Journal of
Emerging Investigators

Differentiation of Waste Plastic Pyrolysis Fuels to Conventional Diesel Fuel

Zachary Jewison[1], Owen Rokita[1], and Joe Rasmus[1]

[1] Williamston High School, Williamston, MI

Summary

Plastic pollution and energy shortages are pressing issues in today's world. Waste plastic pyrolysis attempts to solve these problems by eliminating waste from the environment while creating a viable alternative fuel to replace conventional fuels. This research examined whether waste plastic pyrolysis fuels are similar to conventional diesel and, thus, a plausible alternative fuel. We created three distinct waste plastic pyrolysis fuels: high-density polyethylene, polypropylene/low-density polyethylene, and a mixed fuel. Four tests isolated specific characteristics of each fuel: efficiency, calorific value, burn time, and relative density. Results showed that waste plastic pyrolysis fuels were not comparable in performance to conventional diesel: diesel had the longest burn time, the highest calorific value, and the highest efficiency of all fuels tested. These results suggest that conventional diesel is a superior fuel compared to waste plastic pyrolysis fuels.

Received: May 25, 2017; **Accepted:** March 27, 2018; **Published:** May 25, 2018

Introduction

Environmental problems due to waste plastic extend all over the globe and are as prominent as ever. The United States discards thirty million tons of plastic per year, and as little as seven percent of these plastics are recycled. Much of the rest is disposed of in landfills where it remains for hundreds or thousands of years (1). Moreover, there is plenty of plastic that does not ever reach landfills and that will harm the environment as a result. Approximately eight metric tons of waste plastic enter the world's oceans each year (2), and at least one hundred million marine animals die annually as a result of waste plastics (3). In addition to environmental effects, each year the manufacturing of plastics uses eight percent of the world's production of petroleum (4). This indicates that waste plastic does more than harm the environment; it also wastes the valuable resources used in its manufacturing.

An ideal situation would be to curtail waste plastic while simultaneously using it for something productive. This is what we set out to do. Specifically, we aimed to change waste plastic into an alternative fuel that can be used in an identical fashion as conventional gasoline or diesel fuel, using a technique called pyrolysis. Pyrolysis is defined as decomposition with the use of high temperatures. Pyrolysis converts plastic into a fuel alternative that can be used in a very similar way to traditional fuels. In this scenario, plastic is to be decomposed into liquid fuel alternatives with high temperatures. The use of waste plastics to create an alternative fuel will help address two problems: first, it can reduce the physical amount of waste plastics around the world, as those waste products could be utilized to synthesize fuel. Second, the alternative fuels created may help address traditional fuel shortages by functioning as substitutes.

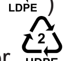
In this paper, we vaporized and condensed multiple types of plastics into fuels:

Polypropylene (also PP or 

)

Low-density polyethylene(also LDPE or 

)

High-density polyethylene (also HDPE or 

).

We then measured the quality of each fuel by testing its specific characteristics. We hypothesized that fuels recovered from plastic pyrolysis will be similar to conventional diesel fuels and could thus serve as viable alternative fuels.

Results

We conducted four tests on each waste plastic pyrolysis fuel and the same four tests on diesel fuel. We first tested the efficiency of each fuel (**Figure 1**). This test consisted of burning fuels and measuring the mass of the fuel sample before and after burning was complete. We calculated the percent decrease in mass in order to determine the efficiency. The largest percent decrease of any fuel was diesel (86.05%); its percent decrease was 56.35% greater than the next highest fuel (Mixed). The range in percent decrease by mass across all fuels is 70.1%. The waste plastic pyrolysis fuels have similar efficiency values with a range between them of only 13.75%. This is a much smaller range in values than the range of all fuels when diesel is considered.

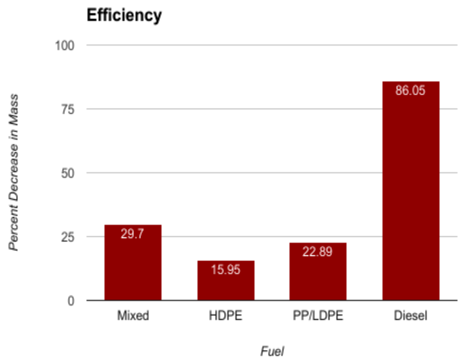


Figure 1: Fuel efficiency based on measurements of mass taken before and after combustion.

