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Research Article

FAST PYROLYSIS OF WASTE PLASTIC FOR PRODUCTION OF FUEL OIL

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Abstract: Plastic pollution is a severe threat to the environment, and waste plastic can take several decades to degrade completely under environmental conditions. The present study deals with fuel oil production from mixed plastic wastes. The pyrolysis can be used to convert waste plastic to fuel oil. The moisture content, bulk density, calorific value, volatile matter and fixed carbon content of mixed plastic wastes were found to be 0.18%, 38 kg/m^3, 40.98 MJ/kg, 97.6% and 0.5%, respectively. The reaction conditions may vary for different feedstock for better fuel oil yield. For process optimization, three reaction temperatures (400, 450, and 500°C) and four nitrogen gas flow rates (5, 10, 15, and 20 ml/min) were used in a pyrolytic reactor. Results showed that the maximum fuel oil yield was 84.35% at 450°C, and nitrogen flow rate of 10 ml/min. The minimum yield of fuel oil was 54.60% at 400°C, and nitrogen flow rate of 20 ml/min. The cost of the fuel oil produced from mixed plastic waste in the reactor was arrived to be Rs. 51.56/- per liter. The fuel properties of fuel oil produced from plastic wastes were on par with diesel fuel.

Keywords: *Fast pyrolysis, Waste plastic, Fuel oil*

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Introduction

Petroleum fuels are playing an essential role in all sectors, including industries, transportation, and agriculture. The ill-effects of these fuels are climate change, pollutions, global warming, and instability economy linked with variation in fuel price. There is a need to search for alternate fuel production from cheap feedstocks such as biomass and waste plastic. The plastics are found for many applications in almost all industries. Global plastic production in 2015 was 3.35 × 10^5 kt [1] due to overpopulation and improved standard of living. Even though plastic has several excellent properties, the used plastic is being discarded as waste and mostly dumped in the environment. There is no method available for the safe disposal of plastic wastes.

Pyrolysis involves the thermal degradation of the substances under heat, pressure, and oxygen-free environment [2]. Generally, liquid, gas, and solid residue are produced in the pyrolysis process. A liquid product derived from the pyrolytic conversion of any plastic waste is referred to as fuel oil. Without upgrading/treatment, the fuel oil can be used as a fuel in furnaces, boilers, turbines, and diesel engines. The oil yield may vary due to variation in the feedstock's composition. Thus, it results in different reaction conditions for better yield of fuel oil from plastic waste feedstocks also. Therefore, higher fuel oil yield can be achieved by varying process conditions and ultimately optimal reaction conditions for pyrolysis may be identified [3]. This paper explains the effect of process conditions (reaction temperature and nitrogen supply) on the yield of fuel oil from waste plastic, and results are briefly discussed.

Materials and methods

Four waste thermoplastic (plastic cup, water bottle, cover, and bag) were selected for this study. The standard methods are employed to determine the properties of waste plastic such as moisture content (ASTM D3173), volatile matter (ASTM D 3175-89), ash content (ASTM D 3174-89), fixed carbon (ASTM D 3172-89), bulk density (ASTM E-873-06) and calorific value (ASTM D 2015-77).

Experimental details

A laboratory-scale fast pyrolytic reactor available at the Department of Renewable Energy Engineering was used to produce fuel oil from plastic wastes [4], and the average value of three trials was reported. The reactor consists of a feeding system, timer, pyrolysis set up with a controller for reaction temperature and nitrogen gas flow rate. Based on the literature, the reaction temperatures of 400, 450, and 500°C and nitrogen gas flow rates of 5, 10, 15 and 20 ml/min were selected to study their influence on the yield of three end pyrolysis products.

For each experiment, the feed hopper was loaded with five kg of mixed waste plastic. After attaining reaction temperature, the plastic waste supplied at the rate of 1 kg/h to the reactor by a screw auger. During pyrolytic conversion, gases produced and sent it to a condenser for collecting fuel oil. The solid residue in the reactor was collected after the experimental trials. The yields of pyrolytic products such as fuel oil, solid residue and pyrolytic gas were calculated as follows.

Fuel oil yield, %(FO)= [Weight of fuel oil / Weight of waste plastic use] X 100

Solid residue yield,% (SR) = [Weight of solid residue / Weight of waste plastic use] X 100

Pyrolytic gas yield, % = 100 – (SR+FO), %

Fuel properties of fuel oil were determined using standard methods viz., specific gravity (IS: 1448-1972), kinematic viscosity (ASTM 445-72), calorific value (ASTM D 2015-77) flashpoint (ASTM D93), carbon residue (ASTM D524-IP14/65) and ash content (ASTM D 482).

Results and Discussion

The proximate composition *viz*., moisture content, volatile matter, ash and fixed carbon content, bulk density and calorific value of mixed plastic wastes were studied, and found to be 0.18%, 97.6%, 1.72%, 0.50%, 38 kg/m^3, 40.98 MJ/kg, 97.6% and 0.5%, respectively.

Optimal conditions for fuel oil production

For this study, three levels of temperature (400, 450, and 500°C) and four levels of nitrogen gas flow rate (5, 10, 15 and 20 ml/min) were used to determine the optimal conditions for higher fuel oil yield from mixed plastic waste. The yield of pyrolytic products (fuel oil, solid residue, and pyrolytic gas) obtained from the pyrolysis of mixed plastic wastes at selected reaction temperatures (400, 450 and 500°C) and nitrogen flow rate (5, 10, 15 and 20 ml/min) is presented in [Fig-1].

