Research Article

New Alternative Vehicle Hydrocarbon Liquid Fuels from Municipal Solid Waste Plastics

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Abstract

Millions of vehicles on the road today are releasing a large amount of carbon dioxides (CO2) causing the climates to change drastically. Studies indicate that the CO2 released from vehicles is the main contributor of global warming. Alternative fuels developed from waste plastics have the potential to have a positive impact on the environment in two ways. First of all, the presence of waste plastics in the landfill causes fertile soils to decay and these waste plastics can be used for the production of high quality alternate fuels. Removing these harmful waste plastics from landfill and converting them into liquid hydrocarbon fuels can create a more stable environment than the one we are living in. This technology is environmentally friendly and projected to be produced at a very low cost compared to the current commercial fuels. Preliminary results showed that the NSR fuel has many similar characteristics as the current gasoline.

Keywords

fuel; hydrocarbon; thermal; waste plastic; condensation; catalyst; DSC; fraction; FT-IR; GC/MS

1 Introduction

Plastic is a macromolecule polymer, formed by polymerization of hydrocarbon materials and it has the ability to be shaped by the application of reasonable amount of heat and pressure. Plastics contain compounds such as carbon monoxide, sulfur and nitrogen. Plastics are being used all over the world, and afterwards, these plastics turn into waste plastics. The types of plastics include high-density polyethylene (HDPE, code 2), low-density polyethylene (LDPE, code 4), polypropylene (PP, code 5), and polystyrene (PS, code 6). According to a recent study, in the U.S., 30 million tons of total plastic are produced each year, with only about 4% now being recycled [5]. The rest of the waste plastics either end up in landfill or incineration. The waste plastic that ends up in the landfill when littered does not degrade for thousands of years causing lands to become infertile and environmentally unsafe for its inhabitants around them. Due to excessive amount of waste plastics discarded everyday, a large amount of them end up in incineration facilities. When incinerated, waste plastics release toxic gases such as carbon monoxide (CO), which causes health hazards, sulfur dioxides (SO2) when incinerated, which contributes to acid rain, nitrogen oxides (NOx) which contribute to ozone depletion and acid rain, and carbon dioxide (CO2), greenhouse gases that contribute to global warming.

Plastics like polyethylene bags are very lightweight. They do not stay steady in the landfill. If the plastic bags are not recycled, eventually they will find their way into water stream and end up in the Ocean region. Not only plastic bags but any plastic materials that are not recycled end up in the Ocean as well. This is proven in a study conducted by Charles J. Moore (Long Beach, California) about the Great Pacific Garbage Patch, which shows the horror and impacts that waste plastic can have on oceanic and marine life. According to his study, the Garbage Patch is estimated to be twice the size of Texas and contains ~ 3.5 million tons of waste material and 80% of it is waste plastic litter [9]. According to C. J. Moore’s 1999 study, there were 6 times more waste plastic in this part of the ocean than the zooplankton that feeds ocean life [9]. Also another study performed in 2002 showed that even off the coast of California, waste plastic outweigh zooplankton by a factor of 5 to 2 [10].

Many researches have been conducted to convert waste plastics into renewable energy sources. This is possible because plastics are originally made from crude oil. Crude oil is a very limited natural resource that is used to make transportation fuel, plastics and other products. Crude oil is a non-renewable energy source and since it is a natural resource it will deplete in the near future.

Successful methods have been carried out to convert waste plastics into liquid based fuels [1,8,12]. These methods include various procedures to convert the waste plastics such as Pyrolysis, in which the contents of waste plastics are thermally degraded to produce liquid-based fuels and other products without the presence of oxygen [3,
The process described in this particular paper to convert solid waste plastics into renewable energy sources is accomplished utilizing a basic form of thermal degradation. The basic form of thermal degradation has been tested and proven to produce fuel that can be used as an energy source [2,11,13,15].

The final product produced obtained from utilizing the thermal degradation process is in the form of liquid and it contains hydrocarbon materials. The experiment conducted to produce the liquid fuel is carried out in a stainless steel reactor system (Figure 1).

Figure 2 shows the process in which the waste plastics is processed using thermal degradation and distillation process.

Figures 3, 4, and 5 demonstrate the carbon content of NSR, NSR-1, and NSR-2 fuel in against their retention time analyzed using a GC/MS.

