Sustainable Energy - Pyrolysis of Low Density Polyethylene

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***Abstract* - With global plastic production growing at an unprecedented rate, plastic waste pollution is continuously growing, causing threats to wildlife, and increasing greenhouse gas emissions. The development of an electric-powered pyrolysis system that converts plastic waste to liquid fuel presents a promising solution to this problem, and an incentive to collect plastic waste that is so abundant in the environment. The proposed system is modular, benchtop scaled, and able to be powered by renewable energy sources. The system also provides a base for further implementation with other existing refining technologies such as fractionation. Furthermore, it creates an economic incentive to collect plastic waste in the environment, as it provides an efficient and reliable way to convert it into usable fuel.**

I. Introduction

According to PLOS ONE, 351x10^6 metric tonnes of plastic was produced in 2015 [1]. Of that plastic approximately 90% goes unrecycled. Pyrolysis, the thermal decomposition of a material at high temperatures, presents a way to harness energy from waste plastic. By pyrolyzing low-density polyethylene (LDPE), energy can be extracted from the plastic in the form of shorter length hydrocarbons. LDPE, $(C2H4)_n$, is the most used packaging material globally and is resistant to biodegrading, making it an appropriate plastic to study due to its significant negative environmental impact. Hydrocarbons from LDPE can be condensed and used in a similar fashion to hydrocarbons produced in a standard oil refining process. Hydrocarbons come in a vast assortment of lengths, with only chains of lengths 14-20 carbons corresponding to diesel. Vapor from the pyrolyzed LDPE is sorted through zone heating such that only hydrocarbons that are diesel length are recovered. Once passed through these zones, the diesel-like hydrocarbons are cooled in a condenser, converting the vapor into liquid fuel. Plastic-to-fuel technology such as this system is proven to reduce greenhouse gas emissions and fossil fuel use.

II. System Components and Methods

A. *Experimental Process*

LDPE is loaded into the furnace where it will eventually vaporize from high temperatures provided by electric heating. The vapor will then pass through the reactive distillation column where a chemical reaction occurs, altering the chemical composition of the vaporized feedstock. Finally, the vapor passes through a condenser where diesel like fluid is yielded.

B. *Furnace*

The furnace is carbon steel pipe with a dome shaped bottom. There is a pressure release valve that doubles as an inlet for purging. The top of the furnace is flat plate with 3 holes: one for a Type K thermocouple for temperature monitoring, one for an agitator that stirs plastic within the furnace, and one for an outlet that transports plastic vapor from the furnace to the RDC. To minimize heat loss, the furnace is wrapped in a layer of fiberglass wrap. Additionally, a fiberglass insulated sheet metal cylinder encloses the furnace.

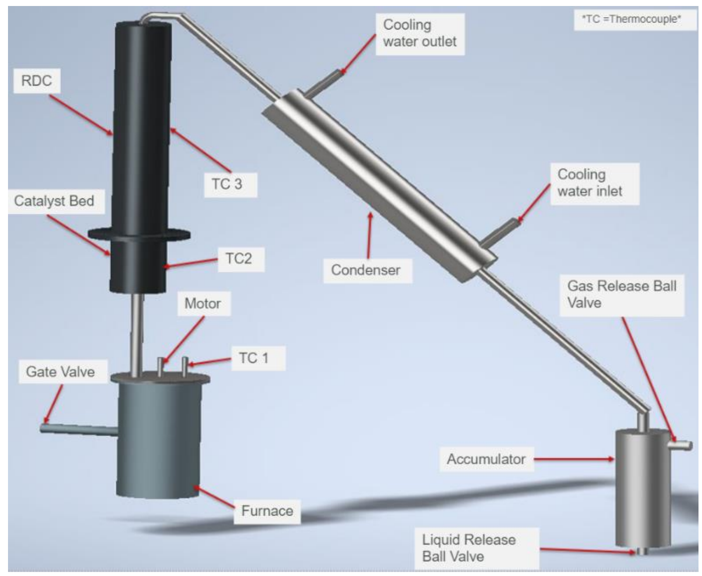

Figure 1: 3D Model of System

C. *Reactive Distillation Column (RDC)*

The RDC is composed of two flanged, carbon steel pipes with endcaps welded at the opposite ends. The flanged pipes allow users to disassemble the RDC to clean interior walls as well as add or remove the catalyst bed. There are two heating zones within this component. One located at the catalyst bed and the other towards the top of the RDC.

