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Distillation of Pyrolytic Oil Obtained from Fast Pyrolysis of Plastic Wastes

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Abstract

Fast pyrolysis of plastic wastes, at temperatures from 500-800°C, gives as a main product, a dark brown liquid (a mixture of gasoline, diesel and heavy oils). Fractional distillation is commonly used to separate petroleum oils. However, information on the distillation of the pyrolytic oil obtained from fast pyrolysis of plastic wastes is scarce. We studied the distillation of two pyrolytic oil samples derived from fast pyrolysis of polyethylene and mixed plastic wastes. The former was distilled at the temperature of 180°C for 60 minutes and the latter was distilled at the temperature of 150°C and 180°C for 90 minutes. We observed that the distillates had a lighter color than the pyrolytic oil samples. The distillates were light yellowish at 180°C and colorless at 150°C. In the early stage of distillation, distillation rates increased with elapsed time and reached a maximum at approximately 25-35 mL/min and then gradually dropped. The distillates had lower densities and viscosities than the pyrolytic oils and both distillate properties were similar to those of gasoline, i.e. densities of 706-728 kg/m³ and viscosities of 0.39-0.43 × 10⁻⁶m²s⁻¹.

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1. Introduction

The raw pyrolytic oil obtained from commercial rotary kiln pyrolysis for municipal plastic waste contained a wide range from compounds from C₅ about C₂₅ as well as other products [1]. This pyrolytic oil represents renewable energy. For example, blends of 'plastic' oil from catalytic pyrolysis of waste high density polyethylene (HDPE) with

diesel was tested in a compression ignition (CI) engine [2]. The result showed brake specific fuel consumption (BSFC) increases with increase in waste plastic oil blend ratio and decreases with increase in engine load. Mechanical efficiency increases with brake power at all blend ratios. In addition, the carbon monoxide (CO) emission for almost all loads and all blends was lower than for diesel.

The pyrolytic oil obtained from fast pyrolysis has been separated and improved with various distillation methods, catalytic and molecular distillations and vacuum fractional distillation. Wang et al. [3] adopted the methanol-water method to enrich pyrolytic lignins in the heavy fraction of bio-oil by molecular distillation. The gasoline and diesel like fuels from waste tire oil (WTO) was produced by using catalytic distillation [4]. The WTO in produced fuels was 18%, 70%, and 12% by weight for the light fuel, heavy fuel, and other product, respectively. Choi et al. [5], took crude bio-oil from brown algae (*Saccharina japonica*) and separated it into four fractions in a vacuum fractional distillation column. Three fractions condensed as distillate according to the controlled distillate temperature and bottom fraction was solid residue. However, study of distillation of the pyrolytic oil obtained from fast pyrolysis of plastic wastes is scant. Therefore, we aimed to study the product obtained from pyrolytic oil from polyethylene and mixed plastic wastes.

2. Methods

2.1 Raw materials

Gasoline and diesel oil were purchased from common commercial PTT oil stations in Thailand. The pyrolytic oil was collected from fast pyrolysis process of polyethylene and mixed plastic wastes. The fast pyrolysis operates at a heating rate of 10°C/min up to 420°C in a laboratory scale reactor.

2.2 Distillation of mixture of gasoline and diesel oil

Type K thermocouples were installed in 6 positions: re-boiler, cooling water inlet and outlet, outside column environment, vapor phase and distillate. 5 liters of 1:1 by volume gasoline and diesel oil mixture was poured into the re-boiler and then heated at temperatures between 70-200°C, i.e. the range of boiling points of the components of gasoline and diesel oil. Cooling water flow rate was set at 20 liters per minute. The distillation column is a 10 tray fractionation column. The temperature was recorded every minute for 1 hour. Time from the first drop of distillate and then for every 500 ml of distillate for an hour and distillate volume were recorded. The distillate was kept in a glass bottle in a dark place. The first drop of distillate, maximum vapor temperature and mixture in reboiler temperature at steady state was illustrated as Fig. 1.

2.3 Distillation of pyrolytic oil obtained from fast pyrolysis of plastic waste

In this section, we ran two sets of experiments to distill pyrolytic oil obtained from (a) polyethylene waste (opaque plastic bottles) and (b) mixed plastic waste. The distillation procedure was similar to that in Section 2.2: we only changed the temperature at the re-boiler to 180°C with 1 hour of operation for polyethylene and 150-180°C with 1.5 hours for mixed plastic.

2.4 Determination of properties of distillate product

The calorific value of the distillate product was tested using a bomb calorimeter (Gallenkamp model adiabatic). The viscosity was measured by timing oil flow through viscometer number 50 and calculated from

$$\text{Viscosity} = \text{calibration constant} \times \text{time} \quad (1)$$

where the calibration constant is 0.004484, time and viscosity are in minute and mm^2/s (or cSt). The mass of 20ml in a volumetric flask was measured with a balance (Ohaus model EP413 with accuracy of 0.001 g) and used to calculate density. Each property was measured in triplicate.