### 2 Experimental process description

The process uses thermal cracking to heat the waste plastic to form a liquid slurry, at a temperature ranging from 370 °C–420 °C, then the liquid slurry turns into vapor; that vapor is then condensed/distilled (see Figure 1) to produce the liquid hydrocarbon fuels. It should be noted that no chemicals are used to carry out this process and the end product is filtered using a commercial fuel purifier that operates using coalescence and centrifugal force.
Experiments conducted in a mini-scale have been performed with the majority of waste plastic 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 and in combination with each other. In a laboratory scale, the weight of a single batch of input plastic for the fuel production process ranges from 350 gm to 5 kg. The waste plastics are collected, optionally sorted, cleaned of contamination or without cleaning and grinded into small pieces prior to the thermal liquefaction process. In the double condensation process, two different types of fuel are collected at two types of different temperature range. The double condensed fuels are classified as NSR-1, NSR-2. NSR-1 (gasoline) will be collected at 200–240 °C and NSR-2 (diesel) in the range of 240–360 °C. Also during the fuel production process, some very light gas is produced (C1–C4). The gases include methane, ethane, propane and butane. These gases can be utilized as a heat source to carry out the fuel production process. A very minimum amount of solid carbon residue is leftover from the production step. The residues contents are similar to contents which are used for road and roof carpeting.

The initial and double condensed fuels were tested by the GC/MS to identify their compositions. A hydrocarbon chain length of (C3–C27) is present in the NSR fuel with a retention time ranging from 2 min to 27 min. After fractionating the NSR fuel, hydrocarbon chains are broken down into shorter ones because different temperature is used for each of the fuels. NSR-1 hydrocarbon chain was in the range (C4–C12) (see Table 2) and NSR-2 in the range (C9–C27) (see Table 3). These data indicate that the NSR fuels have a wide range of hydrocarbon groups resulting in a higher thermal content. The thermal content allows the fuel to burn for a longer period of time resulting in efficiency when used in compatible engines.

3 Fuel analysis and discussion

The initial and double condensed fuels were tested by the GC/MS to identify their compositions. A hydrocarbon chain length of (C3–C27) is present in the NSR fuel with a retention time ranging from 2 min to 27 min. After fractionating the NSR fuel, hydrocarbon chains are broken down into shorter ones because different temperature is used for each of the fuels. NSR-1 hydrocarbon chain was in the range (C4–C12) and NSR-2 in the range (C9–C27). These data indicate that the NSR fuels have a wide range of hydrocarbon groups resulting in a higher thermal content. The thermal content allows the fuel to burn for a longer period of time resulting in efficiency when used in compatible engines.

Experiments conducted showed that 2 mL of initial fuel could burn for about 5 min; also, emission released from burning of the fuel contains very low concentration of benzene, toluene, styrene, xylene, and naphthalene and contains low traces of sulfur.

Results obtained from Elemental Analyzer (EA) – 2400 series II CHNS mode indicate that the initial fuel contains 86.44% carbon and 13.96% hydrogen. The average of the fractionated fuels contains 86.00% carbon and 13.00% hydrogen. Empirical formula indicates that all the fuel’s carbon and hydrogen ratio is 1:2.

