Converting Waste Plastic to Hydrocarbon Fuel Materials

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ABSTRACT

The increased demand and high price for energy sources are driving efforts to convert organic compounds into useful hydrocarbon fuels. Although much of this work has focused on biomass, there are strong benefits to deriving fuels from waste plastic material. Waste plastic is abundant and its disposal creates large problems for the environment. Plastic does not break down in landfills, is not easily recycled and degrades in quality during the recycling process, and can produce waste ash, heavy metals, and potentially harmful gas emissions if incinerated at high temperatures. However, chemical processes that can be used to convert plastics into hydrocarbon fuels have unlimited applications in residential and industrial heating, transportation, and electricity generation. These chemical processes are used to break down the long carbon chains found in plastic into the shorter chains found in gasoline or diesel-type fuels.

Natural State Research (NSR) has invented a simple and economically viable process to decompose the hydrocarbon polymers of waste plastic into the shorter chain hydrocarbons of liquid fuel (patent pending). The method and principal of the process/production will be discussed.

Keywords: waste plastic, hydrocarbon fuels, biodegradation, thermal process.

INTRODUCTION

According to a recent study, the United States produces 30 million tons of waste plastic, but only 10% of solid waste plastics are recycled [1]. The rest of the waste plastics either end up in a landfill or are incinerated. The waste plastic that goes to a landfill doesn’t degrade for thousands of years, causing land to be less fertile and environmentally unsafe for
its inhabitants. The waste plastics that end up in incineration facilities release toxic gases such as carbon monoxide (CO), which causes health hazards; sulfur dioxides (SO$_2$), which contribute to acid rain; nitrogen oxides (NO$_x$), which contribute to ozone depletion and acid rain; and carbon dioxide (CO$_2$), a greenhouse gas that contributes to global warming.

According to another study, about 380 billion plastic shopping bags are produced worldwide and only about 5.2% are recycled [2]. The rest of the bags end up in a landfill, are incinerated, or get clogged in city waterways, pipes, drains, and ditches; that’s why many cities and governments are trying to ban all kinds of plastic shopping bags. A recent survey shows that the city of San Francisco spends $8 million a year for bag clean up [2].

Research conducted by Charles J. Moore (Long Beach, California) about the “Great Pacific Garbage Patch” shows the horror and impacts 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 about 3.5 million tons of waste material, 80% of which is waste plastic litter [3]. According to Moore’s 1999 study, there was 6 times more waste plastic in this part of the ocean than the zooplankton that feeds ocean life [3]. Another study performed in 2002 showed that, off the coast of California, waste plastic outweigh zooplankton by a factor of 5 to 2 [4].

Alternative fuels developed from these waste plastic sources have the potential to overcome many environmental and economical problems by providing a steady, low-cost source of fuel, providing local employment in energy production, and helping organisms live better lives. A great deal of research and development in alternative fuels has focused on biomass; for example, creating cellulosic ethanol from non-edible biomass sources. However, biomass energy requires that a large amount of arable

![Figure 1. Management of Waste Plastic in US](source: Feed Stock Recycling Book)
land be devoted to the cultivation of plant sources. Similar source limitations are applicable for the initiatives in solar and wind energy.

There are strong benefits in deriving fuels from waste plastic materials. Waste plastic is abundant and creates large environmental problems as mentioned above. Chemical processes such as pyrolysis and depolymerization can be used to safely convert plastics into hydrocarbon fuels that can be used for transportation [5-7]. From the 30 million tons of waste plastic generated in the US per year, about 300 million barrels of fuel can be obtained (using a factor of one ton of waste plastics yielding 10 barrels of fuel by the process described in this article). This could replace up to 9% of fossil fuel dependency in the US. Additionally, effectively recycling one ton of waste plastic can save an estimated 7.4 cubic yards of landfill and associated procedural costs.

