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RESEARCH ARTICLE

STUDY ON PYROLYTIC OIL PRODUCTION FROM RICE HUSK AND HDPE PLASTIC WASTE: A RESEARCH

[1]Shilpa Rai, [2]Dr. Ashok Sharma, [3]Dr· Sarita Sharma and [4]Dr. Sanjay Verma

[1]M.Tech Scholar, Department of Chemical Engineering, Ujjain Engineering college Ujjain, Madhyapradesh, India; [2,3,4] Professor, Department of Chemical Engineering, Ujjain Engineering college Ujjain, Madhyapradesh, India

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Corresponding author:
Shilpa Rai

ABSTRACT

The main motivation of the current study is the bio-oil upgrading process. Bio-oil is clean and environment friendly, but its properties are inferior to that of petroleum based fuels. Many researchers have shown that co-pyrolysis of biomass and plastic waste provides encouraging results For the co-pyrolysis process, plastics have been chosen as a co-feedstock due to their various advantageous properties, as it has good thermal stability than that of biomass, higher hydrogen and carbon content, plastic being manufactured from petroleum residue and having higher calorific value, which helps to improve the quality of product yield. The main interest to study the upgrading process, viz.co-pyrolysis of rice husk seed and plastic waste is to improve the quality of Mahua seed oil. This study also gives an idea about interaction of feed during co-pyrolysis and it helps to know how it improves the quality and quantity of the product yield. In this study, the obtained product yield from has been compared with co-pyrolysis yield and it shows their difference. The liquid product obtained from co-pyrolysis of is the main product, whereas the char and gas are byproducts. Co- pyrolysis has been carried out with respect to various operating conditions such as time, temperature, inert gas and residence time.

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INTRODUCTION

To convert biomass into biofuels, various thermochemical and biological processes are used. Among these, pyrolysis is one of the most convenient methods because it has several advantages, such as easy optimization, variety in product formation, complete utilization of feedstocks, and diversification in feedstocks (both biodegradable and non-biodegradable) that can undergo pyrolysis (Figure 1) (20). There are three categories of pyrolysis products formed: bio-oil (liquid), biochar (solid), and fuel gas (21). The yield of pyrolytic products is generally governed by the composition of biomass and the operating parameters (22). There are three forms of pyrolysis: slow, fast, and flash. Flash pyrolysis operates with a higher heating rate and shorter reaction time than fast pyrolysis, and the main product formed is bio-oil (23,24), whereas slow pyrolysis is done at low temperature, a low heating rate, and longer vapor residence time. The main product formed from slow pyrolysis is biochar (24). Fast pyrolysis is commonly used and operates at controlled temperatures (~500 ∘ C) for a short residence period (<2 s) and high heating speed (>200 ∘ C s−1). Its main product is bio-oil (23). Fuel gas is an undesirable product, but its production is unavoidable during pyrolysis; hence, it can be used to preheat the biomass, but its combustion byproducts are environmentally undesirable and require neutralization before being released. Pretreatment technologies (such as NOX scrubbers, electrostatic precipitators, adsorption systems for volatile organic compounds using activated carbon, SOX fuel gas desulfurization systems, flares, and biofilters) are used before the release of gasses, and/or optimization to lower its production during pyrolysis is implemented. On the other hand, biochar has been used to heat biomass and generate power for the pyrolysis plant, but recently it was observed that it can also be used as a soil enhancer, compost bulking agent, activated carbon, bioremediater of water and soil, bio-catalyst, energy source, and for carbon sequestration because of its composition (25–29). Bio-oil produced from pyrolysis exists as a dark brown, highly viscous liquid comprised of anhydro sugars, acids, alcohols, aldehydes, phenols, and oligomers. However, since bio-oils produced from biodegradable wastes are chemically unstable owing to high oxygen and water contents, culminating in reduced calorific value, high viscosity, and

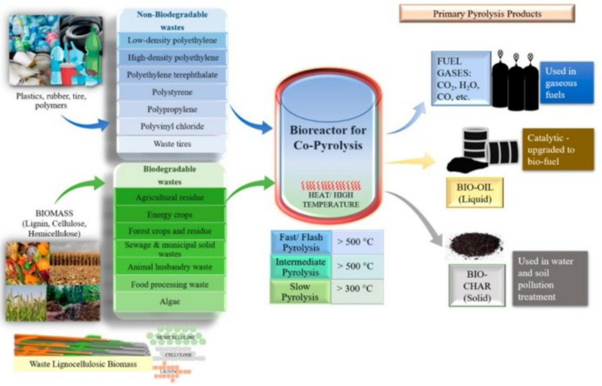


Figure 1. Co-pyrolysis of biodegradable and non-biodegradable feedstocks and its products

problems with corrosion and stability, its upgradation or enhancement is essential for its use as an alternative to crude oil (30). Due to these unfavorable properties, it is incapable of being employed as transportation fuel directly (15). In addition, pyrolysis of biomass results in minor aromatic yield and major coke production as a result of a decreased hydrogen/carbon effective ratio (H/Ceff) in most biodegradable biomasses (31). There are several routes for bio-oil enhancement depending on product requirements, such as emulsification, catalytic deoxygenation/hydrogenation, co-pyrolysis, thermal crack- ing, physical extraction, esterification, or gasification (24). Among all, co-pyrolysis has clearly shown potential for long-term business implementation due to improved results and cost-effectiveness. Co-pyrolysis constitutes the pyrolysis of more than one type of feedstock, resulting in a positive synergistic effect. For instance, co-pyrolysis of biomass along with non-biodegradable polymer waste (such as plastic waste, e-waste, waste tyres, etc.) has often increased the amount of hydrogen produced and also reduced CO content (32).

