Hydrothermal Liquefaction for Conversion of Mixed Plastic Waste to Fuel

Bary Wilson, Ph.D.

Withdrawal of China and other Asia-Pacific countries from the waste recycling market has resulted in large accumulations of both plastic and cellulosic carbon wastes. Attention has turned to the development of environmentally responsible waste to energy technologies to convert these combustible wastes to renewable electrical power or clean hydrocarbon fuels. Due to their relatively high calorific value, non-recyclable plastics are best utilized by conversion to fuels using processes such as hydrothermal liquefaction (HTL). This process can convert both plastic and biomass to ultra-low sulfur diesel fuel oils, methane fuel gas and metallurgical coke, a solid fuel.

EPR and its wholly owned subsidiary, Synergy World Power (SWP), will be using a commercially proven HTL process as the fundamental technology for its stationary and mobile solid waste to fuel systems. This HTL technology has been used in several applications, including the plant shown above that processed 300 tons per day of turkey waste for a ConAgra plant. This plant produced approximately 3 million gallons of EPA certified alternative diesel fuel per year. This process has also been used to extract fuel oil from petroleum tank bottoms, oil shale, heavy oils, and auto shredding residue (ASR or “auto fluff”).

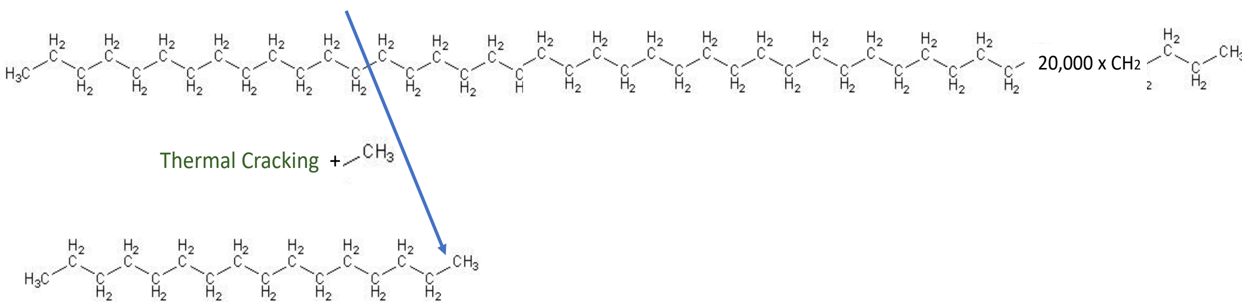
HTL Process Description

HTL processes use superheated water at high pressures in a simple, well controlled system to convert carbonaceous waste to liquid fuel. At temperatures well above the standard boiling point of water, and pressures above a few hundred psi, the properties of water change, making it a good solvent for organic materials. This superheated water conversion requires substantially less thermal energy than steam extraction because the water is held in the liquid phase by the high pressure, thus avoiding the need for the additional energy required to evaporate the water.

HTL conversion of mixed plastics (fossil carbon) to fuel oil has been well demonstrated in the scientific literature [1,2], as has hydrothermal conversion of biomass (cellulosic carbon),[3] as well as unseparated municipal solid in general waste (plastic plus biomass).[4] HTL fuel from plastics and biomass waste is **not** fatty acid methyl ester (“FAME”) bio-diesel, which is often restricted as a blending stock for diesel fuel.

HTL fuel oil yields depend on the feedstock. One metric ton of mixed plastic produces nominally 150 gallons of a #2 diesel fuel, while the same amount of dry biomass yields about 40 gallons of fuel, and a metric ton of food waste (mostly water) yields approximately 10 gallons of fuel. Addition of a catalyst can increase conversion and alter the gas phase to liquid phase product ratio. Production of methane gas (used as generator fuel) also varies according to feedstock in proportion to the liquid fuel yield. Solid fuel yield is inversely proportional to the amount of available hydrogen in the feedstock or reactor environment. Oil from HTL of plastics can reduce GHG emissions by up to 14% [1] compared to conventional diesel.

Figure 1 below depicts the effect of heat on the chemical structure of polyethylene plastic. Heat energy causes weakening of the bonds that link the carbon backbone of the plastic. These bonds eventually break at random sites along the long polymer chain, releasing smaller hydrocarbons such as cetane, a major component of diesel fuel.



Cetane ($C_{16}H_{34}$) MW= 226
Typical component of diesel fuel

Figure 1. Thermal cleavage of carbon-carbon bonds along the polyethylene polymer chain to produce diesel fuel components. The resulting oil is not a fatty acid methyl ester (FAME) biofuel.

HTL allows process conditions to be controlled so that most of the hydrocarbon product leaves the process as a diesel base stock fuel oil. That is, the product fuel meets ASTM D 975 specifications for a motor fuel, and/or ASTM D 396 specification for a fuel oil. Heavy ends (90% over above 673 °F), can be recycled to extinction in the process. These products do not have the specific additives that may be needed for motor fuel use in specific jurisdictions or for the US Military. Distillation of the HTL oil can improve the quality of the fuel.

Diesel oil obtained from distillation of raw HTL oils can be sold as a "drop in" fuel or blended with petroleum derived diesel. Gas phase products of distillation can be used for heat and power onsite. Heavier distillation cuts can be sold as heating oil. Producing ultra-low sulfur fuel oil from plastics has substantial economic and environmental advantages over simply gasifying or incinerating plastics to generate electrical energy.

