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Co-pyrolysis of Polypropylene Plastic Waste and Bamboo Sawdust by Infrared Wave

Md. All Imran, M. M. K. Bhuiya, Iffat Azima Jiban, Itquan Hossen, Rupak Saha, Ankur Kumar Khan, Satu Sarkar*

Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chattogram-4349, Bangladesh

ABSTRACT

This study focuses on the co-pyrolysis of polypropylene (PP) plastic waste, and bamboo sawdust (BS) which has high potential as an energy source. The goal of this research is to produce pyro-oil and to characterize the properties of the pyro-oil. This study was carried out without a catalyst. Using a fixed-bed reactor, materials of different ratios and moisture content were heated by an infrared wave cooker between temperatures of 250℃ and 315℃, resulting in the production of liquid pyro-oil. The highest yield of pyro-oil was 48.56 wt.% consisting of 18.6% moisture content at the infrared power of 800W, and 70 minutes reaction time. The obtained pyro-oil was analyzed by using a bomb calorimeter and found a calorific value of 41 MJ/kg which is comparable with other fuels such as diesel, gasoline, and kerosene. The product produced by co-pyrolysis can be an alternative to fossil fuels.

Keywords: Co-pyrolysis, Polypropylene, Bamboo sawdust, Infrared wave, Pyro-oil.

1. Introduction

Coal, natural gas, and petroleum products are non-renewable energy sources, collectively known as fossil fuels. Decreasing fossil fuels has encouraged researchers to search for alternative sources of energy [1-2]. Decarbonization and alteration of the energy sector require the utilization of new technologies and energy sources [3]. One of the most important forms of energy is renewable energy. The importance of renewable energy is growing in comparison to fossil fuels [4]. Various types of solid waste, including agricultural residues, industrial waste, household waste, medical waste, waste tires, municipal organic waste, etc. contribute to the diverse range of biomass resources available for energy production and waste management. By converting these wastes into valuable fuels using a proper conversion method, the accompanying environmental pollution and waste management issues can be reduced [5]. Biomass is a promising renewable source that can be used to meet the global energy demand. Biomass encompasses energy plants, crop residues, organic waste fractions, and algae, offering fossil fuel-free energy solutions [6]. In addition, one of the most significant issues facing the world today is solid waste management. As urbanization increases, global waste production is accelerating. In the year 2000, about 3 million tons of solid trash were produced daily by the 2.9 billion urban residents (49% of the global population) [7]. Moreover, the number of plastics delivered from daily life has increased in recent years. Both burying and burning plastic trash in landfills or incinerators have been common disposal methods. Again, there are significant environmental risks associated with landfills and incinerators. The treatment of these waste products represents a major challenge in the present world. Baeyens et al. [8] summarized that properly disposing of plastics without endangering the environment is difficult due to ever-increasing environmental constraints. Arena et al. [9] concluded that the problem may be resolved by turning used plastic into fuel. Utilizing applied sciences like gasification, pyrolysis, and co-pyrolysis, waste plastic can be converted into useful fuels or petrochemicals [10-12]. Wang et al. [9] experimented to explore the potential of co-pyrolysis as an efficient and synergistic solution for waste management and energy production by combining waste plastics and solid biomass feedstocks. Co-pyrolysis is a novel and environmentally relevant method that involves the concurrent thermal degradation of both plastic waste and biomass [13]. With or without catalysts, co-pyrolysis is normally anoxygenic and carried out in a closed reactor at standard operating temperatures. Zeolite, metal oxides, charcoal, and other catalysts can all be used to speed up co-pyrolysis [14]. Co-pyrolysis of waste plastic and solid biomass produces synergistic effects that could enhance product quality [15-19]. Through this process, both biomass and plastic waste can be converted into solid, liquid, and gas fuel forms. The product yield of the process can change due to the effects of feedstock ratio, catalyst, temperature, heating rate, reaction time, and moisture content [20-24]. To get the most out of making liquid products, a process that needs low temperatures, high heating rates, and short gas residence times is necessary [25].

Incineration is an alternative method of waste disposal. Incineration alone recovers the calorific value of trash, but it doesn't help recover its chemical value, making this process impossible [26]. The burning of waste in this procedure may create harmful emissions and greenhouse gases such as carbon dioxide that pose a direct hazard to the environment and human health.