In addition, without much alteration to the system, co-pyrolysis results in favorable performance and cost-savings in comparison to other upgradation methods, such as hydrodeoxygenation (HDO) and catalytic cracking (19). It also results in improved quality and quantity of oil with a high calorific value (33). This positive synergistic interaction due to the mixing of feedstocks during pyrolysis has led to efficient oil content in combination with a secure and alternate way to handle non-biodegradable waste, such as plastic, tires, and lubricant oil (34). Thus, co-pyrolysis is an easy, efficient, and feasible strategy for high-quality fuel extraction with the potential to enhance the world’s energy protection, facilitate faster waste management, and decrease dependence on fossil fuels while preserving a healthy climate and ecosystem. The reason that co-pyrolysis has achieved a lot of recognition and success in recent years is that the pyrolysis of biomass and polymer/plastic waste individually and then mixing of their respective bio-oil is uneconomical, as more energy would be required to stabilize the mixture, and there is the possibility of separation after a short period due to the polar characteristic of the biomass pyrolysis oil. However, co-pyrolysis is more consistent in generating homogeneous and stable bio-oil compared to directly blending oil, as the interplay of the radicals leads to the formation of a stable bio-oil and avoids separation. In addition, co-pyrolysis offers a platform to treat a large volume of waste concurrently, which if treated separately would increase the overall cost. Therefore, it not only decreases waste treatment cost, but also solves various environmental issues accompanying traditional treatment methods, such as landfilling and incineration (33). In the past few years, much research related to co-pyrolysis has been documented in various peer-reviewed journals. For instance, Salvilla *et al*. (35) studied the co-pyrolysis of polyolefin plastics synergistically with wood and agricultural wastes and concluded that activation energy of plastic decomposition in co-pyrolysis was reduced, and the results could be used in polyolefin plastic and lignocellulosic waste co-pyrolysis for biofuels production. In another study, co-pyrolysis of woody biomass with plastic waste at an analytical and pilot scale by Johansson *et al*. (36) showed that the addition of plastics considerably impacts the composition and characteristics of the bio-oil. On the other hand, Wang *et al*. (37) considered sewage sludge co-pyrolysis with rice husk and concluded that pyrolysis behavior was improved synergisticically.

LITERATURE REVIEW

D Bisen, *et al* 2024 focused on producing hydrocarbon-based liquid fuels through a catalytic thermochemical process utilizing high-density polyethylene (HDPE) plastic waste and rice husk biomass (RH), with an emphasis on thermogravimetric analysis and gas chromatography-mass spectrometry (GC–MS). (36). Additionally, efforts were made to investigate the kinetic characteristics of the blends at different conversion rates employing the KAS and OFW methodologies. The analysis revealed that the activation energy of HDPE:RH (1:1, wt%) was measured at 126.4 kJ/mol and 114.9 kJ/mol. The dolomite catalyst was calcined at 900 °C to increase its activity as a catalyst. The used dolomite catalyst was calcined at 900 °C and had a surface area (SBET) of 7.45 m2/g, with average particle sizes of CaO and MgO of 77.8 nm and 43.7 nm. Results showed the catalytic co-pyrolysis of HDPE and RH enhanced the fuel properties by 15–20% that were performed at 500 °C at 10 °C/min. The aniline point was found to be 55.4 g/cm3, the fire point and the flash point were 52.2 °C and 49.6 °C, respectively, while the cetane number was determined to be 51.3. A 72.4% increase in carbon content, 12.26% increase in hydrogen content, and decrease in the oxygen extracted from the bio-oil by 17% were also observed.

Guangcan Su 2022 *et al* studied that Pyrolysis is a practical and promising route to reduce the environmental burden by converting food waste into bioenergy. (41). The continuous growth of population and the steady improvement of people's living standards have accelerated the generation of massive food waste. Untreated food waste has great potential to harm the environment and human health due to bad odor release, bacterial leaching, and virus transmission. However, the application of traditional disposal techniques like composting, landfilling, animal feeding, and anaerobic digestion are difficult to ease the environmental burdens because of problems such as large land occupation, virus transmission, hazardous gas emissions, and poor efficiency. This paper aims to analyze the characteristics of food waste, introduce the production of biofuels from conventional and advanced pyrolysis of food waste, and provide a basis for scientific disposal and sustainable management of food waste. The review shows that co-pyrolysis and catalytic pyrolysis significantly impact the pyrolysis process and product characteristics. The addition of tire waste promotes the synthesis of hydrocarbons and inhibits the formation of oxygenated compounds efficiently. The application of calcium oxide (CaO) exhibits good performance in the increment of bio-oil yield and hydrocarbon content. Based on this literature review, pyrolysis can be considered as the optimal technique for dealing with food waste and producing valuable products.