Companies worldwide are making good use of this abundant source of waste plastic. An Australian company, OzmoTech (http://www.ozmotech.com.au/), converts waste plastic to diesel fuel through a process that includes liquefaction, pyrolysis, catalytic breakdown of high molecular weight vapors, and controlled distillation. The resulting fuel is compliant with European regulatory standards and can run any diesel engine without modifications. A plant in India, Unique Plastic Waste Management & Research Co Pvt Ltd, has already demonstrated commercial success and electrical self-sufficiency by converting waste plastics into fuel, using a low-temperature melting process with degasification and depolymerization with a proprietary catalyst. The liquid hydrocarbon fuel produced is a sulfur-free industrial crude oil, which can be used in furnaces or further processed to obtain a finer grade.

Natural State Research, Inc. uses a patent-pending process to convert waste plastic to a liquid hydrocarbon fuel material, and it has successfully demonstrated this on a laboratory scale [8-9]. The advantage of NSR’s technique is its simplicity, which would allow municipalities, oil companies, and airlines to construct remote or local fuel production plants with appropriate fractionation from the general NSR fuel produced from abundant waste plastics. There would be a decrease in foreign oil dependency, which would help stabilize the price fluctuation of the global marketplace and the expense of operating vehicles. The decrease in landfill waste plastic would provide fertile and fresh lands to cultivate, thus decreasing famine worldwide. The reduction in the release of toxic gases from waste plastic incineration would protect the ozone layers, reduce global warming, and improve the quality of the environment.
PROCESS DESCRIPTION

The process involves heating the waste plastic to form a liquid slurry (thermal liquefaction in the range 370 °C to 420 °C), partial cooling of the slurry, distilling the slurry in the presence of cracking (with catalyst and without catalyst), condensing the liquid slurry with distillate to recover the liquid hydrocarbon fuel materials, and routing the remaining slurry residue back into fresh slurry to undergo the same process. No additional chemicals are used in the thermal liquefaction phase. The fuel is filtered using a commercial fuel filter (RCI fuel purifier) that operates using coalescence and centrifugal force.

A small-scale conversion process has been performed with the simplified direct thermal process (shown in Figure 2) using various types of waste plastics, high density polyethylene (HDPE-2), low density polyethylene (LDPE-4), poly propylene (PP-5), and polystyrene (PS-6). These plastics types were investigated singly and in combination with other plastics types. In the laboratory scale process, the weight of a single batch of input plastics for the fuel production process ranges from 300 gm to 3 kg. The plastics are collected, optionally sorted, cleaned of contaminants, and cut into small pieces prior to the thermal liquefaction. It should be noted that the NSR process does not exclude the use of random mixtures of different plastic types.

NSR filtered fuel (1st distillation) went through another distillation process as shown in Figure 2. The early 40% of the distillate (2nd distillation) was collected in the in the 1st collection flask, which is termed the “NSR double-condensed fuel 1st collection,” or “NSR-1”; 50% was collected in the 2nd collection flask and termed the “NSR double-condensed fuel 2nd collection,” or “NSR-2”; the remaining 10% remains in the double-condensed boiling flask and is termed “residual fuel,” or “NSR-3.”

Additional process modifications are in progress for further cost savings for NSR fuel production. These modifications will allow fractional distillation by molecular weight and carbon chain length.

Generation of electricity from NSR-1 fuel and commercial gasoline-87 were tested under similar conditions. For this experiment, a Jiang Dong gasoline generator was used, with 1 litter of NSR fuel and 1 litter of commercial gasoline-87, separately. The electrical energy output from the generator was monitored with an EML 2020 energy monitoring logger. A comparison of data is show in Figure 3.
Figure 2. Schematic diagram of the production from waste plastics to liquid hydrocarbon fuel using NSR *direct thermal process*.

