |
| 2-Pentene                  | (C5H10)  | 1,4-Heptadiene                 | (C7H12)   |
| 2-Pentene,(E)              | (C5H10)  | Cyclohexane,methyl-            | (C7H14)   |
| Cyclohexane                | (C6H12)  | 1-Nonane                       | (C9H18)   |
| Hexane,3-methyl            | (C7H16)  | Styrene                        | (C8H8)    |
| Cyclohexene                | (C6H10)  | Nonane                         | (C9H20)   |
| 1-Hexene,2-methyl-         | (C7H14)  | Benzene,(1-methylethyl)-       | (C9H12)   |
| 1-Heptane                  | (C7H14)  |                                |           |

Fig. 11. GC/MS Chromatogram of Mixed Waste Plastic Fuel to 1st Fractional Fuel (Gasoline)
**Fig. 12. GC/MS Chromatogram of Mixed Waste Plastic Fuel to 2\textsuperscript{nd} Fractional Fuel (Naphtha, Chemical)**

| Compound Name               | Formula  | Compound Name                  | Formula |
|-----------------------------|----------|--------------------------------|---------|
| 1-Hexene                    | (C$_6$H$_{12}$) | Cyclopentane-butyl-            | (C$_9$H$_8$) |
| Hexane                      | (C$_6$H$_{14}$) | Benzene,propyl                 | (C$_9$H$_{12}$) |
| 1-Heptene                   | (C$_7$H$_{14}$) | a-methylsyrene                 | (C$_9$H$_{10}$) |
| Heptane                     | (C$_7$H$_{16}$) | 1-Decene                       | (C$_{10}$H$_{20}$) |
| 2,4-dimethyl-1-heptene      | (C$_9$H$_{18}$) | Cyclopropane,1-heptyl-2-methyl- | (C$_{11}$H$_{22}$) |
| Ethylbenzene                | (C$_8$H$_{10}$) | Undecane                       | (C$_{11}$H$_{24}$) |
| 1-Nonene                    | (C$_9$H$_{18}$) | 1-Dodecane                     | (C$_{12}$H$_{24}$) |
| Styrene                     | (C$_8$H$_{8}$) | Dodecane                       | (C$_{12}$H$_{26}$) |
| 1,3,5,7-Cyclooctatetraene   | (C$_8$H$_{8}$) | Tridecane                      | (C$_{13}$H$_{28}$) |
| Nonane                      | (C$_9$H$_{20}$) | Tetradecane                    | (C$_{14}$H$_{30}$) |

**Table 16. GC/MS Chromatogram Compound List of Mixed Waste Plastic Fuel to 2\textsuperscript{nd} Fractional Fuel (Naphtha, Chemical)**
Fig. 13. GC/MS Chromatogram of Mixed Waste Plastic Fuel to 3rd Fractional Fuel (Aviation)

| Retention Time (Min.) | Compound Name | Formula | Retention Time (Min.) | Compound Name | Formula |
|-----------------------|---------------|---------|-----------------------|---------------|---------|
| 7.04                  | Styrene       | C8H8    | 14.93                 | Tetradecane   | C14H30  |
| 8.60                  | α-Methylstyrene | C9H10  | 16.12                | Cyclopentadecane | C15H30 |
| 10.18                 | Cyclooctane,1,4-dimethyl,cis- | C10H20 | 16.23                | Pentadecane   | C15H32  |
| 10.38                 | 1-Undecene    | C11H22  | 17.37                | 1-Hexadecene  | C16H32  |
| 12.07                 | Dodecane      | C12H26  | 19.80                | E-15-Heptadecanal | C17H32O |
| 13.42                 | 1-Tridecane   | C13H26  | 19.89                | Octadecane    | C18H38  |
| 13.56                 | Tridecane     | C13H28  | 21.13                | Nonadecane    | C19H40  |
| 14.81                 | Cyclotetradecane | C14H28 | 22.45                | Eicosane      | C20H42  |

