Insights into the effects of operating conditions on waste polypropylene and polystyrene co-pyrolysis oil production

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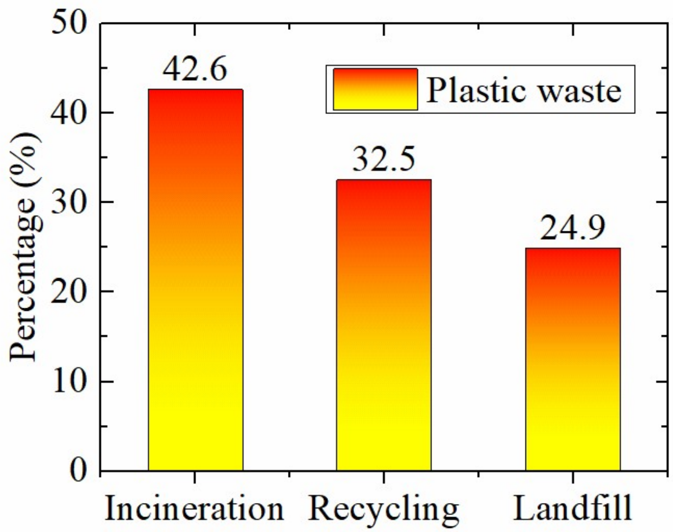


Figure 1. Disposal paths for plastic waste.

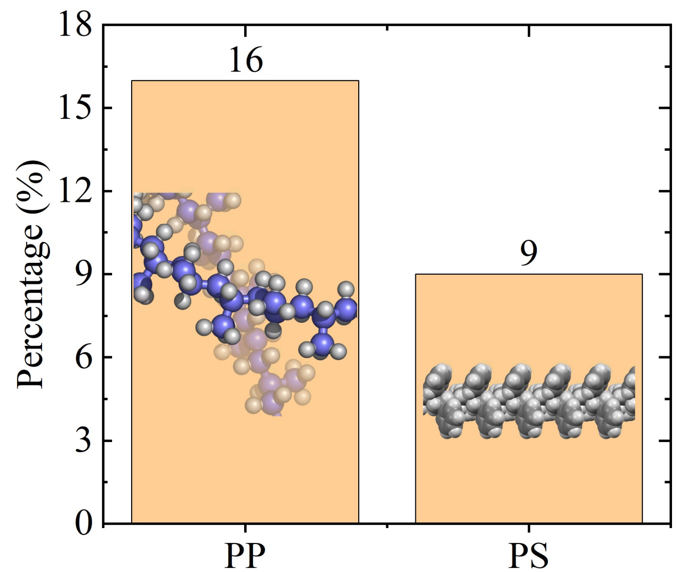


Figure 2. The proportion of waste PE and PS in MSW.

- Nearly **25%** of plastic waste ends up in **landfills**.
- Plastic waste accumulates rapidly due to the **low environmental degradability**.
- Waste polypropylene (**PP**) and polystyrene (**PS**) are a considerable proportion of plastic types found in municipal solid waste (**MSW**), accounting for **16%** and **9%**.

