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EMISSION CHARACTERISTICS OF SPARK-IGNITION ENGINE RUNNING ON PLASTIC WASTE PYROLYSIS OIL AND GASOLINE BLENDS

Gergő Kecsmár, Tamás Koós, Zsolt Dobó

Institute of Energy and Quality, University of Miskolc, Miskolc, Hungary
email: kecsm.gerg@gmail.com

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ABSTRACT

The utilization of liquid products as transportation fuel derived from the thermal decomposition of different plastic waste mixtures was investigated. The production of pyrolysis oils was performed in a laboratory-scale batch reactor utilizing polystyrene (PS), polypropylene (PP), and high-density polyethylene (HDPE) waste blends. Two different mixtures (10% PS – 60% PP – 30% HDPE; 10% PS – 30% PP – 60% HDPE) were prepared, and the influence of reflux was also studied. The pyrolysis oils were blended to commercial gasoline in the 0-100% range. It was found that each blend could be successfully used as an alternative fuel in a traditional spark-ignition engine without any prior modifications or fuel additive. However, based on the engine tests, the presence of the reflux is vital as the composition of the pyrolysis oil is closer to the commercial gasoline. The emission measurements showed increasing NO_x emissions compared to neat gasoline, but, on the other side, a decrease in CO was noticed. These changes were much smaller in cases when reflux was used during oil production. Based on the obtained results, the utilization of reflux-cooling is an effective method to enhance the gasoline range hydrocarbons in the plastic waste pyrolysis oils, and therefore blending these oils to commercial gasoline might be viable.

Keywords: plastic waste, recycling, pyrolysis, emission

1. INTRODUCTION

According to the research of „Our World in Data" [1]: while plastic production was 2 Mt in the 1950's, this amount reached 381 Mt in 2015. Additionally, between 1950 and 2015, the world produced 7.8 billion tons of plastics, which is more than one ton for every person today. Based on the current statistics [2], roughly 9% of plastic waste has been recycled since 1950. Although the degree of recycling and energetic utilization was undoubtedly increased in the last few years, new waste processing technologies arise, such as pyrolysis, which is a promising method to generate transportation fuels from plastic wastes.

The pyrolytic products can be divided into gas, liquid, and solid fraction. Based on the process parameters the gas/liquid ratio can be changed. It was shown in a previous study that the gasoline to diesel ratio in pyrolysis oils could be significantly affected by changing the reflux temperature [3]. Generally, lower reflux temperature generates more gasoline range hydrocarbons in pyrolysis oils, but the intensive molecule scission also produces more short-chain molecules appearing in the gas phase. The literature reveals that the pyrolysis oils blended with conventional fuel could be used for transportation and engine tests even with neat pyrolysis oils are reported. Budsaereechai et al. [4] tested neat pyrolysis oils from HDPE, LDPE, PP, and PS in diesel and gasoline engines. It was shown that the gasoline engine worked only with the PS oil, while the HDPE, LDPE, and PP oils worked only with the diesel engine. A multi-cylinder spark ignition engine was utilized by Kumar et al. [5] to investigate the oil-gasoline blends. The engine operated without any modifications with 0-20% pyrolysis oil in gasoline, and it was noticed that NO_x emission increased and hydrocarbon emission decreased as the concentration of pyrolytic oil in gasoline increased. Kaimal et al. [6] investigated the influence of pyrolysis oil addition to the diesel fuel by

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utilizing a compression-ignition engine. The pyrolysis oil content ranged from 0 to 100%. It was found that although the engine was able to run on neat pyrolysis oil, the 25% oil blended with diesel showed better results than other blends compared to commercial diesel fuel.

The utilization of pure pyrolysis oils is highly desired due to no additional oil separation steps are involved in the fuel production process, such as distillation. In fact, the distillation of pyrolysis oils enhances the quality of the product, which might be even closer to standard regulations, but the utilization of neat pyrolysis oils is also in the focus of recent researches. This study investigates the performance and emission properties of a spark-ignition engine utilizing pyrolysis oils blended with commercial gasoline in 0-100% portion.

2. MATERIALS AND METHODS

The pyrolysis runs were performed in a laboratory-scale batch reactor equipped with reflux. The vapors exiting the reflux are condensed in a water-cooled heat exchanger, and the liquid product (pyrolysis oil) is collected in a product container at room temperature. The remaining gases were collected in a sample bag and flared after the measurements. Fig. 1 shows the schematic illustration of the measurement system. The temperature of the reflux was adjusted to 150 °C in two cases to enhance the gasoline range hydrocarbons in pyrolysis oils. These runs were repeated without reflux cooling as well.