FTIR spectrum shows (Figure 6) NSR fuel has H bonded NH, CH2, C–CH3, non conjugated, conjugated, CH2, CH3, secondary cyclic alcohol, –CH=CH2, –CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis) (cis), NSR-1 fuel (Figure 7) has H bonded NH, C–CH3, C–CH3, C–CH3, amides (–NH), CH3/CH2, CH3, acetates (CH3COO–), secondary cyclic alcohols,–CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), NSR-2 fuel (Figure 8) has H bonded NH, C–CH3, C–CH3, C–CH3, secondary cyclic alcohols,–CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis). NSR initial fuel, NSR-1 and NSR-2 contain secondary cyclic alcohols, C=CH2, C=CH2 and Trans alkenes as well as CH3, CH2 group. These fuels have many compound group similarities, such as H bonded NH, C–CH3, –CH=CH2, –CH=CH– (trans) and
–CH=CH– (cis). These similar groups resemble the fuels containing an identical fingerprint, which suggests that the fuels are of a good quality. From the above comparative discussion, we can say that our NSR initial fuel, NSR-1 fuel and NSR-2 fuel have very long carbon chain hydrocarbon functional groups. Also most of the groups in the fuel are short chain hydrocarbon and contains light compounds resulting in higher burning time.
| Compound name                  | Formula     |
|-------------------------------|-------------|
| Cyclopropane                  | C3H6        |
| 2-Butene, (E)-                | C4H8        |
| Pentane                       | C5H12       |
| Pentane, 2-Methyl-             | C6H14       |
| 1-Pentene, 2-methyl-           | C6H12       |
| Hexane                        | C6H14       |
| 1-Pentene, 2,4-dimethyl-       | C7H14       |
| 1-Heptene                     | C7H14       |
| Heptane                       | C7H16       |
| Heptane, 4-methyl-             | C8H18       |
| Toluene                       | C7H8        |
| 1-Octene                      | C8H16       |
| Octane                        | C8H18       |
| Heptane, 2,4-dimethyl-         | C9H18       |
| 2,4-Dimethyl-1-Heptene         | C9H18       |
| Ethylbenzene                  | C9H10       |
| Styrene                       | C9H8        |
| Benzene, (1-methyl)-           | C10H12      |
| -Methylstyrene                | C10H10      |
| Decane                        | C10H22      |
| Nonane, 2,6-dimethyl-          | C11H24      |
| Benzene, 1-Propenyl-           | C10H10      |
| Cyclooctane, 1,4-dimethyl-,    | C10H20      |
| trans-                        |             |
| Cyclopropane, 1-heptyl-2-methyl-| C11H22     |
| Undecane                      | C11H24      |
| 1-Dodecanol, 3,7,11-trimethyl- | C13H32O     |
| 1-Dodecene                    | C12H24      |
| Dodecane                      | C12H26      |
| Decane, 2,3,5,8-tetramethyl-   | C13H30      |
| 1-Tridecene                   | C13H26      |
| Tridecene                     | C13H28      |
| Isotridecanol-                | C13H32O     |
| Benzene, heptyl-              | C13H20      |
| 5-Tetradecene, (E)-           | C14H28      |
| Tetradecane                   | C14H30      |
| Benzene, (3-Octylundecyl)-    | C15H34      |
| 1-Pentadecene                 | C15H30      |
| Pentadecane                   | C15H32      |
| Benzene, 1,1’-(3-methylbutylidene) bis- | C17H30      |
| 1-Hexadecene                  | C16H32      |
| Hexadecane                    | C16H34      |
| Benzene, 1,1’-(1,3-Propanediyl) bis- | C15H16      |
| Heptadecane                   | C17H36      |
| Benzene, 1,1’-(2-Butene-1,4-Diyil) bis- | C16H16      |
| 3-Eicosene, (E)-              | C20H40      |
| Nonadecane                    | C19H40      |
| 9-Nonadecene                  | C19H38      |
| Eicosane                      | C20H42      |
| 2-Phenylcyclohexene           | C16H12      |
| Heneicosane                   | C21H44      |
| Nonadecane                    | C19H40      |
| Benzene, hexadecyl-           | C22H38      |
| Heptacosane                   | C27H56      |

Table 1: GC/MS chromatogram of NSR fuel carbon compound and formula list.

| Compound name                | Formula     |
|-----------------------------|-------------|
| 2-Methyl-1-Propene          | (C3H8)      |
| Pentane                     | (C5H12)     |
| 3. 2-Methyl-Pentane         | (C6H14)     |
| 2-Methyl-1-Pentene          | (C7H14)     |
| Hexane                      | (C6H14)     |
| 2,4-Dimethyl-1-Pentene      | (C7H14)     |
| 3,5-Dimethyl-2-Hexene       | (C8H16)     |
| Toluene                     | (C7H8)      |
| Octane                      | (C8H18)     |
| 2,4-Dimethyl-1-Heptene      | (C9H18)     |
| Ethyl-Benzene               | (C8H10)     |
| Styrene                     | (C6H5)      |
| 1-Methyl-Benzene            | (C9H12)     |
| 1-Decene                    | (C10H20)    |
| 3,3-Dimethyl-Octane         | (C10H22)    |
| 3,7-Dimethyl-1-Octene       | (C10H30)    |
| Undecane                    | (C11H24)    |
| Dodecane                    | (C12H26)    |

Table 2: GC/MS chromatogram of NSR-1 fuel carbon compound and formula list.