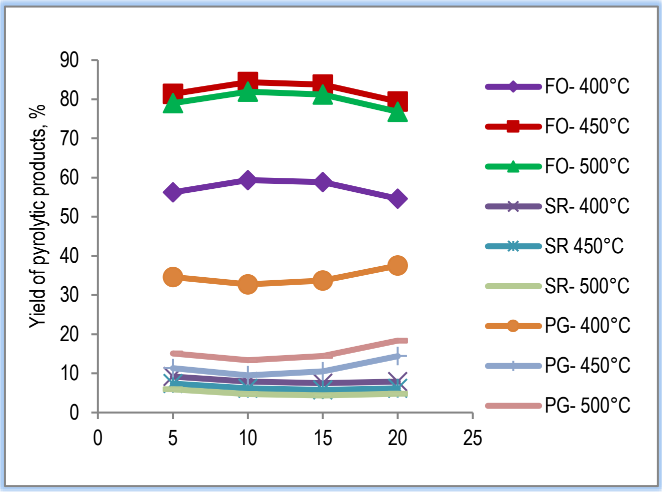

Fig-1 Effect of reaction temperature and nitrogen flow rate on the yield of pyrolytic products

At 5 ml/min nitrogen flow rate, the fuel oil yield of mixed plastic waste was increased from 56.24 to 81.33% when the process temperature was increased from 400 to 450°C. Further increase in temperature to 500°C resulted in a reduced fuel oil yield of 78.98 % [Fig-1]. At the nitrogen flow rate of 10 ml/min, the recorded maximum fuel oil yield of 84.35% at 450°C, and the lowest of 59.35% at 400°C was observed. Further increase in temperature to 500°C, reduced the fuel oil yield to 81.92%.

At 15 ml/min nitrogen flow rate, the fuel oil yield of mixed plastic waste was increased from 58.80 to 83.72% for the reaction temperature from 400 to 450°C. The fuel oil yield at 500°C was reduced to 81.20 %. At the nitrogen flow rate of 20 ml/min, the recorded maximum fuel oil yield was 79.43 % at 450°C, and the lowest was recorded as 54.60% at 400°C. For the reaction temperature of 500°C, the fuel oil yield was 76.82%.

The maximum fuel oil yield was 84.35% under optimal reaction conditions (450°C and nitrogen flow rate of 10 ml/min). The minimum fuel oil yield was 54.60% at 400°C, and nitrogen flow rate of 20 ml/min.

Properties of raw oils and their biodiesel

The fuel properties such as specific gravity, kinematic viscosity, calorific value, flash point, ash content, and carbon residue of fuel oil and diesel are presented in [Table-1].

Table-1 *Comparison of properties of fuel oil and diesel*

Properties	Fuel oil	Diesel
Specific gravity	0.802	0.840
Kinematic viscosity @40°C, mm^2/s	4.12	3.52
Calorific value, MJ/ kg	44.52	46.45
Flashpoint, °C	43	50
Ash Content, %	0.004	0.01
Carbon Residue, %	0.60	0.21

The specific gravity of the fuel oil was found as 0.802, which was lower than that of diesel (0.840). The kinematic viscosity of fuel oil (4.12 mm^2/s) was almost closer to the desirable kinematic viscosity of diesel fuel (1.9-4.10 mm^2/s) [5]. The fuel oil's calorific value was recorded as 44.52 MJ/ kg, which was lower than diesel fuel (46.45 MJ/kg^{-1}). The flashpoint of fuel oil was 43°C, lower than diesel fuel (50°C). The ash content of fuel oil (0.004%) was lower than diesel fuel (0.01%). The carbon residue of fuel oil and diesel was 0.06 %, 0.21%, respectively. The fuel properties of fuel oil were comparable to diesel fuel standards.

Cost economics

The cost economics for fuel oil production was calculated and details are given below.

i. Fixed costs

Cost of laboratory-scale reactor (C)	= Rs. 2.00 lakhs
Life period (L)	= 15 years
Salvage value (S)	= Rs. 13,340/-
Depreciation per year	= Rs. 12,444/-
Depreciation per day	= Rs. 34/-
Interest per year (7 %)	= Rs. 7, 467/-
Interest per day	= Rs. 20.46/-
Housing cost per year	= Rs. 1,067/-
Housing cost per day	= Rs. 2.92/-
Total fixed cost per day	=Rs. 57.38/-

ii. Variable costs

Production of fuel oil per day	= 8.40 liters
Cost of plastic waste	= Rs. 10/kg
Cost of feedstock per day	= Rs. 80/-
Labor charges per day (1 person @Rs.150 per person per day), Rs.	= 150/-
Electricity charges per day, Rs.	= 80/-
Repair cost per annum, Rs.	= 24,000/-
Repair cost per day, Rs.	= 65.75/-
Total variable cost per day, Rs.	= 375.75/-
Net cost per day fuel oil production, Rs.	= 433.13/-
Cost of fuel oil per liter, Rs.	= 51.56/-

Conclusion

The maximum fuel oil yield (84.35%) was achieved under optimal pyrolysis reaction conditions of process temperature at 450°C and nitrogen flow rate of 10 ml/min. The minimum fuel oil yield was recorded as 54.60% at 400°C and nitrogen flow rate of 20 ml/min. The fuel properties of fuel oil produced from mixed plastic wastes were on par with diesel fuel.

Application of research: Alternate fuel from plastic waste

Research Category: Fuel oil production

Abbreviations: ASTM - American Society for Testing and Materials

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Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
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