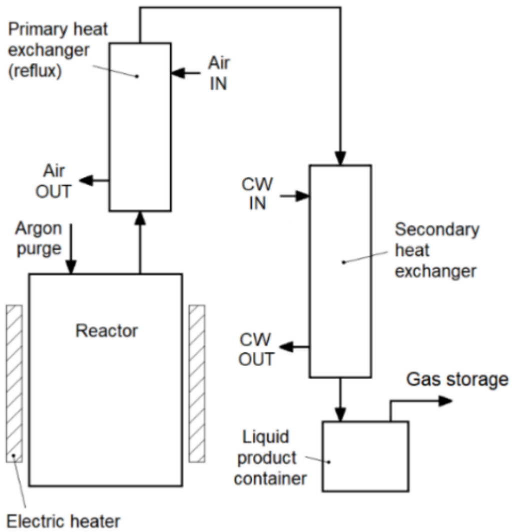

Figure 1. Schematic illustration of pyrolysis system used in this research.

Two plastic waste mixtures were used; one contained 10% PS – 60% PP – 30% HDPE, and the other contained 10% PS – 30% PP – 60% HDPE. These plastic types were separately gathered from local waste streams, and only the plastics with clearly visible identification codes were utilized. 200 g solid waste blend was loaded into the reactor in each case, then the reactor was flushed with nitrogen before measurement to eliminate the air from the system. The heat-up procedure started after the nitrogen flush, and the pyrolysis runs were typically stopped when the temperature inside the reactor reached ≈520 °C as the cracking reactions ended by this temperature.

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The pyrolysis oil and gasoline blends were tested in a traditional spark-ignition engine (Honda, GC-135) equipped with a carburetor. An electric generator was connected to the engine, while 500 W standard lamp was used as a load. Fuel consumption and exhaust gas emission (NO_x, CO, H_2, CH) during the engine tests utilizing oil/gasoline blends were measured and compared to the results obtained with commercial gasoline (RON=95). The NO_x emissions were monitored by Horiba PG-250 type flue gas analyzer, while the CO and H_2 were measured by gas chromatography (Dani Master) where a sampling bag was used to gather and store the flue gas. Additionally, the amount of CH content was measured by a hydrocarbon analyzer (model: Bernath Atomic 3002). The NO_x and CH emission measurement was based on MSZ EN ISO 8178-1:1999 standard method.

3. RESULTS AND DISCUSSION

The mass distribution of different products after the pyrolysis runs are summarized in Table 1. Based on the obtained results, it can be stated that the temperature of the reflux has a significant impact on the liquid and gas yield. The influence is not evident in the case of solid residues. Typically, the temperature of the pyrolysis vapors entering the water-cooled heat exchanger was 150 °C when the reflux was utilized, while the temperature reached 300 °C without reflux. The main goal of the reflux is to capture heavy hydrocarbon molecules and return them into the reactor for further molecule scissoring, which in situ increases the amount of C1-C4 products. Therefore the influence of the reflux can be investigated and compared to the thermal cracking without reflux cooling. Additionally, it can be concluded that the gas heating values are significantly higher when high portion of PP is present in the initial solid waste as PP typically generates C_3H_6 molecules.

Table 1. Pyrolysis summary of mixtures used in this study. The numbers in notation of concentration indicate the mass distribution of plastic types in each blends.

Mixture names	Product, W/W%			Reflux temperature, °C	HHV_{gas} MJ/Nm^3
	Gas	Liquid (oil)	Solid		
30PE-60PP-10PS	17.45	79.10	3.45	300	62.5
60PE-30PP-10PS	15.2	80.60	4.2	300	49.7
30PE-60PP-10PS-R	34.78	61.13	4.1	150	61.1
60PE-30PP-10PS-R	38.48	58.08	3.45	150	51.3

3.1. Engine test

Engine tests were performed to investigate the fuel consumption and emissions and compare them to commercial gasoline with RON=95. The volumetric fuel consumption change in the case of different oil/gasoline blends is shown in Fig. 2. It can be seen that fuel consumption is reduced by the growing amount of pyrolysis oil, compared to the consumption of neat gasoline. The fuel consumption was reduced by ≈10% in the case of neat 10PS-30PP-60HDPE.