Table 17. GC/MS Chromatogram Compound list of Mixed Waste Plastic Fuel to 3rd Fractional Fuel (Aviation)
Fig. 14. GC/MS Chromatogram of Mixed Waste Plastic Fuel to 4th Fractional Fuel (Diesel)

| Compound Name          | Formula    | Compound Name         | Formula    |
|------------------------|------------|-----------------------|------------|
| Pentane                | (C5H12)    | 1-Pentadecene         | (C15H30)   |
| 1-Pentene, 2-methyl-   | (C6H12)    | Pentadecane           | (C15H32)   |
| Heptane, 4-methyl-     | (C8H18)    | 1-Nonadecanol         | (C19H40 O) |
| Toluene                | (C7H8)     | 1-Hexadecene          | (C16H32)   |
| E-14-Hexadecenal       | (C16H30 O) | Eicosane              | (C20H42)   |
| 4-Tetradecene, (E)-    | (C14H28)   | Heneicosane           | (C21H44)   |
| Tetradecane            | (C14H30)   | Octacosane            | (C28H58)   |

Table 18. GC/MS Chromatogram Compound List of Mixed Waste Plastic Fuel to 4th Fractional Fuel (Diesel)
Table 19. GC/MS Chromatogram Compound list of Mixed Waste Plastic Fuel to 5th Fractional Fuel (Fuel Oil)

| Compound Name               | Formula       | Compound Name               | Formula       |
|-----------------------------|---------------|-----------------------------|---------------|
| 1) 1-Propene, 2-methyl-     | (C₄H₈)       | 16) Tridecane               | (C₁₃H₂₈)     |
| 2) Pentane                  | (C₅H₁₂)       | 17) Tetradecane              | (C₁₄H₃₀)     |
| 3) 1-Pentene, 2-methyl-     | (C₆H₁₂)       | 18) Pentadecane              | (C₁₅H₃₂)     |
| 4) Hexane                   | (C₆H₁₄)       | 19) Hexadecane               | (C₁₆H₃₄)     |
| 5) Heptane                  | (C₇H₁₆)       | 20) Benzene, 1,1’-(1,3-     | (C₁₅H₁₆)     |
|                             |               | propanediyl)bis-            |               |
| 6) α-Methylstyrene          | (C₉H₁₀)       | 27) Heneicosane              | (C₂₁H₄₄)     |
| 7) Decane                   | (C₁₀H₂₂)      | 28) Tetracosane              | (C₂₄H₅₀)     |
| 8) Undecane                 | (C₁₁H₂₄)      | 29) Heptacosane              | (C₂₇H₅₆)     |

GC/MS analysis of fractional distillation fuel, a lot of compound is appeared in each individual fuel. Some of those compounds are mentioned, such as in Gasoline (1st Fraction) we found Carbon range C₄ to C₅ and compound is 1-Propene-2-Methyl (C₅H₈) to Benzene, (1-methylethyl) - (C₆H₁₂) [Shown above, Fig.11 & Table-15]. In naphtha (2nd Fraction) Carbon range is C₅ to C₁₄ and compound is 1-Hexene (C₆H₁₂) to Tetradecane (C₁₄H₃₀) [Shown above, Fig.12 & Table-16]. In Aviation fuel (3rd Fraction) Carbon range is C₅ to C₂₀ and compound is Styrene (C₆H₈) to Eicosane (C₂₀H₄₂) [Shown above, Fig.13 & Table-17]. In Diesel (4th Fraction) Carbon range is C₅ to C₂₈ and compound is pentane (C₅H₁₂) to Octacosane (C₂₀H₄₀) [Shown above, Fig.14 & Table-18]. Eventually in Fuel oil (5th Fraction) Carbon range is C₄ to C₂₇, and compound is 1-Propene-2-methyl (C₅H₈) to Heptacosane (C₂₇H₅₆) [Shown above, Fig.15 & Table-19].
4.3 FTIR (Spectrum-100) analysis

Analysis of Individual waste plastics (HDPE-2, LDPE-4, PP-5, and PS-6) to individual fuel:

![FTIR Spectra of HDPE-2 Plastic to Fuel](image)