Next, we conducted a calorific value test. A basic calorimeter (**Figure 2**) was created and was designed to measure the energy contained within each fuel. The highest value belonged to diesel (1.413 kcal/g), indicating that it releases the most energy of those tested (**Figure 3**). Two of our fuels, PP/LDPE and Mixed, have very similar calorific values. The difference is only 0.009 kcal/g. Also, these calorific values are from waste plastic pyrolysis fuels that include more than one plastic type. HDPE, which consists of only one type of plastic, has a calorific value that is dramatically different, and is less than half the magnitude of the other waste plastic pyrolysis fuels.

Figure 2: The basic calorimeter used in the process of measuring calorific value for each fuel.

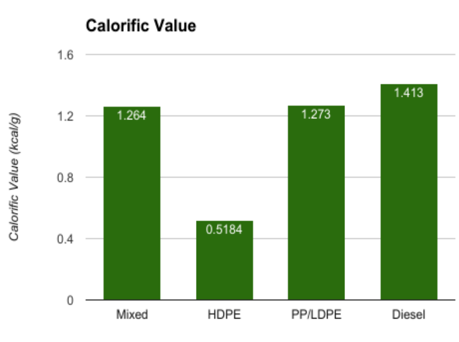


Figure 3: The energy released by each fuel, measured based upon changes in water temperature after combustion.

We then tested the time it took for each sample of fuel to burn completely (**Figure 4**). The fuel that had the longest burn time was diesel, with a time of 104.38 seconds. This is approximately 2.20 times higher than the lowest burn time of 47.28 seconds, and 1.43 times higher than the next highest fuel (PP/LDPE with a time of 73.17 seconds).

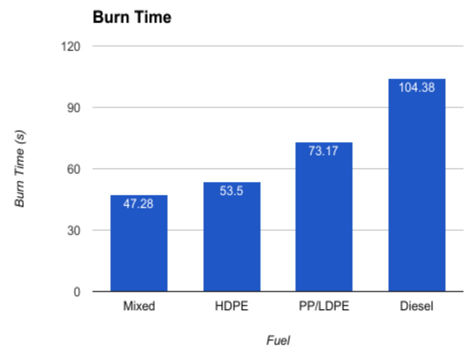


Figure 4: Duration of combustion for each fuel.

The last test was designed to determine relative densities of waste plastic pyrolysis fuels (**Figure 5**). We determined that our waste plastic pyrolysis fuels did not have similar densities to diesel: distinct layers between the substances in the test tubes can be easily discerned, suggesting contrasting densities.

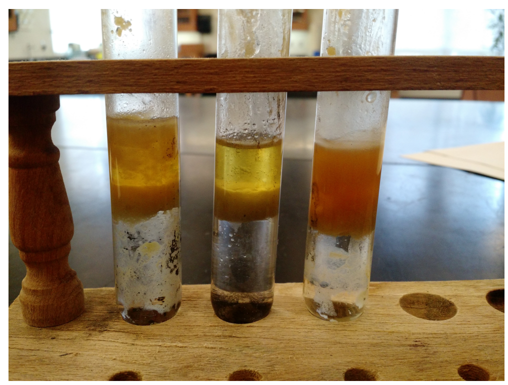


Figure 5: Results of the density test. Water, diesel, and one type of waste plastic pyrolysis fuel were placed in a test tube and observations were made regarding their relative densities. From left to right in the image, the test tubes contain PP/LDPE, Mixed, and HDPE fuels, respectively.

Discussion

We hypothesized that fuels recovered from plastic pyrolysis would be similar to conventional diesel fuel and thus, a viable alternative fuel. While we were able to obtain several different fuels through the process of pyrolysis that were combustible, their characteristics were not similar to those of conventional diesel. Our research did not find that waste plastic pyrolysis fuels are alike in quality and characteristics to conventional diesel fuel.