Fig. 3 shows the influence of pyrolysis oil concentration at NO_x and CO emission measurements. Compared to the emission values of gasoline, pyrolysis oil concentration increase lead to higher NO_x emission. The most significant difference (by three times) in NO_x emission can be observed at the 100%

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pyrolysis oil in the case of 10PS-30PP-60HDPE. It can be stated that a higher amount of NO_x is shown at those blends containing more PE; moreover, this also referred to more intensive and higher temperature combustion. Additionally, the utilization of pyrolysis oils produced without reflux generated more soot, which can be elucidated with the presence of long carbon chains. The CO emission level decreased undoubtedly when pyrolysis oils produced without reflux were utilized. The CO is a toxic intermediary product that must be controlled according to health and environmental rules.

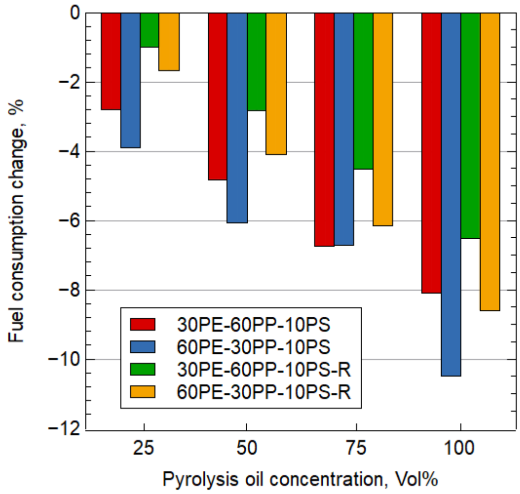

Figure 2. Effect of the pyrolysis oil concentration on fuel consumption trends. Typical fuel consumption of the engine utilizing traditional gasoline (RON=95) was 0,63 l/h.

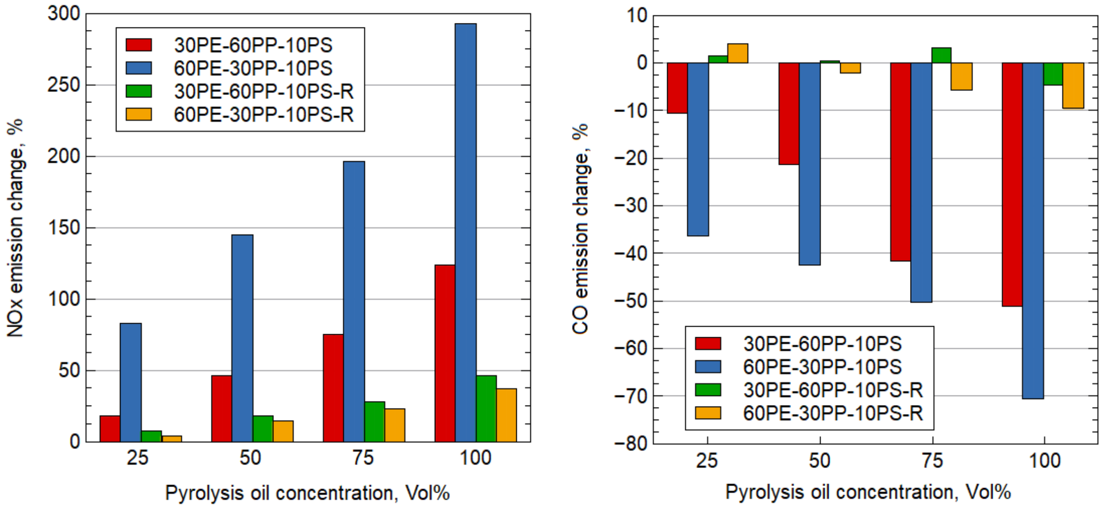

Figure 3. Left: NO_x emission change of the engine using various plastic gasoline compared to reference measurements. The typical NO_x emission of reference measurement was 124 ppm. Right: CO emission change of the engine using various plastic gasoline compared to reference measurements. The typical CO emission of reference measurement was 4,1 Vol%.

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Similar behavior can be seen in H_2 emissions (Fig. 4) compared to CO. The emitted H_2 is decreased by more than 70% in the case of neat pyrolysis oil produced without reflux. The measurement of CH emission (Fig. 4) presented unexpected results as an increase in trends was observed in almost all cases, except 60PE-30PP-10PS, where 25-50% oil blended to gasoline resulted in lower CH emission.