Fig. 16. FTIR Spectra of HDPE-2 Plastic to Fuel

| Band Peak Number | Wave Number (cm⁻¹) | Compound Group Name          |
|------------------|--------------------|------------------------------|
| 1                | 2956.38            | C-CH₃                        |
| 2                | 2921.84            | C-CH₃                        |
| 3                | 2853.19            | CH₂                          |
| 4                | 1641.69            | Non-Conjugated               |
| 5                | 1465.41            | CH₃                          |
| 6                | 1377.92            | CH₃                          |
| 7                | 991.76             | -CH=CH₂                      |
| 8                | 965.02             | -CH=CH-(Trans)               |
| 9                | 909.08             | -CH=CH₂                      |
| 10               | 721.39             | -CH=CH-(Cis)                 |
| 11               | 667.88             | -CH=CH-(Cis)                 |

Table 20. FTIR Spectra of HDPE-2 Plastic to Fuel Functional Group Name

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Fig. 17. FTIR Spectra of LDPE-4 Plastic to Fuel

| Band | Peak Number | Wave Number (cm⁻¹) | Functional Group Name |
|------|-------------|-------------------|-----------------------|
| 1    | 2956.72     | C-CH₃             |
| 2    | 2922.13     | C-CH₃             |
| 3    | 2853.50     | CH₂               |
| 4    | 1641.78     | Non-Conjugated    |
| 5    | 1458.43     | CH₃               |
| 6    | 1377.96     | CH₃               |
| 7    | 964.96      | -CH=CH₂           |
| 8    | 909.10      | -CH=CH-(Trans)    |
| 9    | 887.93      | -CH=CH₂           |
| 10   | 721.71      | -CH=CH-(Cis)      |
| 11   | 667.91      | -CH=CH-(Cis)      |

Table 21. FTIR Spectra of LDPE-4 Plastic to Fuel Functional Group Name
Fig. 18. FTIR Spectra of PP-5 Plastic to Fuel.

| Band Peak Number | Wave Number (cm⁻¹) | Compound Group Name | Band Peak Number | Wave Number (cm⁻¹) | Compound Group Name |
|------------------|--------------------|---------------------|------------------|--------------------|---------------------|
| 1                | 3074.99            | H Bonded NH         | 8                | 1377.07            | CH₃                 |
| 2                | 2955.87            | C-CH₃               | 9                | 1155.03            |                     |
| 3                | 2912.71            | C-CH₃               | 10               | 965.06             | -CH=CH- (Trans)     |
| 4                | 2871.87            | C-CH₃               | 11               | 887.02             | C=CH₂               |
| 5                | 2842.66            | C-CH₃               | 12               | 739.06             | -CH=CH-(Cis)        |
| 6                | 1650.20            | Amides              | 13               | 667.85             | -CH=CH-(Cis)        |
| 7                | 1465.95            | CH₂                 |                  |                    |                     |

Table 22. FTIR Spectra of PP-5 Plastic to Fuel Functional Group Name
Table 23. FTIR Spectra of PS-6 Plastic to Fuel Functional Group Name

| Band Peak Number | Wave Number (cm⁻¹) | Compound Group Name | Band Peak Number | Wave Number (cm⁻¹) | Compound Group Name |
|------------------|--------------------|---------------------|------------------|--------------------|---------------------|
| 1                | 3083.59            | =C-H                | 15               | 1414.28            | CH₂                 |
| 2                | 3060.73            | =C-H                | 16               | 1376.10            | CH₃                 |
| 3                | 3027.21            | =C-H                | 17               | 1317.86            | Acetates            |
| 4                | 2966.73            | C-CH₃               | 18               | 1288.55            | Conjugated          |
| 5                | 2874.03            | C-CH₃               | 19               | 1202.23            | CH=CH-(Cis)         |
| 6                | 2834.62            | C-CH₃               | 20               | 1178.59            | CH=CH-(Cis)         |
| 7                | 1943.85            |                     | 21               | 1082.33            | Acetates            |
| 8                | 1802.56            | Non-Conjugated      | 22               | 1028.94            | -CH=CH₂             |
| 9                | 1693.70            | Conjugated          | 23               | 1020.83            | -CH=CH₂             |
| 10               | 1630.02            | Conjugated          | 24               | 990.91             | Acetates            |
| 11               | 1603.28            | Conjugated          | 25               | 906.80             | Acetates            |
| 12               | 1575.74            |                     | 26               | 775.16             |                     |
| 13               | 1494.73            |                     | 27               | 729.65             | -CH=CH-(Cis)        |
| 14               | 1450.70            | CH₃                 | 28               | 694.78             | -CH=CH-(Cis)        |