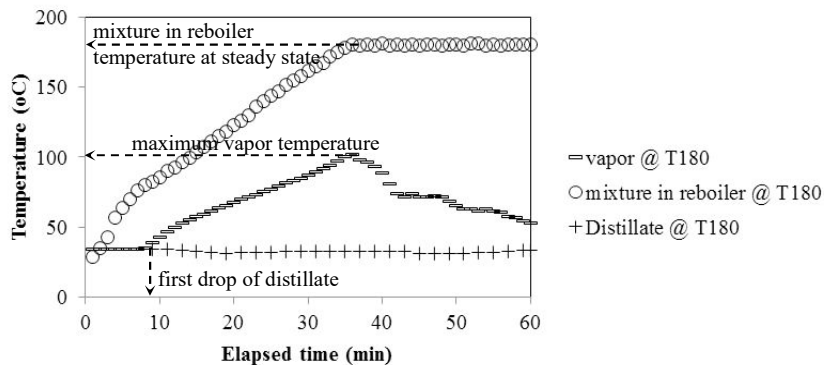


Fig.1. The first drop of distillate, maximum vapor temperature, and mixture in reboiler temperature at steady state

3. Results and Discussion

3.1 Distillation of mixture of gasoline and diesel oil

Fig. 2 shows the temperatures of vapor, distillate and mixture in reboiler during 1 hour of distillation. Vapor temperature and mixture in reboiler temperature gradually increased with time. The vapor temperature reached a maximum coinciding with the mixture temperature in the reboiler at steady state (close to set temperature). After that, vapor temperature fell to around 34°C because the volume of mixture in the reboiler decreased. Distillate and surrounding temperatures were nearly constantly during 1 hour distillation. The temperature difference between cooling water inlet and outlet was approximate 3–4°C (data not shown).

Vapor did not condense at the top of tower for a distillation temperature of 70°C because heating the reboiler at this temperature could not generate sufficient pressure to overcome the pressure drop over the length of the distillation tower. However, distillation at temperatures of 80–200°C led to the first drop of vapor appearing at the top of tower after 5 minutes. The maximum vapor temperature and mixture temperature in reboiler at steady state have been moved due to increasing of distillation temperature.

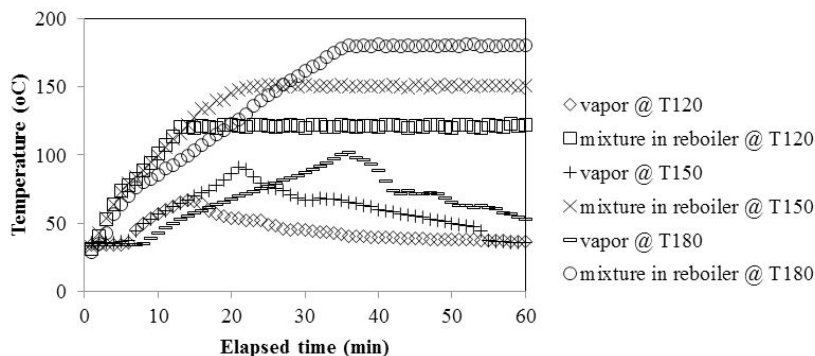


Fig. 2. Temperatures of vapor, distillate, and mixture in reboiler at different distillation temperatures

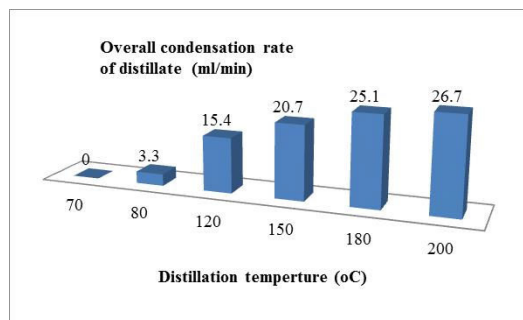


Fig. 3. Overall condensation rate of distillate versus temperature

Distillate volume and condensation rate increased in the early stages and was later decreased. The overall distillation rate increased with distillation temperature (Fig. 3). Distillate at each distillation temperature was clear and homogeneous without impurities and had no change after left for three days.

3.2 Distillation of pyrolytic oil obtained from fast pyrolysis of plastic waste

Temperature changes of vapor, distillate, and mixture in reboiler were similar to changes for distillation of mixtures of gasoline and diesel oil - see Fig. 2. The first drops of distillates from polyethylene and mixed plastic wastes appeared later (about 14-15 minutes) due to several components in the pyrolytic oil. Moreover, maximum vapor temperature and mixture temperature in the reboiler at steady state appeared later (about 30 minutes) compared with the distillation of the gasoline and diesel oil mixture.