From the literature reviews, it is seen that very few works have been done on co-pyrolysis process by infrared heating. The combustion of waste by infrared waves is an environmentally friendly process. Infrared wave heating provides continuous heating across a surface. Typically, conventional thermal heating transfers heat to materials by use of an external heat source. Infrared-assisted co-pyrolysis has shown better product yield and quality than traditional pyrolysis systems in both laboratory and pilot scales. But it faces significant challenges when it comes to using it on a large scale in industry, such as reactor design, penetration depth, and the need for a lot of money to invest [27]. In contrast, microwave heating is a unique technique that produces heat through an interaction of electromagnetic waves and exhibits a high electrical energy-to-heat conversion efficiency. Furthermore, infrared heating facilitates the achievement of high temperatures and rapid heating rates [27]. The liquid oil generated using an infrared heat source in the co-pyrolysis process possesses considerable promise for energy conversion technology within the renewable energy sector. To improve the co-pyrolysis efficacy related to microwaves, the incorporation of a fixed-bed reactor may be beneficial. This made it easier to make gases or liquids more efficiently. The objective of this study is to generate pyro-oil from bamboo sawdust and polypropylene plastic utilizing an infrared wave cooker.

2. Methodology

2.1 Materials

This study employed recycled polypropylene plastic pellets and bamboo sawdust. Local suppliers provided us with recycled polypropylene plastic pellets. The size of the plastic pellets varied from 1 to 2 mm. Bamboo sawdust was made from bamboo that was cut down near a bamboo thicket. Fig. 1 shows the recycled polypropylene plastic pellets and bamboo sawdust that were used in the co-pyrolysis process.

(a)

(b)

Fig. 1 (a) Polypropylene plastic pellets, (b) Bamboo Sawdust.

2.2 Experimental setup and procedure

The experimental setup consists of an infrared induction cooker, stainless steel reactor, argon gas cylinder, ice bath, copper tube, nitrogen gas cylinder, thermocouple, etc. These parameters were utilized in the co-pyrolysis process of polypropylene and sawdust to produce pyro-oil [28]. At first, recycled polypropylene plastic pellets and bamboo sawdust were weighted and fed into the fixed bed reactor which was 10 cm in inner diameter and 15 cm in length. Then the reactor was properly insulated with glass fiber and aluminum foil to prevent heat loss and manage temperature uniformity. Afterward, two ports of the reactor were utilized: one connected to an argon gas cylinder, and the other connected to a condenser for the condensation of the pyro-oil in its gaseous form. Both connections were made using copper tubes because of their excellent heat-exchanging qualities. An ice bath was used to enhance the condensing process. Additionally, a thermocouple wire was connected to the reactor for temperature measurement. After all connections were completed, the reactor was positioned over an infrared cooker as it provides continuous and controlled heating. It was capable of producing 2000 watts of power. Finally, the materials were heated to initiate the co-pyrolysis process of polypropylene and bamboo sawdust. During thermal decomposition, vapor and gas were generated and then passed through the copper tube to the ice bath condenser. Condensable products were condensed at the bottom of the condenser, while gaseous products were passed through a hole in the condenser. Then condensate oil was stored for further analysis. In this study, argon gas was used to create an inert environment and the flow was continuous throughout the process. This study was conducted with different moisture content levels (11.5%, 14%, 18.6%) of sawdust and various feedstock ratios (1:1, 2:1, 3:1, and 4:1 PP:BS) of polypropylene and bamboo sawdust. The process was continued at 800 W of the infrared cooker and reaction time was 70 minutes. Here, Fig. 2 shows the image of the co-pyrolysis process.

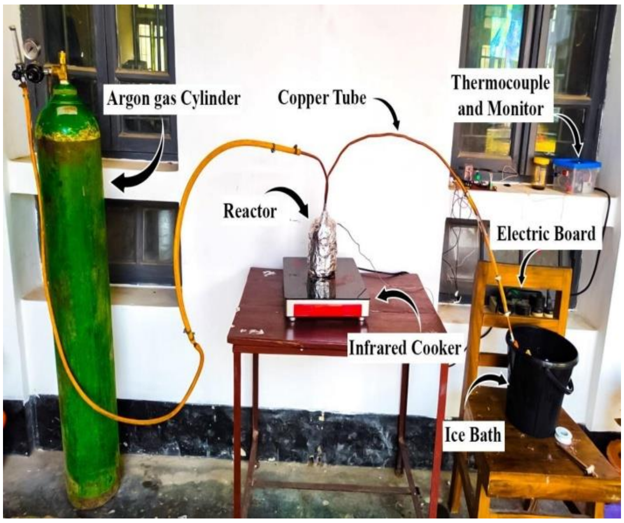


Fig. 2 Photograph of co-pyrolysis process.

2.3 Product of co-pyrolysis process and pyro oil analysis

In this study, the co-pyrolysis process was conducted using polypropylene plastic pellets and bamboo sawdust. Pyro-oil, char, and gas were produced as products of the co-pyrolysis process through the thermal decomposition of polypropylene and bamboo sawdust. During the process, pyro-oil was obtained by condensing the vapors and gases. However, not all vapors and gases were condensed because there were non-condensable gases like light hydrocarbons and other gaseous materials. The char produced in the co-pyrolysis process remained in the reactor. The pyro-oil is reddish-brown, and the char is black. Here, Fig. 3 shows the pyro-oil and char from the co-pyrolysis process.