Fig. 19. FTIR Spectra of PS-6 Plastic to Fuel
In FTIR analysis of HDPE-2 fuel obtained functional groups are C-CH$_3$, CH$_2$, Non-Conjugated, CH$_3$-CH=CH$_2$. CH=CH-(Cis) and -CH=CH-(Trans) [Shown above, Fig.16 & Table-20]. In LDPE-4 analysis functional groups are C-CH$_3$, CH$_2$, Non-Conjugated, CH$_3$-CH=CH$_2$. -CH=CH-(Cis) and -CH=CH-(Trans) [Shown above, Fig.17 & Table-21]. In PP-5 analysis functional groups are CH$_3$-CH$_2$. -CH=CH-(Cis) and -CH=CH-(Trans). [Shown above, Fig.18 & Table-22]. Subsequently in PS-6 analysis obtained functional groups are CH$_2$, CH$_3$, Acetates, -CH=CH$_2$ and -CH=CH-(Cis) etc. [Shown above, Fig.19 & Table-23].

**FTIR Analysis of Mixed Waste Plastics to Fuel:**

![FTIR Spectra of Mixed Waste Plastic to Fuel](image)

**Table 24. FTIR Spectra of Mixed Waste Plastic to Fuel Functional Group Name**

| Band Peak Number | Wave Number (cm$^{-1}$) | Functional Group Name | Band Peak Number | Wave Number (cm$^{-1}$) | Functional Group Name |
|------------------|-------------------------|-----------------------|------------------|-------------------------|-----------------------|
| 1                | 3075.19                 | H Bonded NH           | 13               | 1377.71                 | CH$_3$ Acetates       |
| 2                | 2916.58                 | CH$_2$                | 19               | 1029.84                 |                       |
| 3                | 2728.78                 | C-CH$_3$              | 20               | 990.95                  | Secondary Cyclic Alcohol |
| 5                | 1938.53                 | Non-Conjugated        | 21               | 965.16                  | -CH=CH-(trans)        |
| 6                | 1818.59                 | Non-Conjugated        | 22               | 908.64                  | -CH=CH$_2$           |
| 7                | 1781.20                 | Non-Conjugated        | 23               | 887.75                  | C=CH$_2$             |
| 8                | 1720.59                 | Non-Conjugated        | 26               | 739.15                  | -CH=CH-(cis)         |
| 9                | 1649.79                 | Amides                | 27               | 727.92                  | -CH=CH-(cis)         |
| 10               | 1605.54                 | Non-Conjugated        | 28               | 696.66                  | -CH=CH-(cis)         |
| 12               | 1452.16                 | CH$_2$                | 29               | 675.78                  | -CH=CH-(cis)         |
In FTIR analysis of mixed waste plastics to NSR fuel obtained functional groups are: \( \text{CH}_3 \), Acetates, Secondary Cyclic Alcohol, \(-\text{CH=CH}_2\), \( \text{C=CH}_2 \), \(-\text{CH=CH-}_\text{(Cis)} \) and \(-\text{CH=CH-}_\text{(Trans)} \) etc. [Shown above, Fig. 20 & Table-24].

**FTIR Analysis of Mixed Waste Plastics to Fractional Distillation Fuel:**

![FTIR Spectra of Mixed Waste Plastic Fuel to 1st Fractional Fuel (Gasoline)](image)