I. Introduction: plastic waste issue

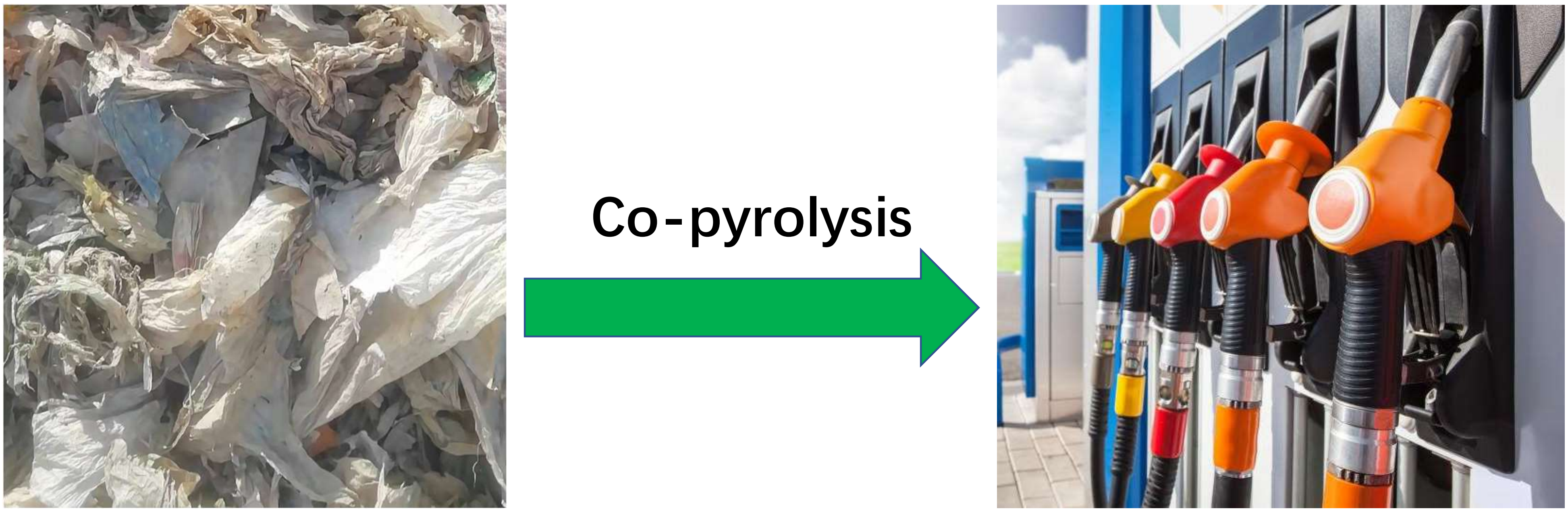
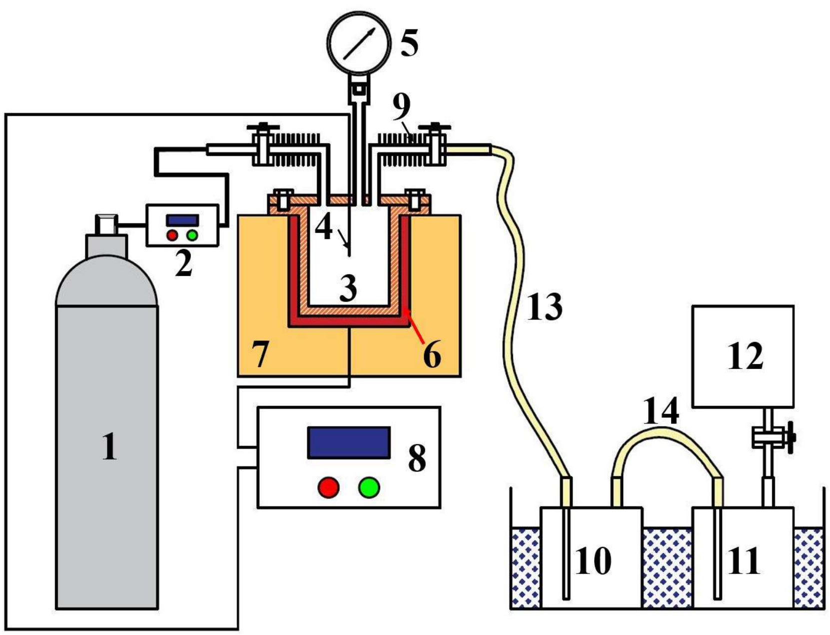


Figure 3. High-quality oil production from waste PP and PS co-pyrolysis.

II. ANN-GA coupled with a central composite design



1. N2 gas
2. Gas flow controller
3. Semi-batch reactor
4. Thermocouple
5. Pressure gauge
6. Heating element
7. Insulation
8. PID controller
9. Metal cooling fins
10. Glass bottle 1
11. Glass bottle 2
12. Gas bag
13. Rubber tube 1
14. Rubber tube 2

Figure 4. The experimental schematic diagram of waste PP/PS co-pyrolysis for the liquid fuel production.

- The pyrolysis experiments were performed in a 200 mL bench-scale semi-batch reactor.
- Waste PP and PS were provided from a Plastic Recycling & Development Base. It was recycled from municipal solid waste (MSW) and cut into about 3 mm pellets.