**FUEL CHARACTERIZATION**

Tests have been performed to investigate the composition of the produced fuel. The gas chromatogram and mass spectrometer (GC/MS) of five different fuels have provided five different carbon chain lengths: (a) NSR double-condensed fuel 1st collection (NSR -1), (b) NSR double-condensed fuel 2nd collection (NSR -2), (c) commercial gasoline-87, (d) aviation fuel, and (e) diesel fuel [6-7]. The NSR fuel contains hydrocarbon group C\textsubscript{4} to C\textsubscript{27}, as compared with commercial gasoline-87 (with an octane rating of 87) containing group C\textsubscript{4}- C\textsubscript{9}. A GC/MS chromatogram has shown peak intensity distribution throughout the range of hydrocarbon group C\textsubscript{4} to C\textsubscript{27}, with retention time ranging from 2 to 27 minutes. The major deference between NSR-1 fuel and NSR-2 fuel is that NSR-1 fuel has a lighter carbon compound (C\textsubscript{4} - C\textsubscript{12}) and NSR-2 fuel has a heavier carbon compound (C\textsubscript{10} - C\textsubscript{27}). Also, there is a difference in density between NSR-1
fuel (0.74 g/ml) and NSR-2 fuel (0.80 g/ml). A GC chromatogram of commercial fuel shows the different ranges of hydrocarbon groups that are present: commercial gasoline-87 contains carbon chain C₄ - C₉, aviation fuel contains carbon chain C₉ - C₁₉, and diesel fuel contains carbon chain C₉ - C₂₇. A chromatogram of NSR-1 fuel and commercial gasoline-87 is provided in Figures 4 and 5, respectively, for visual understanding.

A differential scanning calorimeter shows that NSR fuel has a higher boiling point (94.52°C) than does commercial gasoline-87 (68.14°C). These boiling points indicate that NSR fuel contains more long-chain hydrocarbon compounds than commercial gasoline-87; these long chain hydrocarbons can be shortened during further fractionation. DSC graph onset of NSR fuel 1st collection (NSR-1), NSR fuel 2nd collection (NSR-2), commercial gasoline-87, aviation fuel, and diesel comparison data are show in Figure 6.

A comparison of some physical properties of the two fuels with commercial fuels from data analysis performed by Intertek, New Jersey and commercial fuel data obtained from open literature [10-12] are:

- The energy content of the NSR fuels NSR-1 (113,934.00 Btu/gal) and NSR-2 (133,366.00 Btu/gal) is comparable to commercially available fuels such as gasoline-87 (125,000.00 Btu/gal), jet fuel (120,200.00 Btu/gal), and diesel (138,700.00 Btu/gal).

- Dry vapor pressure for NSR-2 fuel (0.36 psi) is much lower than for NSR-1 fuel (5.18 psi).
Cold filter plugging point for NSR-2 (10°F) is much higher than for NSR-1 fuel (<-59.8°F).

Cloud point for NSR-2 fuel (10.4°F) is much higher than for NSR-1 fuel (<-11.2°F).

These preliminary tests will be supplemented in the future by rigorous ASTM testing of various fractions for direct comparison to the specifications of conventional fuels. The un-fractionated NSR-1 fuel has a research octane rating of 79.2 and motor octane number 72.6. These octane ratings are consistent with the results described in the GC/MS data. NSR, therefore, expects to obtain high-quality gasoline and aviation replacement fuels when both NSR fuels (NSR-1 & NSR-2) have properly fractionated.
CONCLUSION

A simple thermal degradation process for de-polymerization of waste plastic to liquid hydrocarbon fuel materials has been developed and further refined using a laboratory scale double-condensation process. Characterization studies by GC/MS indicate the de-polymerization product is essentially all straight chain hydrocarbons when linear thermoplastic polymers are used as the feed. Both GC/MS & DSC studies indicate that both NSR fuels (NSR-1 & NSR-2) include hydrocarbon compounds ranging from C_4 - C_{27}, a range that includes commercial gasoline-87, aviation fuel, and diesel fuel. Initial analysis of NSR-1 fuel indicates a research octane rating of 79.2 and motor octane rating of 72.6, which is lower than commercial gasoline-87. A change in octane rating is expected with appropriate fractionation, which will be confirmed in the future per the ASTM specifications. A comparison of physical properties, DSC graph, and GC/MS chromatograms suggests that collection of NSR (both fuels) can be further fractionated and used as appropriate—NSR-1 as gasoline and NSR-2 as aviation and diesel fuel.

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References


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