Figure 2 shows a simplified process flow block diagram of the HTL process that will be used for the PTF plant at Las Vegas. Advantages of this system, as compared to conventional pyrolysis, include the fact that the reactions take place in a hydrogen-rich (chemically reducing) environment, resulting in a more energy rich liquid fuel. The use of superheated high-pressure water as a reaction medium means that many of the unwanted elements such as sulfur, chlorine, nitrogen, and oxygen will be dissolved and remain in the water when the oil and water phases are separated.

Not shown in the diagram is the recycle of heavy end oils back through the water reactor to continue the cracking process, resulting in lighter oils. Using water as a reaction medium also allows the use of dead leg devices to remove any insoluble particles from the reaction mixture based on their density. Finally, in continuous flow operation, the recycle water picks up components from the fuel that can greatly improve its solvent and reactant properties as the process continues.

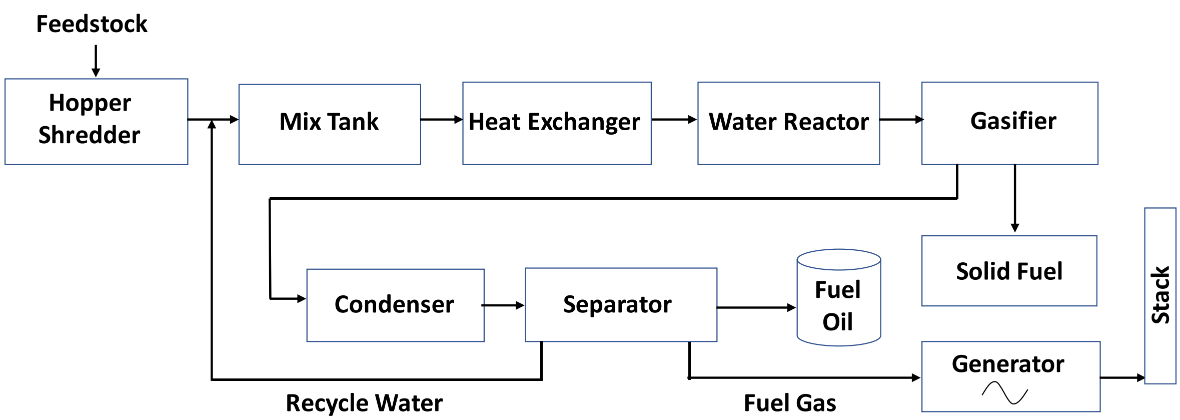


Figure 2. Simplified block flow diagram of the HTL process

Shown in the three images below (**Figure 3**) is an earlier, less thermally efficient, version of the HTL process in commercial operation. As mentioned, the plant made up to 3 million gallons per year of EPA certified diesel from a 300 t/d of turkey offal. The plant ceased operation in 2012 due to a substantial increase in the cost of the feedstock.

Figure 3. Three views of an HTL plant producing 3 million gallons per year of diesel fuel

HTL Products

For HTL plants processing more than approximately 100 tons per day of mixed plastic waste, the addition of distillation and filtration can be of benefit in obtaining more consistent quality fuel oils. The distillation process produces fuel gas used for generating electrical power or heat for the HTL plant. Heavy ends above the diesel fuel distillation range can be used for industrial or marine fuel oils. Bottoms for the distillation process, and from the HTL process itself, can be processed in a delayed coker to produce a pet coke solid fuel.

EPR is developing HTL for the conversion of mixed plastic wastes to liquid fuels. HTL was selected over conventional pyrolysis because HTL process equipment is simple, relatively inexpensive compared to conventional pyrolysis, and more readily maintained. The initial cost of this equipment is generally lower than that used for conventional pyrolysis conversion of plastics to liquid fuels. Because HTL processes operate in a chemically reducing environment, and recycle of heavy ends is an option, HTL generally produces a better-quality fuel oil from a wider variety of waste plastic feedstocks than can be obtained from conventional pyrolysis processes.

____

References

1. Benavides et a.l (2017) Life-cycle analysis of fuels from post-use non-recycled plastics, **Fuel** Vol 203 pp11-22. https://www.sciencedirect.com/science/article/pii/S0016236117304775

2. Wang and Bucanon (2019) Millions of tons of the world's plastic waste could be turned into clean fuels, other products through chemical conversion. https://www.purdue.edu/newsroom/releases/2019/Q1/millions-of-tons-of-the-worlds-plastic-waste-could-be-turned-into-clean-fuels,-other-products-through-chemical-conversion.html

3. Behrendt, et al (2008) Direct Liquefaction of Biomass, **Chemical Engineering and Technology** Vol 31; 5 pp 667-677 https://onlinelibrary.wiley.com/doi/pdf/10.1002/ceat.200800077

4. Seshasayee and Savage (2019) Study of Hydrothermal Liquefaction as a Process for Utilizing Municipal Solid Waste Without Separation https://drawdown.psu.edu/poster/study-hydrothermal-liquefaction-process-utilizing-municipal-solid-waste-without-separation

---

Contact:

Commercial: Keith Hulbert khulbert@eprenewable.com Ph: +1 703 725-7687
Technical: Bary Wilson bwilson@eprenewable.com Ph. +1 954 683 8706