SBE Esso 2022 *et al.* investigated the quantity of organic solid waste (OSW) discharged by the public as bio-waste and plastic waste. Bio-waste, also known as biomass, is a sustainable and abundant energy source available in diverse forms. (42). Plastic waste is a cheap hydrogen source contained within OSW. The transformation of OSW via pyrolysis involves the thermochemical conversion of biomass and plastic. This conversion can mitigate waste accumulation issues and lead to synergistic product improvements for fuels and chemicals. the occurrence and extent of the synergistic/interactive effect during the co-pyrolysis of plastic waste and biomass. The influence of various factors, including the plastic type, biomass type, mixing ratio, reactor type, heating rate, reaction temperature, and catalysts, on the synergistic effect is considered. Furthermore, reasonable interaction mechanisms related to the synergistic effect during co-pyrolysis are presented. The outcome of this review revealed that the interaction mechanisms by which the synergistic effect may occur are the transfer of active hydrogen radicals from plastic to the biomass unstable oxygenated radicals, the catalytic activity of the alkali/alkaline earth metal species in biomass, and the heat and mass transfer during the co-conversion. Biomass pre-treatment, the use of catalysts, and the similarity between the chemical structure of the biomass and the plastic used can strengthen the interactions. Synergistic effects are likely to occur to a great extent at a low heating rate at high temperatures. The conclusions regarding the blend ratio are inconclusive.

Nadhilah Aqilah Shahdan *et al* 2022 analysed the rice husk ash (RHA) has been used as a catalyst precursor but there are lack of studies on the application of the resulting catalyst. (45). This study allows researchers to have an insight on using RHA-sourced catalysts in pyrolysis and be encouraged to utilize waste materials in the future. The goal of this study is to examine the effect of catalysts derived from rice husk ash (RHA) using the solvent-free method, labelled as RHA-T, on the catalytic co-pyrolysis of empty fruit bunch (EFB) and high-density polyethylene (HDPE) via thermogravimetric analyser (TGA). Comparisons were then made with co-pyrolysis and catalytic co-pyrolysis over raw RHA and Hydrogen-exchanged Zeolite Socony Mobil-5 (HZSM-Thermogravimetric analysis was conducted (EFB-to-HDPE mass ratio of 1:1, catalyst-to-feedstock mass ratio of 1:1) in a nitrogen atmosphere, where samples were heated from 30 °C until 700 °C (heating rate 20 °C/min). The order of runs with highest mass loss in the second phase is as follows, with the term ‘BP’ indicating the biomass-plastic feedstock: BP-RHA-T (98.17 wt%), BP-RHA (96.25 wt%), BP (86.82 wt%) and BP-HZSM-5 (70.59 wt%). Kinetic analysis using Coats-Redfern method and comparing between different diffusional reaction models showed that using BP-RHA-T follows a one-dimensional diffusion reaction, similar to the non-catalytic run. Using RHA-T resulted in higher activation energy (83.03 kJ/mol to 84.91 kJ/mol) compared to the non-catalytic run (62.39 kJ/mol to 68.97 kJ/mol). Thermodynamic analysis showed the pyrolysis runs were endothermic and non-spontaneous. Using RHA-T resulted in a higher change of enthalpy, a lower change of Gibbs free energy and a less negative change of entropy. It can be concluded that applying catalysts synthesized using low-cost materials like RHA can improve the degradation of EFB and HDPE via pyrolysis, compared to commercial HZSM-5 catalysts.

Burra, K. G. *et al.* (2018) studied co-pyrolyze pinewood and other plastic wastes such as Polypropylene (PP), polyethylene terephthalate (PETE), and polycarbonate (BPC) in various mass fractions. (55). The results compared with the pyrolysis of individual components revealed non-additive synergistic effects from co-pyrolysis. Differential thermography (DTG) results showed enhanced decomposition peaks of biomass along with longer evolution of syngas and decreased peak of plastic polymers using BPC or PETE. Char residue was non-additively reduced by some 5% (dry wt. basis) using PP and BPC, and by 2-3% using PETE when pyrolyzed with biomass. This suggests increased carbon conversion efficiency and volatiles yield during co-pyrolysis compared to individual component pyrolysis. First order distributed activation energy modeling (DAEM) with 5 pseudo-components revealed that the synergistic effects of biomass with PP or PETE were mainly due to physical nature of the polymers as observed from increased activation energy bandwidth of biomass decomposition. BPC and pinewood mixtures showed an overlap in their activation energy distribution between 100-150 kJ/mol. This overlap caused the set of reaction with similar energetics to mutually interact chemically and enhance the composite mixture pyrolysis. Activation energy of BPC in the presence of pinewood was reduced by some 50 kJ/mol compared to individually examined polymer decomposition. The observed quantitative synergistic kinetics results in co-pyrolysis of biomassplastic wastes mixtures as compared to individual component pyrolysis provide vital information towards the development of feed-flexible, clean pyrolysis and gasification system for efficient fuels production.