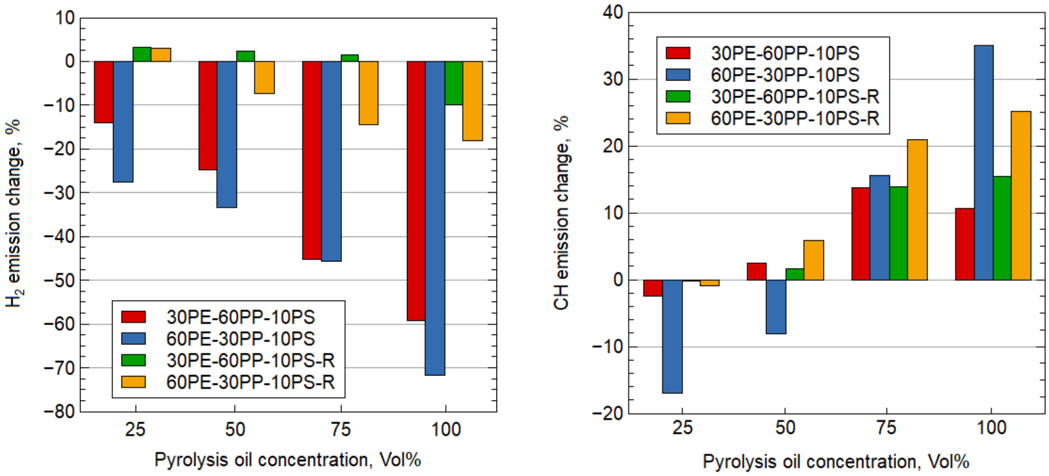

***Figure 4.** Left: H_2 emission change of the engine using various plastic gasoline compared to reference measurements. Typical H_2 emission of reference measurement with reflux was 1,2 Vol%. Right: CH emission change of the engine using various plastic gasoline compared to reference measurements. Typical CH emission of reference measurement with reflux was 763 ppm.*

Based on the obtained emission measurement results, it was concluded that by utilizing the reflux during pyrolysis oil production the fuel blends show similar results compared to commercial gasoline. Although the engine was able to run in each case, the oils produced without reflux cooling showed significant differences. Thus, these oils should be blended to gasoline in a limited proportion.

4. CONCLUSIONS

In this study, two blends were made from the most common plastics, such as polystyrene (PS), polypropylene (PP), and high-density polyethylene (HDPE). The prepared blends were pyrolyzed in a batch reactor under different reflux conditions, and the produced pyrolysis oils were tested in a traditional spark-ignition engine using different oil/gasoline blends. It was concluded that the utilization of reflux significantly enhances the gasoline-range hydrocarbons in oils, and therefore the oil/gasoline blends provide closer emission trends compared with the no-reflux cases. Additionally, the fuel consumption decreased in all cases investigated in this study. It is worth noting that the obtained pyrolysis oils do not meet the criteria of standard transportation fuels, thus, upgrading the oils to improve the quality is recommended. The reflux geometry and operation might play an important role when high-quality pyrolysis oils suitable for transportation are desired.

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REFERENCES

[1] Hannah Ritchie, Max Roser. Plastic Pollution. 2018. https://ourworldindata.org/plastic-pollution
[2] PlasticsEurope- Association of Plastics manufacturers. Plastic- the facts 2012-2018. https://www.plasticseurope.org/en/resources/market-data
[3] Zsolt Dobó, Tamara Mahner, Gergő Kecsmár, Gábor Nagy: The influence of reflux temperature on the yield of transportation fuels during plastic waste pyrolysis. Materials Science and Engineering 2020. 45/1. kötet. HU ISSN 2063-6792.
[4] Supattra Budsaereechai, Andrew J. Hunt and Yuvarat Ngernyen. Catalytic pyrolysis of plastic waste for the production of liquid fuels for engines. The Royal Society of Chemistry 2019, 9, 5844–5857. DOI: 10.1039/c8ra10058f
[5] Kumar, K. V.; Puli, R. K. Effects of Waste Plastic Oil Blends on a Multi Cylinder Spark Ignition Engine. MATEC Web Conf. 2017, 108, 08005. DOI 10.1007/s12206-018-0341-3
[6] Kaimal, V. K.; Vijayabalan, P. A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends. Energy Convers. Manag. 2015, 105, 951−956. DOI: 10.1016/j.enconman.2015.08.043