Available online at http://www.urpjournals.com

Advances in Polymer Science and Technology: An International Journal

ISSN 2277 – 7164

Review Article

Thermofuel – " Pyrolysis of waste plastic to produce Liquid Hydroocarbons"

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Received 11 January 2013; accepted 01 February 2013

Abstract

Thermofuel is a process that converts waste plastics into valuable liquid hydrocarbon product that can be utilized as energy source for many purposes such as diesel engines, generators, vehicles, etc. The gaseous by-product obtained in the process can be used for domestic use by refilling it in the cylinders and also to run gas turbines. Thus THERMOFUEL process can be considered as another non-conventional energy source. We all know that crude oil is the ultimate source of plastics and most of the chemicals. Out of total 100 million tons plastics produced every year all over the world, 25 million tons is dumped. By dumping such hefty amount of waste plastics, we are wasting lots of energy in the form of crude oil that is used to make plastics. This wasted energy can be recovered back using THERMOFUEL process. By doing this we can save our conventional energy source i.e. crude oil and ultimately country foreign exchange.

KEYWORDS: Thermofuel, plastic waste, diesel fuel, Pyrolysis, cracking, distillation

INTRODUCTION

The disposal of waste plastics has become a major environmental problem all over the world. USA, Europe and Japan generate about 50 million tons of post consumer plastic waste material. Saudi Arabia is one of the major producers of plastic in the world with total production capacity of around six million metric tons per year. The amount of plastic wastes in Saudi Arabia is about 15-wt% in the composition of domestic municipality waste. The number of landfill sites is decreasing. Also landfilling could result in plastic additives such as phthalates and various dyes polluting ground water. Incineration is an alternative to landfill disposal of plastic wastes, but this practice could result in the formation of unacceptable emissions of gases such as nitrous oxide, sulfur oxides, dusts, dioxins and other toxins. The option of secondary recycling or mechanical recycling, which is the reprocessing of plastic waste into new plastic products with a lower quality level, is not showing any signs of growth in the recycling industry. Tertiary recycling, this returns plastics to their constituent monomers or to their higher value hydrocarbon feed stock and fuel oil, is gaining momentums an alternative method. Tertiary recycling includes all those processing which attempt to convert the plastic wastes to basic chemicals by the use of chemical reactions such as hydrolysis, methanolysis and ammonoloysis for condensation polymers and to fuels with conventional refinery processes such as pyrolysis, gasification, hydrocracking, catalytic cracking, coking and vis breaking for addition polymers excluding PVC. Pyrolysis and catalytic conversion of plastic is a superior method of reusing the waste. The distillate product is an excellent fuel and makes Thermo Fuel one of the best, economically feasible and environmentally sensitive recycling systems in the world today. Thermo Fuel diesels can be used in any standard diesel engine, trucks, buses, trains, boats, heavy equipment and generators.

Suitable Plastic Material for Treatment

As a rule of thumb, approximately 950ml of oil can be recovered from 1kg of plastics such as Polyolefin's including Polyethylene (PE) and polypropylene (PP), or polystyrene (PS).

Although not suitable, the process can nevertheless tolerate small quantities of plastics containing heteroatom's. Heteroatom's are atoms other than carbon and hydrogen such as chlorine, sulphur and nitrogen. Since heteroatom's are heavier than the light elements such as carbon and hydrogen these increase the density of the plastic. This can be used as a guide to which plastics are suitable for Thermo Fuel. A rough rule of thumb is to take a representative sample of the flaked waste plastic and add it to a jar of water. If more plastic floats than sinks then the plastic scrap is acceptable feedstock for Thermo Fuel. The floatable fraction represents mainly polyolefin's (that is polyethylene and polypropylene) and expanded polystyrene. Polyolefin's give the best yield of distillate due to their straight-chain hydrocarbon structure. Polystyrene is beneficial in the mix since it contributes aromatic character to the distillate and improves the pour point properties (that is, the low-temperature viscosity properties).