The pyro-oil generated by the co-pyrolysis process was preserved for analysis. A rotational viscometer was used to measure the viscosity of the pyro-oil. It was set to 100 revolutions per minute, and the measuring process employed a spindle of type 3. Density was calculated using a formula. The flashpoint and fire point measuring instrument were used to determine the flash and fire points of the pyro-oil. Subsequently, a bomb calorimeter was used to determine the calorific value of the pyro-oil.

(a)

(b)

Fig. 3 (a) Pyro-oil from the co-pyrolysis process, (b) char from the co-pyrolysis process.

3. Results and Discussion

3.1 Product Yield Percentage

The co-pyrolysis of polypropylene and bamboo sawdust was carried out using 50 g feedstock samples under varying moisture contents and mixing ratios. Oil yield increases with higher moisture content: 30.4% → 36% → 48.56%. This occurs as biomass moisture helps secondary cracking and stabilizes radicals, improving condensable vapors. Gas yield decreases with increased moisture content: 47.2% → 42.4% → 32.16%. The moisture suppresses gas-phase reactions. Furthermore, char yield decreases with moisture: 22.4% → 21.6% → 19.28%, because more water enhances depolymerization and reduces solid residue. The highest pyro-oil yield, 48.56 wt.%, was achieved at a 4:1 polypropylene to sawdust ratio with 18.6% moisture content, reaching a peak temperature of 305℃. Fig. 4 shows the pie chart of product yield.

3.2 Effects of Feedstock Ratio

Co-pyrolysis was performed with polypropylene and bamboo sawdust at ratios of 1:1 to 4:1 (PP:BS) with 18.6% moisture content. Pyro-oil yield increased from 32 wt.% at 1:1 to 48.56 wt.% at 4:1. The higher polypropylene content contributed to better oil production due to its rich tertiary carbon structure, which enhances thermal degradation. As

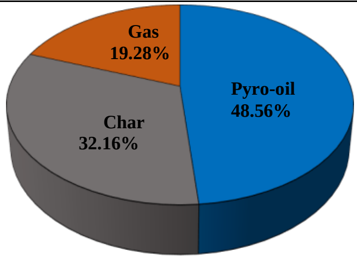


Fig. 4 Maximum percentage of product yield.

the PP ratio increased, char and gas yields decreased. Fig. 5 illustrates the effects of various feedstock ratios of polypropylene and bamboo sawdust.

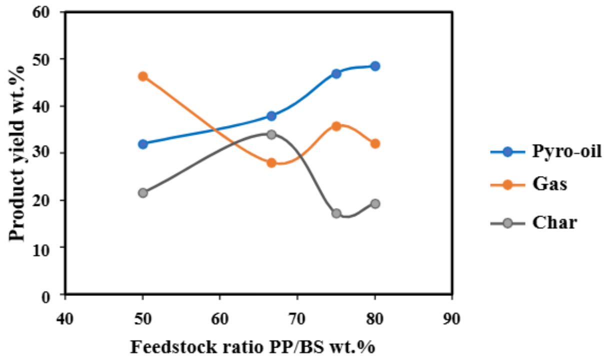


Fig. 5 Product yield vs feedstock ratio.

3.3 Physical Properties of Pyro-oil

To determine the physical properties of the pyro-oil, various tests had been done. Finally, properties such as calorific value, density, flash point, fire point, dynamic viscosity, kinematic viscosity, and specific gravity were determined. Table 1 demonstrates the properties of liquid pyro- oil.

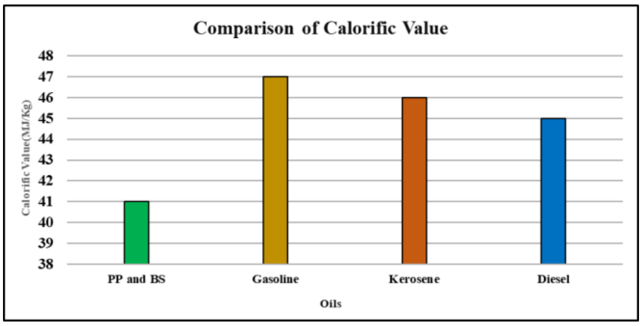
Table 1 properties of liquid pyro- oil.