D. *Condenser*

A water-cooled condenser is used to condense yielded product. It utilizes room temperature water from a large container, and a pond pump to control the flow of water.

E. *Accumulator*

The accumulator acts as a collection vessel for yielded liquid as well as a pressure release for uncondensed vapors. There are two ball valves used to control the outgoing flow of these two fluids.

III. Data

Data that is collected is composed of both thermal and chemical behavior data. Initially, thermal testing of the components was conducted, monitoring temperature using thermocouples to observe the general behavior of the furnace and RDC. In any case, heating a steel vessel externally requires heat transfer analysis. To do this, one would use the following equation to get an estimate of the power needs for one hour of heating to achieve a certain internal surface temperature.

$$KW = \frac{W_t * C_{px} * \Delta T}{3412} * (h) \quad (1)$$

Here, KW is the kilowatt amount needed for the process. W_t is the weight of the material being heated by conduction heating, C_{px} is the specific heat of the material, ΔT is the temperature difference from start of process to the end, and h is the time in hours of the process. 3412 is the conversion factor to go from BTU/lb*°F to KWh. Figure 2 shows the trend of thermal behavior for the furnace and RDC, where figure 3 shows the thermal gradient of the furnace.

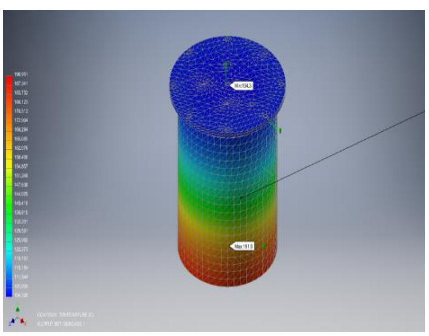

Figure 2: Thermal Gradient of Furnace

Temperature data from Type K thermocouples displays a relatively constant, yet down trending heating rate for the furnace. The reactive distillation column settles at two distinct temperature zones separated by approximately 30C. The temperature difference of the RDC is crucial for isolating heavier than diesel hydrocarbon fractions that have a higher boiling point than diesel. As the vapor passes up into the RDC, heavier fractions will see a progressively lower temperature along the height of the RDC and condense inside. These fractions fall back into the furnace, where the diesel fractions will continue in vapor form to be condensed.

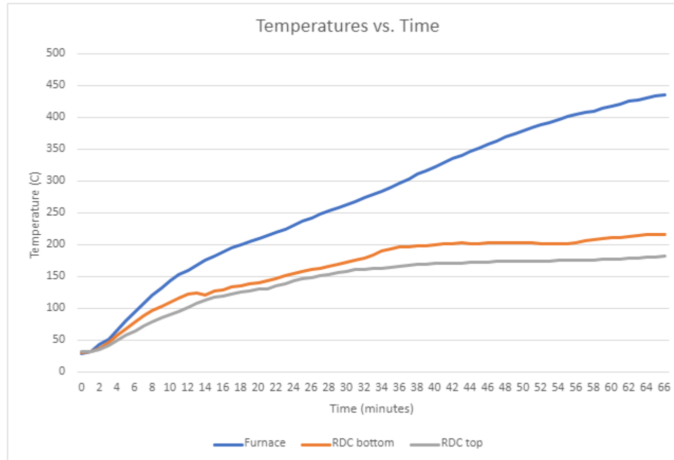

Figure 3: Heating Rates per Minute

When considering the efficiency of the system, standard mass balance was used. The volume of the input was recorded and compared to the recovered volume from the outlet of the accumulator. Ideally ratio would be 1, however inefficiencies of the system such as leaks within welds and pipe connections allow for some vapor to escape. The following formula describes this relation:

$$RP = \frac{v_f}{v_i} \quad (2)$$

where RP is the recovery percentage of liquid product, v_i is the initial volume of the feedstock, and v_f is the final collected liquid volume. Expected RP is within the 20%- 45% range, based on trial data. In the case of LDPE, using the average density of the LDPE and weight of the feedstock is sufficient to calculate volume, initially.

IV. Conclusion

The data collected from test runs using water as feedstock proves that the system exceeds required temperatures for this process to occur, but also shows that the system is capable of vaporizing and condensing a substance in a closed environment. Based on thermal behavior of the system, it can be inferred that feedstocks with higher boiling points can be processed in the pyrolysis system.

Acknowledgment

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References

[1] S. Royer, S. Ferron, S. Wilson, D. Karl (2018). "Production of methane and ethylene form plastic in the environment." Plos One, 13(8): e0200574. https://doi.org/10.1371/journal.pone.0200574