Table 1. Selection of plastic

Resin	Thermo Fuel system suitability
Polyethylene (PE)	Very good
Polypropylene PP)	Very good
Polystyrene (PS)	Very good (gives excellent fuel properties).
ABS resin (ABS)	Good. Requires off-gas counter measure
Polyvinylchloride (PVC)	Not suitable, should be avoided.
Polyurethane (PUR)	Not suitable, should be avoided
Fiber Reinforced Plastics (FRP)	Fair. Pre-treatment required to remove fibers.
PET	Not suitable, should be avoided.

Typical Examples of Waste Plastics for the Thermo Fuel Process

Thermo Fuel can process commingled and miscellaneous waste plastics such as:

1. plastic packaging scrap from material recovery/sorting facilities
2. oil and detergent bottles
3. off-cuts/trimming from nappy production,
4. mulch film and silage wrap,
5. mixed post-consumer plastics,
6. caps/labels/rejected bottles from bottle recycling operations.
7. commercial stretch and shrink wrap.

Fig 1: Plastic waste

Plastics from Kerbside

Plastics recovered from kerbside collection of recyclables are generally an ideal feedstock for Thermo Fuel. However, given the appreciable market value of PET these are generally sorted and removed first. The commingled plastics that remain after undesirable and other use plastics have been recovered, can be processed easily by Thermo Fuel. Once PET and PVC are removed, there is generally no need to identify plastics by type for it to be suitable for Thermo Fuel processing. It is worth noting that the majority of unsuitable feedstock plastics are generally very rare in the common waste stream. Contamination such as organic matter or paper can be tolerated, but these will have an effect on yield and sulphur levels and should be less than 10% by weight.

Agricultural Plastics

Mulch and silage film is mainly polyethylene-based but may be contaminated with soil. This contamination is no problem for the Thermo Fuel system. The soil and dirt simply act as an inert filler and exits the process in the char/coke stream. Other suitable agricultural plastics are used plastic (non PVC) pipes, used herbicide and other chemical containers, greenhouse film, trickle tape and dripper tube.

Commercial Shrink and Stretch Wrap

Pallet wrap and shrink/stretch wrap is based on low and linear-low density polyethylene's and makes ideal feedstock for Thermo Fuel. Large quantities of these films are collected

in the commercial field and due to their tacky nature they collect dirt/dust which makes other recycling methods difficult. In the Thermo Fuel process such films give very high yields of distillate.

Multilayer Films and Laminates

Multilayer plastic films and packaging are difficult to mechanically recycle due to the presence of dissimilar polymers and metals that are often adhesively bonded. This makes mechanical recycling uneconomical. Thermo Fuel, on the other hand, can handle such stream without difficulty since aluminium laminates are not volatile and simply end up in the solid char stream. Only the plastics are pyrolised.

Pyrolysis of Plastics

The system consists of continuous plastics infeed system, pyrolysis gasification chamber, catalytic converter, condensers, gas scrubber, centrifuge, oil recovery line, off-gas cleaning. Waste plastics are loaded via a hot-melt infeed system directly into main pyrolysis chamber.

Fig.2 Pyroliser

The chamber can generally be filled within 2 hours. When the chamber temperature is raised, agitation commences to even the temperature distribution and homogenise the feedstocks. Pyrolysis then commences to the point of product gasification. Non-plastic materials fall to the bottom of the chamber. The gas goes through the catalytic converter and is converted into the distillate fractions by the catalytic cracking process. The liquid distillate then passes into the operating tank after cooling in the distillation tower. From the operating tank, the product is sent to a hydro-cyclone to remove contaminants such as water or carbon. The cleaned distillate is then pumped to the quality tank, then to the storage tanks.