Diesel was the most efficient fuel of those tested since it had the largest decrease in mass, indicating that more of the diesel had combusted. This corresponds to less “left-over” fuel after burning and thus, a greater efficiency. With respect to calorific value, it can be concluded that waste plastic pyrolysis fuels created from mixed types of plastic are similarly energetic to diesel fuel. Both waste plastic pyrolysis fuels made from mixed types of plastic showed similar calorific values to each other and to diesel. This result might imply that more energetic waste plastic pyrolysis fuels are created by combining multiple types of plastic. However, diesel fuel’s calorific value surpasses the next highest by 0.14 kcal/g, indicating that diesel is still the most energetic fuel of those tested. Density of a fuel is a defining characteristic; however, the lack of numerical results from the density test makes it difficult to draw conclusions. Based on visual observations, we concluded that waste plastic pyrolysis fuels are generally denser than diesel fuel (**Figure 5**). It is likely that denser fuels will be of lower quality than less dense fuels.

Overall, diesel fuel burns much longer than all other tested fuels. This fact combined with its calorific value and efficiency scores suggest that, among those tested, diesel is the highest-quality fuel. Our results differ from other published research; specifically, Nageswara *et al.* found that waste plastic pyrolysis fuels mixed with diesel performed extremely similarly to pure diesel (6). The researchers tested for fuel consumption and thermal energy. These results supported the equality of alternative fuels to diesel and were consistent with several other pieces of published research that we have read, as well. Our research was limited in comparison to other published works involving this matter. We did not have access to very advanced materials and technology such as a reactor chamber; other similar researchers had access to and used batch reactors, semi-batch reactors, and fixed fluidized bed reactors (5). With access to those types of reactors, it is likely we could have produced much higher quality waste plastic pyrolysis fuels. Without specialized machinery capable of determine the exact chemical compositions, chemical differences in our fuels could not be measured. Furthermore, access to an advanced calorimeter to complete our calorific value tests may have strengthened the accuracy of the results. Recommendations for other researchers pursuing a similar project design would include using a condensation tube for the plastic vapors and exploring how to refine the fuels they would potentially obtain. Both techniques would likely increase the quality of the alternative fuels and therefore strengthen their similarity to diesel. Another consideration in this area of research is whether waste plastic pyrolysis fuels result in a net gain of energy. Alternative fuels such as those described in this experiment take a large input of energy to create, so this requirement must be weighed against the energy output these alternative fuels can provide and could be a potential drawback to their use.

As dependency on plastic and plastic-related environmental problems increase, waste plastic pyrolysis research will continue to become even more important. Not only does this line of research look to develop a potential fuel source for an energy-dependent world, but it could also greatly contribute to bettering the waste plastic problem facing the world today. This research has many real-world applications that make it relevant and important to explore further.

Materials and Methods

Each fuel used to test our hypothesis was derived as a part of this research. The first step in the experimental process was building a pyrolysis reactor. Pyrolysis of waste plastics was carried out in a mid-sized reactor; the body was constructed from a ten-gallon steel barrel and approximately six feet of copper tubing. This tubing was attached to the top of the barrel, creating the condensation tube. The reactor was placed on an iron stand and was heated from the bottom. Heat was supplied by one central propane burner (built into the iron stand) and four additional Bunsen burners. Natural gas was used as the fuel to heat the reactor.

Once the reactor’s construction was complete, the fuels had to be created. For each trial, two-thirds of the reactor’s total volume was filled with waste plastics. Trials are defined as filling the reactor with one or more types of plastic, completely vaporizing, and condensing and collecting the resulting material. If more than one type of plastic was used in the trial, each type of plastic was in roughly the same proportion. The trial creating the waste plastic pyrolysis fuel HDPE consisted of 100% HDPE plastic. PP/LDPE fuel was created by filling the barrel with 50% LDPE plastic, and 50% PP plastic. Lastly, Mixed fuel was created by including 33% of each type of plastic: HDPE, LDPE, and PP.

Heating the reactor began after the correct amount of each plastic was placed in the barrel. At this point, the plastics were heated and vaporized. Condensation was achieved by bubbling vapors from the reactor directly into water; the water was held in a three-quarter filled, gallon-sized container. All material that was obtained condensed on top of the water in the bubbling container, resulting in fuel which was used for the experimental tests.