K.G. Burra *et al* 2018 investigated Co-pyrolysis of pinewood and different kinds of plastic wastes in different mass fractions using polypropylene (PP), polyethylene terephthalate (PETE), and polycarbonate (BPC) were investigated. (57). The results compared with the pyrolysis of individual components revealed non-additive synergistic effects from co-pyrolysis. Differential thermography (DTG) results showed enhanced decomposition peaks of biomass along with longer evolution of syngas and decreased peak of plastic polymers using BPC or PETE. Char residue was non-additively reduced by some 5% (dry wt. basis) using PP and BPC, and by 2–3% using PETE when pyrolyzed with biomass. This suggests increased carbon conversion efficiency and volatiles yield during co-pyrolysis compared to individual component pyrolysis. First order distributed activation energy modeling (DAEM) with 5 pseudo-components revealed that the synergistic effects of biomass with PP or PETE were mainly due to physical nature of the polymers as observed from increased activation energy bandwidth of biomass decomposition. BPC and pinewood mixtures showed an overlap in their activation energy distribution between 100 and 150 kJ/mol. This overlap caused the set of reaction with similar energetics to mutually interact chemically and enhance the composite mixture pyrolysis. Activation energy of BPC in the presence of pinewood was reduced by some 50 kJ/mol compared to individually examined polymer decomposition. The observed quantitative synergistic kinetics results in co-pyrolysis of biomass-plastic wastes mixtures as compared to individual component pyrolysis provide vital information towards the development of feed-flexible, clean pyrolysis and gasification system for efficient fuels production.

Suat Uçar 2014 *et al* focussed on the co-pyrolysis of pine nut shells (PNS) with scrap tires (ST) at different blend ratios was carried out at 500 °C. (59).The addition of ST into PNS in the co-pyrolysis process not only increased bio-oil yields but also improved bio-oil characteristics when compared with the pyrolysis of PNS. The carbon content in bio-oils from all PNS/ST blend ratios was higher and oxygen content was lower than that of PNS-derived oil. This is an indication of the improved characteristics of bio-oils from the co-pyrolysis of biomass with scrap tires. The blend ratio in the feedstock of co-pyrolysis had a significant effect on the product distributions and physico-chemical properties of bio-oils. When heating values of bio-oils produced from the pyrolysis of PNS were compared with bio-oils obtained from the co-pyrolysis of PNS with ST, the addition of ST into PNS led to increase heating values of bio-oils with the exception of PNS/ST (4:1)-derived bio-oil. In addition, the heating values of gas products and levels of hydrogen and hydrocarbons (from C1 to C4) in the gas products from the co-pyrolysis of PNS/ST blends were higher than that of the pyrolysis of PNS. The heating values of chars produced from the co-pyrolysis of PNS/ST blends were found to be in the range of 31.1 and 32.9 MJ kg−1.

Paula Costa *et al* 2014 objective of this study is to access the technical and economical viability of using pyrolysis technology applied to the rice production main wastes to produce bio-fuels to substitute fossil fuels and electricity consumption during rice milling processes. (59) Therefore, it was studied the effect of operating conditions (reaction temperature, initial pressure and reaction time) on products yields and quality, as well as the possible synergetic effects that may occur during the pyrolysis of these wastes. The pyrolysis experiments were performed in 1 L capacity batch reactor made of Hastelloy C276 and built by Parr Instruments. According to previous studies, the range of operational conditions studied was: 350-430 ºC for reaction temperature, 2-10 bar for initial pressure and 10-60 min for reaction time. So far, the results obtained showed that these two wastes can be processed together. The presence of PE seems to favour the biomass conversion, as PE is easily converted into liquids by pyrolysis, which increases heat and mass transfer in the reaction medium

Çepelioğullar *et al.* (2013) examined Co-pyrolysis properties and kinetics of biomass-plastic blends. Cotton stalk, hazelnut shell, sunflower residue, and arid land plant Euphorbia rigida, were blended in definite ratio (1:1, w/w) with polyvinyl chloride (PVC) and polyethylene terephthalate (PET). (60). Experiments were conducted with a heating rate of 10 °C min−1 from room temperature to 800 °C in the presence of N2 atmosphere with a flow rate of 100 cm3 min−1. After thermal decomposition in TGA, a kinetic analysis was performed to fit thermogravimetric data and a detailed discussion of co-pyrolysis mechanism was achieved. Experimental results demonstrated that the structural differences between biomass and plastics directly affect their thermal decomposition behaviors. Biomass pyrolysis generally based on three main steps while plastic material's pyrolysis mechanism resulted in two steps for PET and three steps for PVC. Also, the required activation energies needed to achieve the thermal degradation for plastic were found higher than the biomass materials. In addition, it can be concluded that the evaluation of plastic materials together with biomass created significant changes not only for the thermal behaviors but also for the kinetic behaviors.