Properties	Standards	Experimental value	ASTM recommendations [29]
Calorific value (MJ/Kg)	ASTM D240	41	35–45
Density (Kg/m^3)	ASTM D4052	680	650–900
Flash point (℃)	ASTM D93	35	30–50
Fire point (℃)	ASTM D93	41	40–60
Dynamic viscosity (cP)	ASTM D7042	4.6	6-150
Kinematic viscosity (cSt)	ASTM D7042	6.75	8-200
Specific gravity	ASTM D4052	0.684	0.65-0.90

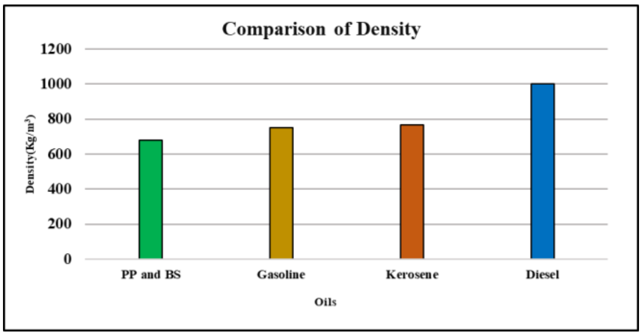
3.4 Comparison of Pyro-oil with Different Fuels

Fig. 6 demonstrates the Comparison of the calorific value, density, viscosity, and flashpoint of pyro-oil with gasoline, kerosene, and diesel. Fig. 6(a) depicted that the calorific value which is 41 MJ/kg similar to commercial diesel, lower than those of other fuels. This characteristic suggest that the oil can burn efficiently and may be suitable for blending with petroleum fuels. Fig. 6(b) indicates that density (680 kg/m³) of pyro-oil is lower than other fuels. The viscosity of the pyro-oil is higher than that of other fuels, as shown in Fig. 6(c). But, Fig. 6(d) illustrates that the flashpoint of pyro-oil (35°C) is closest to that of kerosene, making it unsafe for handling and storage without modification. Moreover, low flash point prevents direct use in diesel engines due to safety and ignition control concerns.

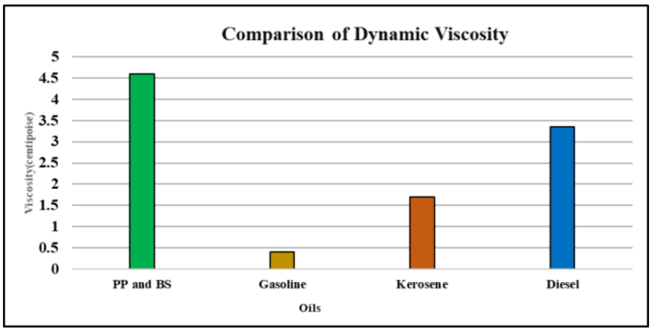
To enhance safety and usability, upgrading steps such as distillation and catalytic treatment are necessary. Overall, while the pyro-oil shows promise as a diesel alternative, it requires modifications to be effectively utilized.



(a)



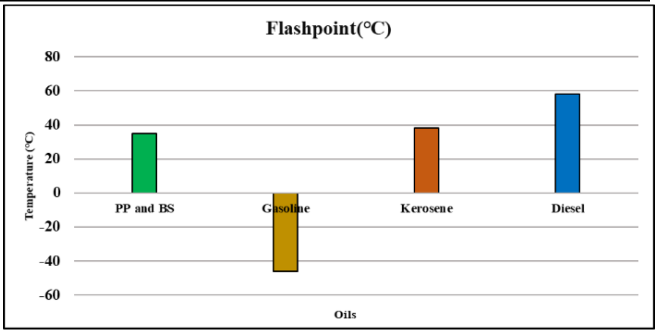
(b)



(c)

4. Conclusion

Co-pyrolysis process offers a great approach for converting plastic waste and biomass into valuable pyro-oil. This study represents an investigation to produce pyro-oil using co-pyrolysis of PP plastic waste and BS. An infrared wave cooker was used in this process to provide consistent and regulated heating. The breakdown of PP and BS is probably accelerated by infrared radiation, increasing the yield of useful byproducts such as pyro-oil, char, and gases. The product yield of the co-pyrolysis process can fluctuate based on factors such as feedstock ratio, temperature, reaction time, and moisture content. The maximum yield of 48.56 wt.% of pyro-oil was achieved at 18.6% moisture content and infrared power of 800 W. Pyro-oil derived from PP and BS



(d)

Fig. 6 Comparison among (a) Calorific value, (b) Density, (c) Viscosity, and (d) Flashpoint of different oils.

exhibits good properties compared to other fuels. Co-pyrolysis of PP and BS under infrared heating shows promising oil qualities, potentially leading to improved product yields compared to individual pyrolysis processes. This process under infrared heating may offer environmental benefits, such as reducing waste accumulation, utilizing renewable biomass resources, and potentially decreasing greenhouse gas emissions. Therefore, PP and BS could be prospective feedstocks for commercial pyro-oil production. Although the test was successful, there is still potential for improvement to enhance the effectiveness of the process. The study may identify areas for further investigation of the kinetics of co-pyrolysis reactions.

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