| Compound name                | Formula     |
|-----------------------------|-------------|
| 2,4-Dimethyl-1-Heptene      | C9H18       |
| Styrene                     | C8H4        |
| Decane                      | C10H22      |
| 2,4-Dimethyl-1-Heptanol     | C9H20O      |
| 1,4-Dimethyl-Cyclooctane    | C9H20       |
| Undecane                    | C11H24      |
| 3,7,11-Trimethyl-1-decanol  | C12H32O     |
| 3-Dodecene                  | C12H24      |
| Dodecane                    | C12H26      |
| 2,3,5,8-Tetramethyl-Decane  | C14H30      |
| 2-Tridecene                 | C13H26      |
| 3-Octadecene                | C14H36      |
| 2-Isopropyl-5-Methyl-1-Heptanol | C12H32O  |
| 1-Tetradecene               | C14H30      |
| Tetradecane                 | C12H30      |
| 2,3,5,8-Tetramethyl-Decane  | C13H30      |
| 1-Tridecene                 | C13H26      |
| Hexadecane                  | C14H34      |
| 3,7,11-Trimethyl-1-Dodecanol | C15H32O    |
| Hexadecane                  | C15H34      |
| 1-Nonadecene                | C16H38      |
| Heptadecane                 | C17H36      |
| Octadecane                  | C18H38      |
| Nonadecane                  | C19H40      |
| Eicosane                    | C20H42      |
| Henicosane                  | C21H44      |
| Heptacosane                 | C27H56      |

Table 3: GC/MS chromatogram of NSR-2 fuel carbon compound and formula list.
According to EPA standards, the NSR-1 fuel contains no additional additives of octane booster as shown in Table 10. Also the concentration of benzene is very negligible.

4 Diesel car test emission result

The NSR-2 fuel was tested in a diesel engine to measure the emission released from burning the fuel. The results are listed in Table 11.

5 ASTM test results

The fuels produced have been also tested according to the American Standard for Testing Materials (ASTM) methods. Tests performed by a third party certified laboratory (INTERTEK, NJ) demonstrate the parameters of the NSR fuels. The results show that a very considerate amount of harmful compounds are present in the NSR fuels. The results are listed in Tables 7, 8, and 9.

Table 4: FT-IR spectrum functional compound group name of NSR fuel.

| Band serial | Band number (cm⁻¹) | Group name               |
|-------------|--------------------|--------------------------|
| 1st         | 3075.19            | H bonded NH              |
| 2nd         | 2916.58            | CH2                      |
| 3rd         | 2728.78            | C–CH3                    |
| 6th         | 1818.59            | Non conjugated           |
| 7th         | 1781.21            | Non conjugated           |
| 8th         | 1720.59            | Non conjugated           |
| 9th         | 1649.79            | Conjugated               |
| 10th        | 1605.54            | Conjugated               |
| 11th        | 1495.36            | CH3                      |
| 12th        | 1452.16            | CH2                      |
| 13th        | 1377.71            | CH3                      |
| 19th        | 1029.84            | Secondary cyclic alcohol |
| 20th        | 990.95             | –CH=CH2                  |
| 21st        | 965.16             | –CH=CH– (trans)          |
| 22nd        | 908.64             | –CH=CH2                  |
| 23rd        | 887.75             | C=CH2                    |
| 26th        | 739.15             | –CH=CH– (cis)            |
| 27th        | 727.92             | –CH=CH– (cis)            |
| 28th        | 696.66             | –CH=CH– (cis)            |
| 29th        | 675.78             | –CH=CH– (cis)            |

Table 5: FT-IR spectrum compound group name of NSR-1 fuel.

| Band serial | Band number (cm⁻¹) | Group name               |
|-------------|--------------------|--------------------------|
| 1st         | 3075.09            | H bonded NH / =C–H       |
| 2nd         | 2892.78            | C–CH3                    |
| 3rd         | 2728.83            | C–CH3                    |
| 4th         | 2672.57            | C–CH3                    |
| 8th         | 1820.76            | Non conjugated           |
| 9th         | 1780.49            | Non conjugated           |
| 10th        | 1721.38            | Non conjugated           |
| 11th        | 1649.97            | ~ amides                 |
| 12th        | 1605.44            | Conjugated               |
| 14th        | 1377.75            | CH3/CH2                  |
| 20th        | 1030.01            | CH3COO–                  |
| 21st        | 1121.51            | Secondary cyclic alcohol |
| 22nd        | 964.73             | –CH=CH– (trans)          |
| 23rd        | 908.97             | –CH=CH2                  |
| 24th        | 887.74             | C=CH2                    |
| 26th        | 728.10             | –CH=CH– (cis)            |
| 27th        | 695.52             | –CH=CH– (cis)            |
| 28th        | 676.14             | –CH=CH– (cis)            |

Table 6: FT-IR spectrum compound group name of NSR-2 fuel.