MATERIAL ANDMETHODS

Feed Materials: Waste polythene samples were then chopped and sized of 20 mm × 20 mm. rice husk sample was collected from rice cultivated area near RUET and also chopped into size of 15 mm×5 mm. The feedstocks were then sun-dried and finally oven-dried at a temperature of 110°C for 2 hour to remove moisture from the samples. The investigation of the suitability of feedstock materials requires proximate and ultimate analysis, and thermo gravimetric analysis (TGA). The proximate and ultimate analysis of polythene and rice husk are presented in Table 1 after been dried in an oven at 110 °C for 2 hours, the original materials were crushed and pulverized to a size of <2 mm before they were analyzed. The TG/DTG plots for polythene and rice husk are presented in Fig. 1. From Fig. 1 it can be seen that decomposition is completed for both of the samples around 500 ^{o}C and decomposition rate is maximum at 250 ^{o}C and 450 ^{o}C for rice husk and polythene, respectively.
3.2 Experimental Section

Proximate Analysis (wt.%) Polythene rice husk Ultimate Analysis (wt.%) Polythene rice husk

Table 1. The proximate and ultimate analysis of polythene and rice husk

Moisture	0.41	9.47	Carbon (C)	83.93	36.48
Volatile matter	96.88	64.45	Hydrogen (H)	12.84	3.60
Fixed carbon	0.28	12.67	Nitrogen (N)	-	-
Ash	2.43	13.41	Oxygen (O)	0.80	46.51
			Sulphur (S)	-	-
			Others	2.43	-

Experimental Section

- The whole experimental process was carried out in a fixed bed pyrolysis reactor.
- The major components of the co-pyrolysis experimental set-up have been represented in Fig.2
- The experimental unit consists of the following components:
- a fixed-bed reactor chamber;
- condenser;
- LPG cylinder with burner;
- K-type (chromel- alumel) thermocouples; (v) liquid collector.

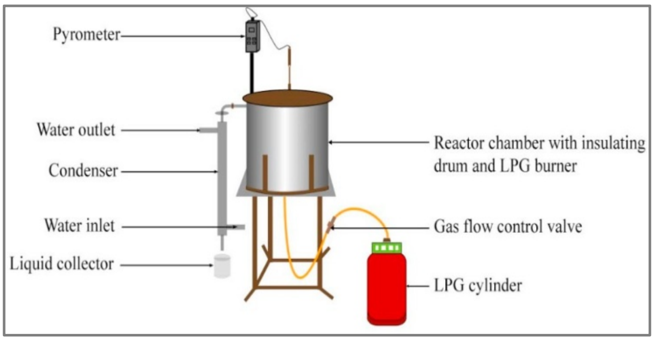


Fig. 2. Main components of the fixed-bed LPG heating pyrolysis system

The cylindrical reactor is made of stainless steel with 100 mm outside diameter and 300mm length and provides vapor residence time of 8s. The reactor was installed inside an LPG burner consisting of four arms each of them are 10mm in diameter, 300 mm length and having ten 5 mm size holes to enable uniform heating of feed in reactor chamber. To reduce heat loss, two layer of 50 mm asbestos layer was used around the reactor.

- The co-pyrolysis temperature in the reactor was measured by a K-type thermocouple that was inserted in the reactor chamber.
- A condenser of 100mm outside diameter and 300mm length was connected to the reactor to condense the pyrolytic vapor.
- The water circulates through the condenser to condense the pyrolytic vapor into pyrolytic oil.
- The waste polythene and rice husk samples were blended together at a weight ratio of 100:0; 75:25; 50:50; 25:75; and 0:100. The reactor was fed with the blended feed materials and closed with a cover.
- The reactor was heated, for 60 min or up to no further visible vapor product coming out, using LPG burner until the desired temperature (450-500 ^{o}C) was achieved. The reactor operating temperature was predicted by TG/DTG results.
- The elevated temperature with short vapor residence time converts the feedstock into gaseous mixture and solid char.
- The pyrolytic vapor products were condensed into the condenser and the liquid products were collected in the liquid collector.
- The uncondensed gases were flared to the atmosphere.
- After the completion of the pyrolytic reaction, the burner and the pyro-vapor exit port was closed.
- The reactor was then cooled and bio-chars formed inside the reactor were collected and weighted.
- Weight of the gas product was determined by subtracting the liquid and char weight from feedstock.
- Several experimental runs were made varying the operating conditions and each time the amount of liquid, char and gas was collected, measured.
- The proximate analysis was carried out according to the American Society for Testing Materials (ASTM) Standard D3172-73 (1984) test procedures for solid fuel, titled “Standard Method for Proximate Analysis of Coal and Coke”.
- The ultimate analysis was carried out by an Elemental Analyzer of model EA 1108 according to the ASTM D3176-84 standard test procedures.
- The amount of carbon, hydrogen and nitrogen was determined and the oxygen content was calculated by difference.
- The derived pyrolytic liquids were mixed properly and homogenized before analysis. Some significant physical properties like density, density, viscosity, flash point, pour point and HHV were determined by using the following standard method: ASTM D189, ASTM D445, ASTM D92, ASTM D97 and ASTM D240, respectively.
- The calorific value of the feedstocks, pyrolysis oil and bio-char was measured using an oxygen bomb calorimeter.