**Table 25. Mixed Waste Plastic Fuel to 1st Fractional Fuel (Gasoline) FTIR Functional Group List**

| Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name               | Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name               |
|------------------|----------------------------|-------------------------------------|------------------|----------------------------|-------------------------------------|
| 1                | 3078.07                    | H Bonded NH                         | 13               | 1378.54                    | \( \text{CH}_3 \)                  |
| 2                | 2921.04                    | C-\( \text{CH}_3 \)                 | 19               | 1030.44                    | Acetates                           |
| 3                | 2732.37                    | C-\( \text{CH}_3 \)                 | 20               | 993.17                     | Secondary Cyclic Alcohol           |
| 4                | 2669.78                    | C-\( \text{CH}_3 \)                 | 21               | 965.30                     | \(-\text{CH=CH-}_\text{(trans)} \) |
| 6                | 1853.61                    | Non-Conjugated                     | 22               | 909.69                     | \(-\text{CH=CH}_2 \)               |
| 7                | 1821.24                    | Non-Conjugated                     | 23               | 888.42                     | \( \text{C=CH}_2 \)                |
| 8                | 1720.48                    | Non-Conjugated                     | 26               | 728.40                     | \(-\text{CH=CH-}_\text{(cis)} \)   |
| 9                | 1642.16                    | Conjugated                         | 27               | 694.80                     | \(-\text{CH=CH-}_\text{(cis)} \)   |
| 10               | 1605.33                    | Conjugated                         | 28               | 675.76                     | \(-\text{CH=CH-}_\text{(cis)} \)   |
| 12               | 1456.00                    | \( \text{CH}_3 \)                  | 29               | 628.70                     | \(-\text{CH=CH-}_\text{(cis)} \)   |
Fig. 22. FTIR Spectra of Mixed Waste Plastic Fuel to 2nd Fractional Fuel (Naphtha, Chemical)

| Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name | Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name |
|------------------|-----------------------------|-----------------------|------------------|-----------------------------|-----------------------|
| 2                | 3063.12                     | =C-H                  | 16               | 1641.16                     | Non-Conjugated        |
| 3                | 2933.39                     | C-CH\(_3\)            | 17               | 1631.00                     | Non-Conjugated        |
| 4                | 2730.96                     | C-CH\(_3\)            | 21               | 1460.04                     | CH\(_3\)              |
| 5                | 2669.39                     | C-CH\(_3\)            | 22               | 1377.48                     | CH\(_3\)              |
| 9                | 1940.47                     | Non-Conjugated        | 30               | 1029.53                     | Acetates              |
| 10               | 1871.71                     | Non-Conjugated        | 31               | 1020.91                     | Acetates              |
| 11               | 1816.96                     | Non-Conjugated        | 32               | 990.38                      | -CH=CH\(_2\)          |
| 12               | 1799.27                     | Non-Conjugated        | 33               | 965.73                      | -CH=CH- (trans)       |
| 13               | 1743.30                     | Conjugated            | 34               | 907.57                      | -CH=CH\(_2\)          |
| 14               | 1717.20                     | Non-Conjugated        | 37               | 728.99                      | -CH=CH- (cis)         |
| 15               | 1685.59                     | Conjugated            | 38               | 700.77                      | -CH=CH- (cis)         |

Table 26. Mixed Waste Plastic Fuel to 2nd Fractional Fuel (Naphtha) FTIR Functional Group List
Fig. 23. FTIR Spectra of Mixed Waste Plastic Fuel to 3rd Fractional Fuel (Aviation)

| Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name | Band Peak Number | Wave Number (cm\(^{-1}\)) | Functional Group Name |
|------------------|-----------------------------|------------------------|------------------|-----------------------------|------------------------|
| 3                | 2929.07                     | C-CH\(_3\)             | 17               | 1467.90                     | CH\(_3\)               |
| 4                | 2730.27                     | C-CH\(_3\)             | 18               | 1377.65                     | CH\(_3\)               |
| 5                | 2671.93                     | C-CH\(_3\)             | 22               | 1029.94                     | Acetates               |
| 8                | 1938.55                     | Non-Conjugated         | 23               | 991.72                      | -CH=CH\(_2\)           |
| 9                | 1868.05                     | Non-Conjugated         | 24               | 965.06                      | -CH=CH\(_2\) (trans)   |
| 10               | 1820.48                     | Non-Conjugated         | 25               | 909.12                      | CH=CH\(_2\)            |
| 11               | 1797.01                     | Non-Conjugated         | 26               | 888.50                      | C=CH\(_2\)             |
| 12               | 1746.03                     | Non-Conjugated         | 29               | 721.81                      | -CH=CH\(_2\) (cis)     |
| 13               | 1713.72                     | Non-Conjugated         | 30               | 698.09                      | -CH=CH\(_2\) (cis)     |
| 14               | 1641.59                     | Non-Conjugated         |                  |                             |                        |
Municipal Waste Plastic Conversion into Different Category of Liquid Hydrocarbon Fuel