5 ASTM test results

The fuels produced have been also tested according to the American Standard for Testing Materials (ASTM) methods. Tests performed by a third party certified laboratory (INTERTEK, NJ) demonstrate the parameters of the NSR fuels. The results show that a very considerate amount of harmful compounds are present in the NSR fuels. The results are listed in Tables 7, 8, and 9.
### Table 7: ASTM test result of waste plastic to produce NSR fuel.

| Method              | Test                        | Result      | Units       |
|---------------------|-----------------------------|-------------|-------------|
| ASTM D240           | Gross BTU-LB                | 19599       | BTU/lb      |
| ASTM D240           | Gross BTU-Gal(calculated)   | 127413      | BTU/gal     |
| ASTM D4052          | API gravity @ 60 °F         | 49.7        | °API        |
| ASTM D86            | Barometric pressure         | 760         | mm Hg       |
| ASTM D86            | IBP recovery                | 109.5       | °F          |
| ASTM D86            | 10% recovery                | 246.2       | °F          |
| ASTM D86            | 50% recovery                | 487.5       | °F          |
| ASTM D86            | FBP recovery                | 633.5       | °F          |
| ASTM D86            | Residue                     | 28.2        | Vol%        |
| ASTM D86            | Corrected loss              | 1.2         | Vol%        |
| ASTM D86            | Corrected recovery          | 70.6        | Vol%        |
| ASTM D97            | Pour point                  | 9           | °C          |
| ASTM D97            | Upper pour point            | 9           | °C          |
| ASTM D2500          | Cloud point                 | 12          | °C          |
| ASTM D2500          | Cloud point                 | 53.6        | °F          |
| ASTM D 2624         | Temperature                 | 72          | °F          |
| ASTM D 2624         | Electrical conductivity     | 2           | pS/M        |
| ASTM D5453          | Sulfur                      | 2.8         | mg/kg       |
| ASTM D1500          | ASTM color                  | 1.5         |            |
| ASTM E203           | Water content               | 37          | mg/kg       |
| ASTM D5708          | Vanadium content            | < 1.00      | mg/kg       |
| ASTM D5708          | Nickel content              | < 1.00      | mg/kg       |
| ASTM D5708          | Iron content                | 2.70        | mg/kg       |
| ASTM D5708_MOD      | Calcium                     | < 1         | ppm         |
| ASTM D5708_MOD      | Copper                      | < 1         | ppm         |
| ASTM D5708_MOD      | Sodium                      | < 1         | ppm         |
| ASTM D482           | Ash @ 775 °C                | 0.001       | Wt%         |
| ASTM D93 (procedure used A) | Corrected flash point | < room temperature | °F |
| ASTM D4530          | Carbon residue              | < 0.10      | Wt%         |
| ASTM D664 (procedure used A) | Acid number               | 0.10        | mg KOH/g    |
| ASTM D2386          | Freezing point              | 12.0        | °C          |
| ASTM D2386          | Freezing point              | 54          | °F          |

### Table 8: Continued.
| Method         | Test                          | Result       | Units |
|----------------|-------------------------------|--------------|-------|
| ICP            | Magnesium                     | < 1          | ppm   |
| ICP            | Copper                        | < 1          | ppm   |
| ICP            | Phosphorus                    | < 0.004      | g/gal |
| IP 309         | Cold filter plugging point    | < –51        | °C    |
| IP 309         | Cold filter plugging point    | < –59.8      | °F    |
| ASTM D6304     | Water                         | 126          | ppm   |
| ASTM D2624     | Temperature                   | 76.0         | °F    |
| ASTM D2624     | Electric conductivity         | 3            | pS/m  |
| ASTM D2500     | Cloud point                   | < –24        | °C    |
| ASTM D2500     | Cloud point                   | < –11.2      | °F    |
| ASTM D4737     | Calculated cetane index       | 42.3         |       |
| ASTM D5972     | Freezing point                | < –50.0      | °C    |
| ASTM D5972     | Freezing point                | < –58.0      | °F    |
| ASTM D5453     | Sulfur                        | 6.2          | ppm   |
| ASTM D240      | Gross heat of combustion-LB   | 18427        | BTU/lb|
| ASTM D240      | Gross heat of combustion-Gal  | 113934       | BTU/Gal|
| ASTM D1319     | Oxygenate corrected olefins   | > 55         | Vol%  |