- **Temperature:** Temperatures are generally below 600°C.
- **Heating Rate:** Slow heating rates, typically ranging from 5 to 100 °C/min.
- **Residence Time:** Relatively long residence times, ranging from minutes to days.
- **Products:** Primarily yields biochar, with significant amounts of bio-oil and gas also produced
- **Heating:** The biomass is heated slowly in a reactor under anoxic conditions.
- **Decomposition:** As the temperature increases, the organic material breaks down into smaller molecules through a series of thermal and chemical reactions.
- **Product Formation:** These reactions lead to the formation of char (a solid residue), bio-oil (a liquid), and gas (including non-condensable gases).

Row material:- 1.Rice husk 2. HDPE (High-Density Polyethylene)

Rice husk (also called rice hull) is the outer protective covering of rice grains that is separated during the milling process Rice husk is made up of: Cellulose (~35%)Lignin (~25%)Silica (~15–20%) Moisture (~8–12%). High-Density Polyethylene (HDPE) is a widely used thermoplastic polymer known for its strength, durability, and resistance to chemicals and moisture. It is made from petroleum and has a linear structure with minimal branching, which gives it high density and crystalline structure.

RESULT AND DISCUSSION

Co-Pyrolysis Results: Rice Husk + HDPE

Product Yield: Bio-oil: Increases significantly with more HDPE.

Char: Decreases as plastic content increases.

Rice husk alone: ~35–40% char.

RH + HDPE mix: drops to ~20–25% char.

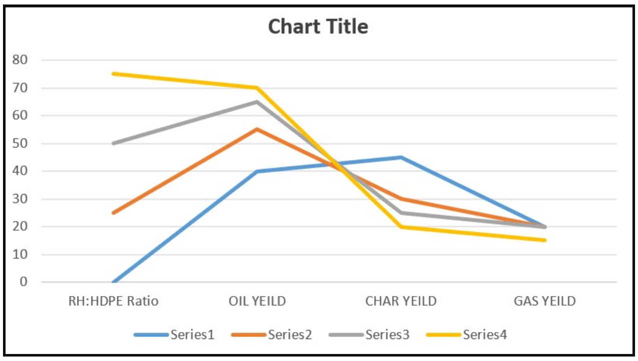
Oil Quality: Heating Value (HHV): ~35–43 MJ/kg, close to diesel (≈45 MJ/kg).

Composition: Alkanes, alkenes, aromatics.

Less oxygenated compounds than pure biomass oil (improves fuel quality).

RH:HDPE Ratio	Oil Yield (%)	Char Yield (%)	Gas Yield (%)
100:0	35–40	45	15–20
75:25	50–55	30	20
50:50	60–65	20–25	15–20
25:75	65–70	15–20	15

Product Yield Oil yield increased with HDPE ratio. Synergistic effect improved quality and quantity of pyro-oil. The liquid products obtained at reaction operating temperature 450oC .The density of pyrolytic liquids was found lower than that of the petrol, diesel and other alternative fuels. The viscosity of liquid products from co-pyrolysis was higher than that of diesel and gasoline fuels but lower than the palm oil. The experiment shows the result between the disrtribution for different blends of rice husk and the polythene are as follows :



Oil Property Comparison

Property	Diesel	Pyrolysis Oil (50:50 RH:HDPE)
Viscosity (cSt @40°C)	3.5	22
HHV (MJ/kg)	45	39.5
pH	~7	3.5
Flash Point (°C)	70	55
Water Content (%)	<0.1	7
Density (kg/m³)	830	950

Variable Product

Variation of product yield with variation of feed-stock blends shows:

The obtained major pyrolytic yields are presented in Fig. 3.

- It is clear from Fig.7 that the maximum pyrolytic oil (80 wt.%) and minimum char (0 wt.%) and gas (21.50 wt.%) were produced from 100% polythene.
- The minimum liquid (40.20 wt.%) and maximum char (26.78 wt.%) and gas products (35.71 wt.%) were obtained from 75% rice husk and 25% polythene blend.
- 50% polythene and 50% rice husk blend can be considered optimum feed mixture as 60.7 wt.% liquid, 18.64 wt.% char and 21 wt.% gas were produced.
- The amount of pyrolytic oil increases and char and gas products decreases with the increase of polythene in the feedstock blends.