Fig. 24. FTIR Spectra of Mixed Waste Plastic to Fuel (Diesel)

| Band Peak Number | Wave Number (cm⁻¹) | Functional Group Name | Band Peak Number | Wave Number (cm⁻¹) | Functional Group Name |
|------------------|--------------------|-----------------------|------------------|--------------------|-----------------------|
| 1                | 3063.15            | =C-H                  | 16               | 1452.15            | CH₂                   |
| 2                | 3027.13            | =C-H                  | 17               | 1377.50            | CH₃                   |
| 3                | 2917.31            | CH₂                   | 22               | 1030.26            | Acetates              |
| 4                | 2730.18            | C-CH₃                 | 23               | 990.17             | -CH=CH₂               |
| 5                | 2674.43            | C-CH₃                 | 24               | 965.09             | -CH=CH- (trans)       |
| 8                | 1938.19            | Non-Conjugated        | 25               | 908.18             | -CH=CH₂               |
| 9                | 1866.94            | Non-Conjugated        | 26               | 889.16             | C=CH₂                 |
| 10               | 1797.37            | Non-Conjugated        | 29               | 742.29             | -CH=CH- (cis)         |
| 11               | 1745.73            | Non-Conjugated        | 30               | 721.52             | -CH=CH- (cis)         |
| 12               | 1721.33            | Non-Conjugated        | 31               | 697.70             | -CH=CH- (cis)         |
| 13               | 1641.33            | Non-Conjugated        |                  |                    |                       |

Table 28. Mixed Waste Plastic Fuel to 4th Fractional Fuel (Diesel) FTIR Functional Group List

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Table 29. Mixed Waste Plastic Fuel to 5th Fractional Fuel (Fuel Oil) FTIR 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           | CH₂                   | 9                | 991.95            | Secondary Cyclic Alcohol |
| 2                | 2853.06           | CH₂                   | 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           | CH₂                   | 14               | 698.20            | -CH=CH- (cis)           |
| 7                | 1377.43           | CH₃                   |                  |                   |                       |

In FTIR analysis of fractional distillation fuel such as in 1ST Fraction Fuel (Gasoline) obtained functional groups are CH₃, Acetates, Secondary Cyclic Alcohol, -CH=CH₂.
C≡CH₂,nad -CH=CH- (Cis). [Shown above, Fig.21 & Table-25]. In 2\textsuperscript{nd} Fraction Fuel (Naphtha) analysis functional groups are CH₃, Non-Conjugated, Acetates,-CH=CH₂,-CH=CH- (Cis) and -CH=CH-(Trans). [Shown above, Fig.22&Table-26]. In 3\textsuperscript{rd} Fraction Fuel (Aviation) analysis functional groups are CH₂, Acetates, C-CH₂,-CH=CH- (Cis) and -CH=CH-(Trans) [Shown above, Fig.23&Table-27]. In 4\textsuperscript{th} Fraction Fuel (Diesel) analysis functional groups are CH₂, CH₃, Acetates,-CH=CH₂, C=CH₂ and,-CH=CH- (Cis) [Shown above, Fig.24 &Table-28]. Subsequently in 5\textsuperscript{th} Fraction Fuel (Fuel Oil) analysis obtained functional groups are Secondary Cyclic Alcohol,-CH=CH₂, C=CH₂, -CH=CH (Trans) and –CH=CH-(Cis) etc. [Shown above, Fig.25&Table-29].

5. Electricity production from waste plastic fuel

Both NSR fractional fuels (NSR fractional 1st Fractional Fuel and NSR 4th Fractional Fuel) have been used to produce electricity by the help of conventional internal combustion generator. A flow diagram illustrating the process of energy production and consumption from NSR Fuel (Heating Oil) is shown below in Fig.26.