The condensation rate of distillate from polyethylene waste distillation at 180°C for 1 hour increased in the first 15-25 minutes at 25 ml/min and then decreased after 25-45 minutes at 4 ml/min. Further distillate did not appear after 45 minutes until 1 hour of distillation. Overall distillation rate was approximate 5.5 ml/min. For distillation from mixed plastic waste at 150°C, distillate only appeared in the first 14-25 minutes at 31 ml/min. Whilst, condensation rate of distillation at 180°C increased in the first 15-35 minutes at 35 ml/min and then decreased in the 35 minutes thereafter at 9.3 ml/min.

Distillate obtained from polyethylene and mixed plastic wastes at 180°C was light yellow, clear and homogeneous without impurities and showed a darker yellow after 2 weeks. However, distillate from polyethylene waste was darker than that from mixed plastic waste (Fig. 4). However, distillate of pyrolytic oil from mixed plastic at 150°C was not changed after 2 weeks.

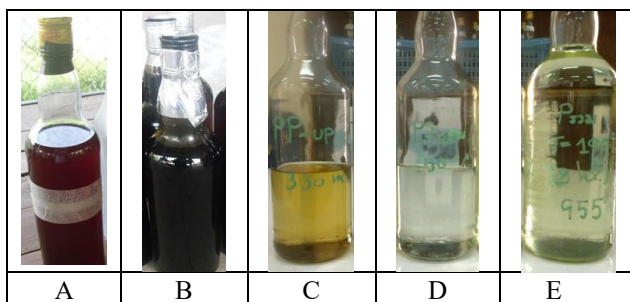


Fig. 4. Color and visual appearance of pyrolytic oil obtained from (A) polyethylene, and from (B) mixed plastic waste, (C) distillate of polyethylene at 180°C, (D) distillate of mixed plastic waste at 150°C and (E) distillate of mixed plastic waste at 180°C, respectively

Distillate of pyrolytic oil from all kinds of plastic waste at temperatures above 150°C had properties (density, viscosity and calorific value) similar to those of gasoline (Table 1). In addition, the remaining mixture in the reboiler after the distillation end had lower density and viscosity but higher calorific value than diesel oil.

Table 1. Density, viscosity and calorific value of distillate and remaining mixture in reboiler after 1 hour of distillation

Items	Temperature (°C)	Density (kg/m ³)	Viscosity (mm ² /s or cSt)	Calorific value (kJ/kg)
Distillate from PE waste	180	721.0±2.10 ^E	0.43±0.00 ^E	26,520.2±2.8 ^F
Distillate from MP waste	150	705.6±0.4 ^F	0.39±0.00 ^F	26,452.2±4.1 ^F
Distillate from MP waste	180	728.0±0.6 ^E	0.42±0.00 ^E	26,461.1±0.3 ^F
Remaining mixture in reboiler from PE waste	180	776.8±0.8 ^C	1.44±0.00 ^B	52,920.5±0.5 ^A
Remaining mixture in reboiler from MP waste	150	776.8±0.9 ^C	1.15±0.00 ^C	52,914.2±0.9 ^A
Remaining mixture in reboiler from MP waste	180	785.0±2.3 ^B	1.43±0.00 ^B	52,904.3±3.1 ^B
Gasoline		721.4±1.2 ^E	0.44±0.00 ^E	34,523.7±1.6 ^E
Diesel oil		817.5±2.3 ^A	3.62±0.02 ^A	36,382.9±1.0 ^E
Pyrolytic oil from PE waste before distillation		768.1±1.7 ^D	1.18±0.00 ^C	52,890.3±3.1 ^B
Pyrolytic oil from MP waste before distillation		767.6±1.4 ^D	1.00±0.06 ^D	52,411.0±1.2 ^C

Note: Polyethylene (PE), mixed plastic (MP) and the different superscript letters mean the significant different values ($p \leq 0.05$)

4. Conclusion

The distillation can separate the lighter product from heavy residue in pyrolytic oil as well. The lighter products (distillate) obtained from pyrolytic oil of mixed plastic waste were colorless at 150°C and yellowish at 180°C. The distillation rate was not constant during operation; it increased in the early period and gradually dropped. The overall distillation rate for mixed plastic waste was higher than that for polyethylene waste. Increased distillation temperature led to increased distillate volume. The densities and viscosities of distillate for both plastic wastes were lower than the pyrolytic oils before distillation. Both of density and viscosity of distillate were similar to those of gasoline, except the calorific value. The distilled product from pyrolytic oil from plastic waste has potential to be used as gasoline replacement fuel.

Acknowledgements

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