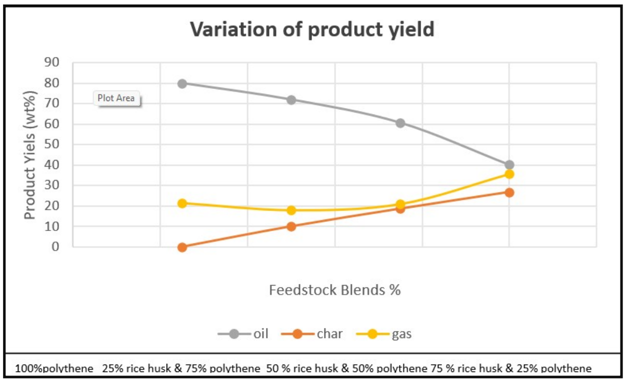


Fig. 3. Pyrolysis product yield distribution for different blends of polythene and rice husk

Properties of the product liquids

Variation of Density

The variations in density are presented in Fig. 4

- The variation of density with wt.% variation of polythene and rice husk in the blend is shown in Fig.4.
- From Fig.4. it is seen that, the highest density of pyrolytic oil was obtained from 100% polythene.
- As the wt.% of polythene decreases in the blend, the density of the liquid decreases.
- The maximum density was 760 kg/m3 when polythene wt % is 100.
- The density of palm oil is 830 kg/m3, pyrolysis of wood is between 800 to 900 kg/m3, diesel is 827 kg/m3 and the gasoline is 790 kg/m3

Table 2. Variation of product density with blend ratio

Feed Materials (wt. %)	Density (kg/m3)
0% rice husk & 100% polythene	760
25% rice husk & 75% polythene	740
50% rice husk & 50% polythene	720
75% rice husk & 25% polythene	700
Palm oil	830
RTP pyrolysis oil of wood	800-900
Diesel	827
Gasoline	710-790

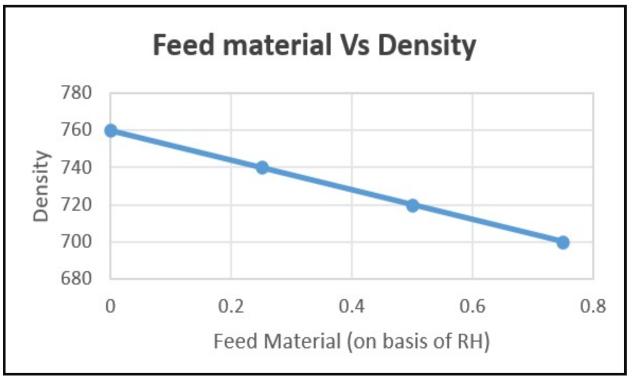


Fig. 4. Variation of density with wt.% variation of polythene and rice husk in the blend

The increase in density of pyrolytic oil with higher weight percentages of polyethylene (PE) in the feedstock occurs primarily due to the production of heavier, longer-chain hydrocarbons and higher concentrations of specific compounds compared to other plastics.

Variation of Viscosity

The variations in viscosity are presented in Fig. 5

- From Fig. 5, the maximum viscosity (9.47 cSt) of the liquid yield was obtained from 100% polythene.
- The viscosity (6.08 cSt) of the liquid yield was obtained from 75% polythene.
- The viscosity (4.86 cSt) of the liquid yield was obtained from 50% polythene.
- The viscosity (3.57 cSt) of the liquid yield was obtained from 25% polythene
- The wt.% increase of rice husk in the blend decreases the pyrolytic oil's viscosity.

Table 3. Variation of product viscosity with blend ratio

Feed Materials (wt. %)	Viscosity (cSt)
0% rice husk & 100% polythene	9.47
25% rice husk & 75% polythene	6.08
50% rice husk & 50% polythene	4.86
75% rice husk & 25% polythene	3.57
Palm oil	41
RTP pyrolysis oil of wood	-

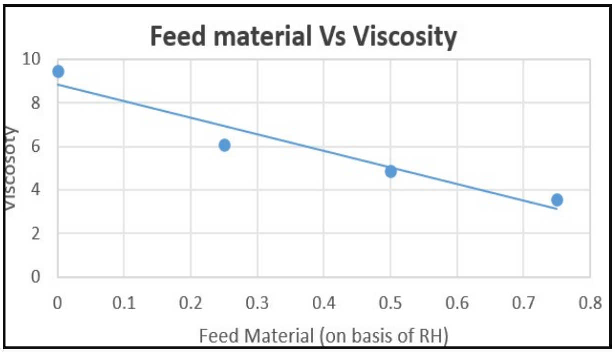


Fig.5. Variation of viscosity with wt.% variation of polythene and rice husk in the blend

The increase in viscosity of pyrolytic oil with higher polyethylene (PE) weight percentage occurs because polyolefins like PE tend to produce higher-molecular-weight hydrocarbons and long-chain, waxy, paraffinic compounds.

Variation of Calorific value

The variations in calorific value are presented in Fig. 6

- The variation of calorific value with wt.% variation of polythene and rice husk in the blend is shown in Fig. 6.
- 0 wt.% rice husk and 100 wt.% polythene in the feedstock blend gives the highest calorific value (38137 KJ/kg) of the pyrolytic oil.
- 25 wt.% rice husk and 75 wt.% polythene in the feedstock blend gives the highest calorific value (34355 KJ/kg) of the pyrolytic oil.
- 50 wt.% rice husk and 50 wt.% polythene in the feedstock blend gives the highest calorific value (30385 KJ/kg) of the pyrolytic oil.
- 75 wt.% rice husk and 25 wt.% polythene in the feedstock blend gives the highest calorific value (22415KJ/kg) of the pyrolytic oil.