Pyrolysis

Pyrolysis is a process of thermal degradation in the absence of oxygen. Plastic waste is continuously treated in a cylindrical chamber and the pyrolytic gases condensed in a specially designed condenser system to yield a hydrocarbon distillate comprising straight and branched chain aliphatics, cyclic aliphatics and aromatic hydrocarbons. The resulting mixture is essentially equivalent to petroleum distillate. The plastic is pyrolised at 370ºC- 420ºC and the pyrolysis gases are condensed through a distillation tower to produce the distillate.

The essential step in the pyrolysis of plastics involves:

1. **Purging** oxygen from pyrolysis chamber.
2. **Evenly** heating the plastic to a narrow temperature range without excessive temperature variations.
3. **Pyrolising** the plastics.
4. **Catalytic conversion** of the gases to specific carbon chain lengths.
5. **Managing** the carbonaceous char by-product before it acts as a thermal insulator and lowers the heat transfer to the plastic.
6. **Careful** condensation and fractionation of the pyrolysis vapours to produce fuels of excellent quality and consistency.
7. **Removal** of sulphurs and residual contaminants.

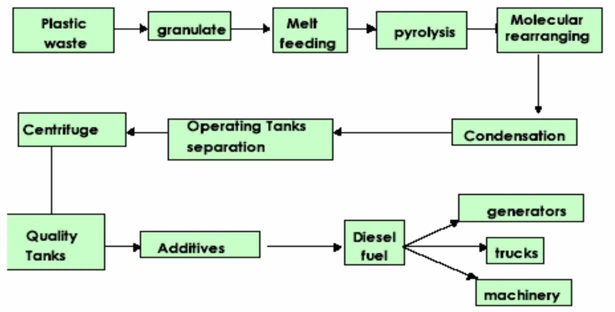

Fig. 3 Thermofuel Process

THE OPERATION:

The heart of the pyrolysis system is the prime chamber, which performs the essential functions of homogenisation, controlled decomposition and outgassing in a single process.

Fig. 4: Operation overview

The process requires minimal maintenance, and produces consistent quality distillate from mixed and low-grade plastic waste. The key to an efficient pyrolysis process is to ensure the plastic is heated uniformly and rapidly. If temperature gradients develop in the molten plastic mass then different degrees of cracking will occur and products with a wide distribution of chain lengths will be formed. Another important aspect of pyrolysis is to heat the plastic in the absence of oxygen. It uses a slight positive pressure (about 1.08 bar) ensuring that pyrolysis gases are quickly removed from the process chamber thereby reducing the incidence of secondary reactions. The polymer is gently 'cracked' at relatively low temperatures to give predominantly straight chain aliphatic hydrocarbons with little formation of by-products.

These hydrocarbons are then selectively cleaved catalytically to produce the average carbon chain length required (peaks at C16) for distillate fuel.

Fig. 5 Fuel Recovery

Operating Features of Thermo Fuel

The process is safe, efficient, easy to operate and highly economical.

Safety

Thermo Fuel operates slightly above ambient pressure.

Maintenance

Coking occurs in the chamber when the pyrolysis of the waste plastics is almost complete. However, Thermo Fuel is designed to minimise coking by stabilising heat conductivity within the pyrolysis chamber. The chamber requires regular cleaning with the char being removed automatically by the built in cleaning system. Depending on contamination levels, the cleaning system may be run daily or less often.

Pre-Treatment

Input feedstock plastics may require washing or sorting to reduce the level of contaminants to below 10%, or to reduce the incidence of unsuitable plastics to acceptable levels. In all circumstances, the plastics must be introduced into the main chamber as a 12-15mm flake.

Pollution

Thermo Fuel produces extremely low level of emissions, due to the capture of almost all of the output, both liquids and gases, inside the system.

Noise or vibration

The system has very few moving parts, and accordingly there is no excessive noise or vibration.

Foreign contaminants

Foreign matters such as soil, sand, papers and organic materials are often adherent contaminants attached to waste plastics. This system is designed to cope with these foreign materials.