Table 8: ASTM test result of waste plastic to produce fuel NSR-1.

| Method          | Test                               | Result       | Units |
|-----------------|------------------------------------|--------------|-------|
| ASTM D4052      | API gravity @ 60 °F                | 44.8         | °API  |
| ASTM D5191 (EPA)| Dry vapor pressure equivalent      | 0.36         | Psi   |
| ASTM D4176 (Procedure 1) | Appearance                | Pass-clear & bright |
| ASTM D4176 (Procedure 1) | Presence of water or particles | None         |
| Color           | Color                             | Undyed       |       |
| ASTM D5453      | Sulfur                            | 3.0          | ppm   |
| ASTM D86        | Initial boiling point             | 341.2        | °F    |
| ASTM D86        | 10% recovery                      | 394.8        | °F    |
| ASTM D86        | 50% recovery                      | 476.9        | °F    |
| ASTM D86        | 90% recovery                      | 576.4        | °F    |
| ASTM D86        | Final boiling point               | 625.9        | °F    |
| ASTM D86        | % recovered                       | 98.1         | Vol%  |
| ASTM D86        | % residue                         | 1.0          | Vol%  |
| ASTM D86        | % loss                            | 0.9          | Vol%  |
| ICP             | Calcium                           | < 1          | ppm   |
| ICP             | Magnesium                         | < 1          | ppm   |
| ICP             | Copper                            | < 1          | ppm   |
| ICP             | Phosphorus                        | < 1          | ppm   |
| IP309           | Cold filter plugging point        | –12          | °C    |
| IP309           | Cold filter plugging point        | 10           | °F    |
| ASTM D6304      | Temperature                       | 93           | ppm   |
| ASTM D2624      | Electrical conductivity           | 65.0         | °F    |
| ASTM D2500      | Cloud point                       | –12          | °C    |
| ASTM D2500      | Cloud point                       | 10.4         | °F    |
| ASTM D4737 (Procedure B) | Calculated cetane index         | 58.3         |       |
| ASTM D240       | Gross heat of combustion-LB       | 19959        | BTU/lb|
| ASTM D240       | Gross heat of combustion-Gal      | 113366       | BTU/gal|
| ASTM D93 (Method A) | Corrected flash point            | 80           | °F    |
| ASTM D482       | Ash @ 775 °C                      | < 0.001      | Wt%   |
| ASTM D445       | Kinematic viscosity @ 100 °F      | 2.187        | cSt   |
| ASTM D2161      | Saybolt universal viscosity @ 100 °F | 33.2        | SUS   |
| ASTM D130       | Copper corrosion @ 122 °F for 3 Hours | 1a          |       |
| ASTM D5972      | Freezing point                    | –7.1         | °C    |
| ASTM D5972      | Freezing point                    | 19.2         | °F    |

Table 9: ASTM fuel test result of waste plastic to produce NSR-2 fuel.

| Flow Int. (kg) | Flow Exh. (kg) | CO₂ (kg) | CO (kg) | HC (g) | NOx (g) | FC (kg) | PM (g) |
|----------------|----------------|----------|---------|--------|---------|---------|--------|
| 135.92         | 132.59         | 11.65    | 4.44    | 3.49   | 74.54   | 3.68    | 0.03098|

Table 11: NSR-2 fuel diesel car emission test result.
Method | Test | Result | Unit
--- | --- | --- | ---
ASTM D5599 (EPA) | Methanol | 0.00 | Vol% 
ASTM D5599 (EPA) | Ethanol | 0.00 | Vol% 
ASTM D5599 (EPA) | t-butanol | 0.00 | Vol% 
ASTM D5599 (EPA) | MTBE | 0.00 | Vol% 
ASTM D5599 (EPA) | DIPE | 0.00 | Vol% 
ASTM D5599 (EPA) | ETBE | 0.00 | Vol% 
ASTM D5599 (EPA) | TAME | 0.00 | Vol% 
ASTM D5599 (EPA) | Oxygen | 0.00 | Vol% 
ASTM D3606 | Benzene | 0.15 | Vol%

Table 10: ASTM fuel additives test result of waste plastic to produce NSR-1 fuel.