The wt.% increase of rice husk in the feedstock blend decreases the calorific value of the liquid.

Table 4 Variation of product calorific value with blend ratio

Feed Materials (wt. %)	Calorific Value (KJ/kg)
0% rice husk & 100% polythene	38137
25% rice husk & 75% polythene	34355
50% rice husk & 50% polythene	30385
75% rice husk & 25% polythene	22415
Palm oil	22100
RTP pyrolysis oil of wood	22100-24300

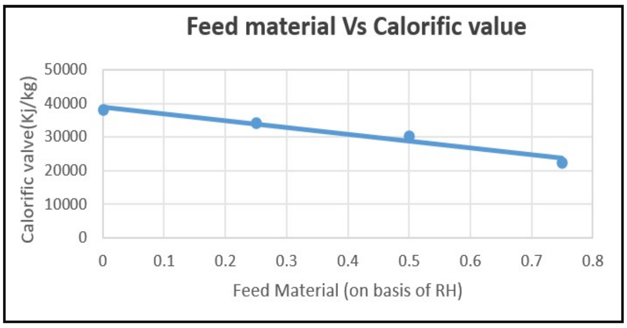


Fig. 6. Variation of calorific value with wt.% variation of polythene and rice husk in the blend

When the weight percentage (wt%) of polyethylene (PE) increases in the feedstock for pyrolysis, the calorific value of the resulting pyrolytic oil increases primarily because polyethylene is a polyolefin with a high hydrogen-to-carbon (H/C) ratio, which translates to a high-energy, hydrocarbon-rich oil.

Variation of Fuel properties: The Bio-oils obtained from the co-pyrolysis of waste polythene and rice husk was homogeneous and no phase separation took place in the storage bottles. Different literature review reports that the water contents usually varies from 15 to 30 wt.%, depending on the initial moisture in feed stocks and pyrolysis conditions. The storage and utilization of bio-oils is greatly influenced by the moisture content in feed stocks. On the one hand, it increases ignition delay, lowers heating values, causes phase separation, and reduces combustion rates during the combustion process. In addition, during the preheating process it leads to premature evaporation and subsequent injection difficulties. On the other hand, it reduces viscosity, facilitates atomization, and reduces pollutant emissions during combustion. The wt.% increase of rice husk in the feedstock blend decreases the calorific value of the liquid. The fuel properties of pyrolysis oil compared to petroleum products are presented in Table 5.

Table 5. The fuel properties of pyrolysis oil compared to petroleum products

Feed Materials (wt. %)	Pour Point (°C)	Flash Point (°C)
0% rice husk & 100% polythene	<-8.7	58.50
25% rice husk & 75% polythene	<-6.6	89.40
50% rice husk & 50% polythene	<-5.7	77.00
75% rice husk & 25% polythene	<-3.2	91.00
Palm oil	20	250
RTP pyrolysis oil of wood	-	-
Diesel	-33 to -15	60-80
Gasoline	-	-45

Flash point is the temperature at and above which a liquid gives off sufficient flammable vapor to ignite in air. The flash point of co-pyrolysis derived liquids was 77°C which is quite near to the flash point of petroleum-refined fuels. For example, kerosene has a required flash minimum point of 23°C , diesel fuel of 75°C and light fuel of 79°C. Previous analysis based on co-pyrolysis reported that the calorific value obtained from the co-pyrolysis of corn-cob and waste cooking oil; tire and nutshell and tire and rice husk are 27500 KJ/kg, 29500 KJ/kg and 33600 KJ/kg, respectively. The calorific value of co-pyrolysis of polythene and rice husk is more suitable than the other above mentioned co-pyrolysis results.

CONCLUSION

The variation of the wt.% of polythene and rice husk has a great influence in the production of pyrolytic products. In this study fifteen experimental runs were made varying the proportion of feed materials. The liquid product yield increases whereas char and gases product decreases with the increase of polythene in the blends. For 50 wt.% polythene and 50 wt.% rice husk, the maximum liquid yields were 60.7 wt% at reactor temperature 450°C. A temperature of 450°C was suggested as the best co-pyrolysis temperature to maximize the pyrolysis oil yield from rice husk mixed with polythene.

The calorific value in pyrolysis oil obtained from co-pyrolysis of rice husk mixed with polythene was higher at 38.13 MJ/kg. The results show that it is possible to obtained liquid products that are comparable to petroleum fuels and valuable chemical feedstock from the selected wastes if the pyrolysis conditions are chosen accordingly.

FUTURE SCOPE

Based on the above results of the study, it can be concluded that the upgradation process like co-pyrolysis is one of the most suitable processes to obtain high grade fuel. Further studies are required to modify the process. The following are the recommendations for the future work:

- Other different types of plastic can also be used in co-pyrolysis process to improve the quality of bio-oil. Pyrolysis oil from rice husk and HDPE shows promising potential as an alternative liquid fuel, especially after simple upgrading treatments (like filtering, water removal, mild catalytic cracking).
- It can supplement diesel in boilers or engines and reduce dependency on fossil fuels while solving waste problems

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