Off Gas

Pyrolysis of plastics tends to occur on irregular basis hence the carbon chain lengths of the pyrolytic gases vary between 1-25. Most of the gas is liquefied in the condensers but some gas remains uncondensed. Hydrocarbons with carbon count of 4 and lower remain as a gas under room temperature.

This off-gas contains methane, ethane, propane, butane, etc. Although volume of the gas differentiates depending upon the types of the plastics, it is generally just 2-5%. The offgas is treated, then returned to the main furnace as an additional heat source, with minimal emissions to atmosphere.

PRODUCT YIELD AND CHARACTERISTICS:

Plastics are separated into oil, gas and char residue by pyrolysis. Recovery ratio and characteristics of the product distillate differs depending on the types of plastics as discussed in detail below, and contamination. In essence, the cleaner the feedstock, the better the yield.

The Char Stream

The carbonaceous char forms in the chamber during pyrolysis. The char residue produced is generally proportional to the level of contaminants which are adhering to the feedstocks. Since the char passes acid leaching tests it can simply be land filled. Inorganic additives such as cadmium pigments from the plastics end up in the char stream. The carbon matrix has a metal .fixing. effect and binds up the metal ions so that no leaching occurs after disposal.

Fig. 6 Carboneous char

ENERGY REQUIREMENTS:

The chamber is heated by natural gas if and where available, or by using fuel produced by the process itself.

OUTPUT FUEL PROPERTIES:

The typical mass balance output from one ton of mixed polyolefin plastic entering the process is approximately 82% hydrocarbon distillate, 4% char, 4% losses in the desulphurization process, 4% losses of non-condensable gases and 6% which is captured and displays similar properties to commonly available .white spirit. or degreaser. The non-condensable gases from the Thermo Fuel plant are passed through a water scrubber and then fed back into the natural gas flow to the thermal oxidiser, which heats the unit, meaning there are minimal net hydrocarbon emissions.

The hydrocarbon fraction in turn comprises approximately 75% distillate cut and 25% paraffin material. The paraffin fraction is continuously cracked after the first condenser until it reaches the desired chain-length range and then added to the primary fuel stream.

A comparison of the distillate produced from a commingled plastic mix compared with regular diesel has been conducted by gas chromatography, and shows excellent similarity between Thermo Fuel and refinery produced diesels.

Uses. The produced distillate is designed to operate in any diesel engine.

Cetane. A key indicator of diesel is the Cetane Number which is analogous to the octane rating for petrol. Cetane is a measure of the ignition delay, that is, the time between injection into the cylinder and the moment of auto-ignition. This is most significant in relation to low-temperature startability, warm-up, and smooth, even combustion. Distillates with a higher cetane rating show increased power and superior performance characteristics. Ideal diesel will have a high proportion of hydrocarbon chains that are 16 carbon atoms long. Hydrocarbon chains of length C16 are known as hexadecane which is the proper chemical name for cetane. Thermo Fuel produced diesel has a cetane number in the range of 57, similar to or higher conventional diesel, which averages 51-54.

Sulphur. Fuels produced from 100% clean plastic feedstocks will reflect extremely low sulphur levels, generally under 10 ppm, well under current Australian and international requirements. The system can be adjusted to further reduce sulphur levels as regulatory limits come into force. It is important however, to recognise that certain contaminants will deliver trace amounts of sulphur into the system.

There are two types of sulphurs in potential contaminants, organic and in-organic, both of this can be removed within the Thermo Fuel system process.

Lubricity. Finally, it is important to emphasise that Thermo Fuel fuel is extremely high in lubricity. In diesel engines some components, including fuel pumps and injectors, are lubricated by the fuel, so good lubricity is key element in reducing wear on these parts.

CONCLUSION:

Thermofuel is a truly sustainable waste solution, diverting plastic waste from landfills, utilizing the embodied energy content of plastics and producing a highly usable commodity that, due to its cleaner burning characteristics, is in itself more environmentally friendly than conventional distillate.

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Source of support: Nil; Conflict of interest: None declared