Figure 9: Comparison graph of NSR-1 and gasoline-87 kilowatt output consumption using gasoline generator.

6 Electricity production

Since the claim is that NSR-1 has similar properties as gasoline, the NSR-1 fuel was used in a gasoline-based generator to test its capabilities (Figure 9). Both NSR-1 and gasoline were injected into the gasoline generator one after the other to compare the kilowatt output of the two. The results showed a significantly higher kilowatt output from NSR-1 than gasoline.

7 Conclusion

As mentioned above, the fraction fuels are obtained at a certain temperature; NSR still has the option to produce the fuels under different temperatures and see if better results are obtainable from the previous temperature profile. Through the use of GC/MS and FTIR, we can assure the identification, accuracy of the fuel to meet the standard requirements for commercialization of the NSR fuel.

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References

[1] M. Akimoto, T. Sato, and T. Nagasawa, Hydrothermal denitrogenation of fuel oil derived from municipal waste plastics in a continuous packed-bed reactor, Ind Eng Chem Res, 42 (2003), 2074–2080.
[2] A. Angyal, N. Miskolczia, and L. Bartha, Petrochemical feedstock by thermal cracking of plastic waste, J Anal Appl Pyrolysis, 79 (2007), 409–414.
[3] J. M. Arandes, I. Torre, P. Castanò, M. Olazar, and J. Bilbao, Catalytic cracking of waxes produced by the fast pyrolysis of polyolefins, Energy and Fuels, 21 (2007), 561–569.
[4] L. Ballice, M. Yüksel, and M. Sağlam, Classification of volatile products from the temperature-programmed pyrolysis of low- and high-density polyethylene, Energy and Fuels, 12 (1998), 925–928.
[5] Characterization of Municipal Waste in the United States, U.S. Environmental Protection Agency, Washington, DC, July 1992.
[6] P. A. Costa, F. J. Pinto, A. M. Ramos, I. K. Gulyurllu, I. A. Cabrita, and M. S. Bernardo, Kinetic evaluation of the pyrolysis of polyethylene waste, Energy and Fuels, 21 (2007), 2489–2498.
[7] H. S. Joo and J. A. Guin, Hydrocracking of a plastics pyrolysis gas oil to naphtha, Energy and Fuels, 11 (1997), 586–592.
[8] S. J. Miller, N. Shah, and G. P. Huffman, Conversion of waste plastic to lubricating base oil, Energy and Fuels, 19 (2005), 1580–1586.
[9] C. J. Moore, S. L. Moore, M. K. Lee caster, and S. B. Weisberg, A comparison of plastic and plankton in the North Pacific central gyre, Mar Pollut Bull, 42 (2001), 1297–1300.
[10] C. J. Moore, S. L. Moore, S. B. Weisberg, G. L. Lattin, and A. F. Zellers, A comparison of neustonic plastic and zooplankton abundance in southern California’s coastal waters, Mar Pollut Bull, 44 (2002), 1035–1038.
[11] S. H. Ng, H. Scoud, M. Stan ciulescu, and Y. Sugimoto, Conversion of polyethylene to transportation fuels through pyrolysis and catalytic cracking, Energy and Fuels, 9 (1995), 735–742.
[12] J. Shabtai, X. Xiao, and W. Zmierczak, Depolymerization-liquefaction of plastics and rubbers. 1. Polyethylene, polypropylene, and polybutadiene, Energy and Fuels, 11 (1997), 76–87.
[13] E. Sugiyama, H. Muta, and H. Ibe, A process of municipal waste plastic, thermal degradation into fuel oil, in 1st International Symposium on Feedstock Recycling of Plastics (ISFR’99), Research Association for Feedstock Recycling of Plastics, Sendai, Japan, October 31–November 3 1999, 205–208.
[14] P. T. Williams and E. A. Williams, Interaction of plastics in mixed-plastics pyrolysis, Energy and Fuels, 13 (1999), 188–196.
[15] J. Yanik, M. Azhar Uddin, and Y. Sakata, The effect of red mud on the liquefaction of waste plastics in heavy vacuum gas oil, Energy and Fuels, 15 (2001), 163–169.