This research focuses on four key characteristics of a fuel. Every characteristic corresponds with a test designed to isolate said characteristics. The four tests were labeled: efficiency, calorific value, burn time, and relative density. The efficiency test consisted of measuring a two-gram sample of fuel, igniting the fuel, allowing it to burn, and measuring its mass after burning was complete. The remaining mass and the starting mass of the fuel was used to calculate its percent decrease in mass, revealing each fuel’s efficiency (**Table 1**).

Calorific value test was designed to measure how energetic each fuel was. A basic calorimeter was created; a metal beaker filled with 200 milliliters of water was placed on a ring stand approximately one inch up from the stand’s base. Next, a watch glass bearing two grams of fuel was placed directly under the metal

Fuel	Mass Initial	Mass Final	Percent Decrease In Mass
Mixed	2.010	1.413	29.72
HDPE	2.013	1.692	15.95
PP/LDPE	2.010	1.550	22.89
Diesel	2.007	0.280	86.05

Table 1: The calculations for percent decrease in mass are summarized within the table. All masses are recorded in grams.

beaker. The fuel was ignited and allowed to burn itself out. The temperature of the water was measured before and after the fuel burned; these data were used to calculate calorific value of each fuel. The numbers are inserted into the generic equation $q = m \times C \times \Delta T$, where C = 4.184 (specific heat of water), m = 200 (mass of the water in grams), and ΔT = the change in the Celsius temperature (based on measured values). This answer is divided by the mass of the original fuel sample to obtain the final result in kilocalories per gram (**Table 2**)

Fuel	Temperature Initial (C)	Temperature Final (C)	Calorific Value (kcal/g)
Mixed	14.8	27.5	1.262
HDPE	18.9	24.1	0.5184
PP/LDPE	14.8	27.6	1.273
Diesel	14.1	28.3	1.413

Note: the result of $q = m \times C \times \Delta T$ is in the unit Joules and is converted into kilocalories using the conversion factor 0.000239

Table 2: The calculations for calorific value are summarized within the table. All temperatures are recorded in Celsius, and calorific value is recorded with units of kilocalories per gram.

Burn time is a relatively simple test; two grams of fuel were ignited on a watch glass and allowed to burn itself out. The time from the ignition of the fuel to the time the flame was no longer visible was measured. Lastly, a test was designed to compare densities of the waste plastic pyrolysis fuels to conventional diesel. Three test tubes were used, one for each type of fuel. Test tubes were filled with a sample of the pyrolysis fuel, diesel, and water. Observations were made, noting the differences and similarities in densities of the three waste plastic pyrolysis fuels and diesel. Only the relative densities can be compared with this test. No numerical results could be obtained from a test with this design. Results of these tests were compiled to evaluate the hypothesis.

Acknowledgements

We would like to thank Tim Kelly for supplying the materials to build our reactor. We would also like to give a gracious thanks to Jakob Gailitis for allowing us to use his lab materials and his classroom to conduct our experiments.

References

1. Headifen, R. “Plastic Litter.” *Plastic Waste Solutions*. http://plasticwastesolutions.com/plastic-litter/. Accessed 23 May 2017.
2. Jambeck, J.R, Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. “Plastic Waste Inputs From Land into the Ocean.” *Science*, vol. 347, no. 6223, 2015, pp. 768-771
3. “Threats to Sea Turtles from Marine Debris.” *Sea Turtle Conservancy*. https://conserveturtles.org/information-sea-turtles-threats-marine-debris/. Accessed 23 May 2017.
4. “What Happens to All That Plastic?” *State of the Planet What Happens to All That Plastic Comments*. http://blogs.ei.columbia.edu/2012/01/31/what-happens-to-all-that-plastic/. Accessed 23 May 2017.
5. Sharuddin, S.D.A., Abnisa, F., Daud, W.M.A.W., and Aroua, M. K. “A review on pyrolysis of plastic wastes.” *Energy Conversion and Management,* vol. 115, 2016, pp. 308-326.
6. Rao, N.L, Jayanthi, J.L., and Kamalakar, D. “Conversion of waste plastics into alternative fuel.” *International Journal of Engineering Sciences and Research Technology,* vol. 4, no. 8, 2015, pp. 195-201.