![Flow diagram of electricity generation consumption](Fig. 26. Flow diagram of electricity generation consumption)

NSR fractional 1st collection fuel was used in a gasoline generator with max 4.0 kW and volt output of 120. ~1 litter of fractional fuel was injected in the generator and with ~2900 watt constant demand; the generator ran a total of 42 minutes. A similar test was performed with commercial gasoline (87). ~1 litter of commercial gasoline (87) was injected and with the same ~ 2900 watt, constant demand the generator ran a total of 38 minutes. The difference in time occurs because NSR fraction 1st collection fuel has longer Carbon content than that of the commercial gasoline (87).

NSR fractional 4th collection fuel was used in a diesel generator with a max 4.0 kW and an output of 120 volt. ~1 litter of NSR fractional 2\textsuperscript{nd} collection fuel was injected in the generator and with a constant demand of 3200 watt; the generator ran a total of 42 minutes. The same
test was conducted with commercial diesel, and with the same demand the generator ran for 34 minutes.

A diagram [Fig.27] is provided below showing the produced electricity consumption of commercial gasoline (87) and NSR fractional fuel 1st collection.

Fig. 27. Electricity Consumption and run time monitored by EML 2020 logger system for 1st Fractional Fuel (Gasoline) and Commercial Gasoline87.

Fig. 28. Electricity Output Comparison Graph of Waste Plastic Fuel to 4th Fractional Fuel and Commercial Diesel Fuel
Comparison of NSR 4\textsuperscript{th} fraction fuel and commercial diesel was conducted using an AMCO Diesel Generator. Above, Fig. 28 and Table 30 demonstrate the comparative results between the two fuels. The results indicate that the NSR-2 fuel provided a longer run time of the generator than the diesel. This is due to the NSR fuel having longer carbon chains than the diesel fuel.

6. Automobile test driving

Both NSR fractional 5\textsuperscript{th} collection fuel and commercial gasoline (87) was used for a comparison automobile test. A 1984 Oldsmobile vehicle (V-8 powered engine) was used for the test-drive and one gallon of fuel was used for both cases after complete drainage of the pre-existing fuel in the fuel tank. The test-drive was done on a rural highway with an average speed of 55 mph.

Based on the preliminary automobile test-drive, the NSR fuel has offered a competitive advantage in mileage over the commercial gasoline-87. NSR fuel showed better mileage performance of 21 miles per gallon (mpg) compared to 18 mpg with commercial gasoline (87).

It is expected that NSR double condensed fuel will show even higher performance with more fuel-efficient car such as V-4 engine and hybrid vehicles. Additional test-driving is going to be conducted in the near future to verify the results.

7. Conclusion

The conversion of municipal waste plastics to liquid hydrocarbon fuel was carried out in thermal degradation process with/without catalyst. Individually we ran our experiment on waste plastics such as: HDPE-2, LDPE-4, PP-5 & PS-6. Each of those experiment procedures are maintained identically, every ten (10) minutes of interval experiment was monitored and found during the condensation time changes of individual waste plastics external behavior different because of their different physical and chemical properties. Similarly, we ran another experiment with 2kg of mixture of waste plastics in stainless steel reactor. Initial temperature is 350 °C for quick melting and optimum temperature is 305 °C. For glass reactor every experiment temperature was maintained by variac meter, when experiment started variac percent was 90% (Tem-405 °C) for quick melting, after melted variac percent decreased to 70% (Tem- 315 °C) due to smoke formation. Average (optimum) used variac percent in this experiment 75% (337.5 °C). Gradually temperature range was maintained by variacmeter with proper monitoring. In fractional distillation process we separated different category of fuel such as gasoline, naphtha, jet fuel, diesel and fuel oil in accordance with their boiling point temperature profile.
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The atmosphere may be our most precious resource. Accordingly, the balance between its use and protection is a high priority for our civilization. While many of us would consider air pollution to be an issue that the modern world has resolved to a greater extent, it still appears to have considerable influence on the global environment. In many countries with ambitious economic growth targets the acceptable levels of air pollution have been transgressed. Serious respiratory disease related problems have been identified with both indoor and outdoor pollution throughout the world. The 25 chapters of this book deal with several air pollution issues grouped into the following sections: a) air pollution chemistry; b) air pollutant emission control; c) radioactive pollution and d) indoor air quality.

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