II. ANN-GA coupled with a central composite design

Table 1. Experimental setup for WPP/WPS co-pyrolysis.

No.	Temperature (°C)	PS (wt%)	Gas velocity (mL/min)
R1	425	10	0
R2	425	10	60
R3	425	20	30
R4	425	30	0
R5	425	30	60
R6	475	10	30
R7	475	10	0
R8	475	20	0
R9	475	20	30
R10	475	30	0
R11	475	20	60
R12	475	30	30
R13	525	10	0
R14	525	10	60
R15	525	20	30
R16	525	30	0
R17	525	30	60
R18	450	15	45
R19	450	25	15
R20	500	15	45
R21	500	25	15
R22	475	10	60
R23	475	30	60

- The effects of temperature, PS mass fraction, and carrier gas flow rate were investigated.
- Through a central composition factorial design, an **empirical model** with a series of **independent variables** (temperature, PS mass fraction, carrier gas flow rate) was studied to **establish liquid fuel yield**.
- A total of 23 sets of experiments were carried out, including **R1–17** for the ANN **training set** and **R18–23** for the ANN **testing set**.

II. ANN-GA coupled with a central composite design

- An artificial neural network (**ANN**) was utilized to establish the **mathematical expressions** between the independent (PS mass fraction, temperature, and carrier gas flow rate) and dependent variables (pyrolysis product yields and oil fractions).
- **GA** was adopted to obtain the **optimal** co-pyrolysis product yields and oil fractions.

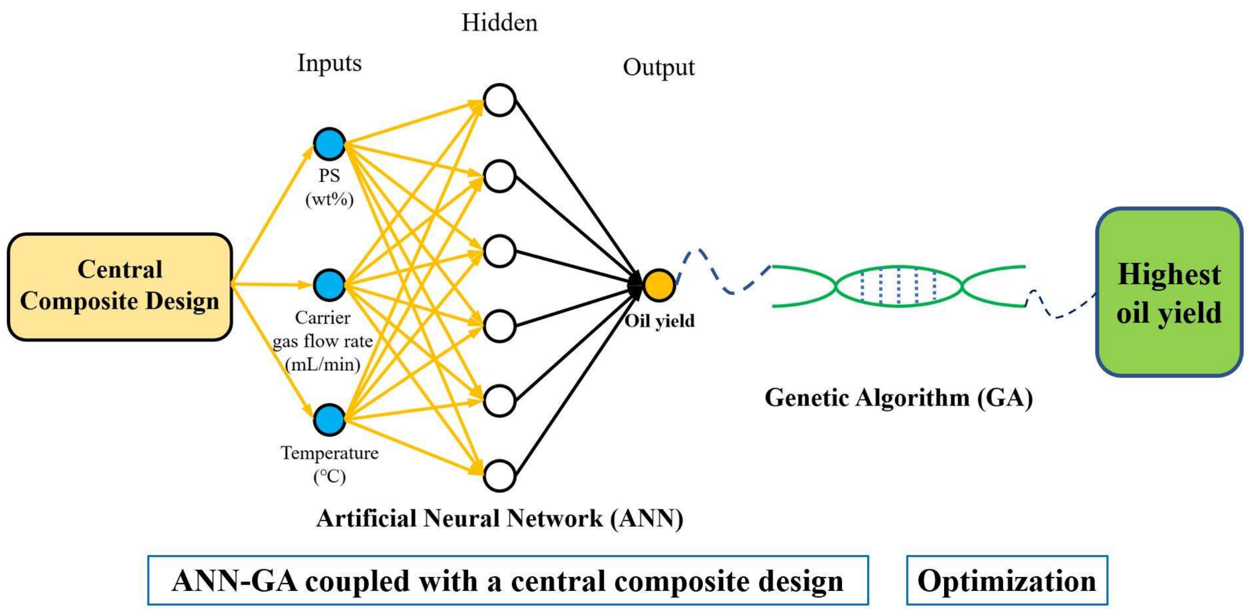


Figure 5. The demonstration of ANN-GA for WPP/WPS co-pyrolysis oil production's evaluation.

III. Optimization for WPP/WPS co-pyrolysis product yields

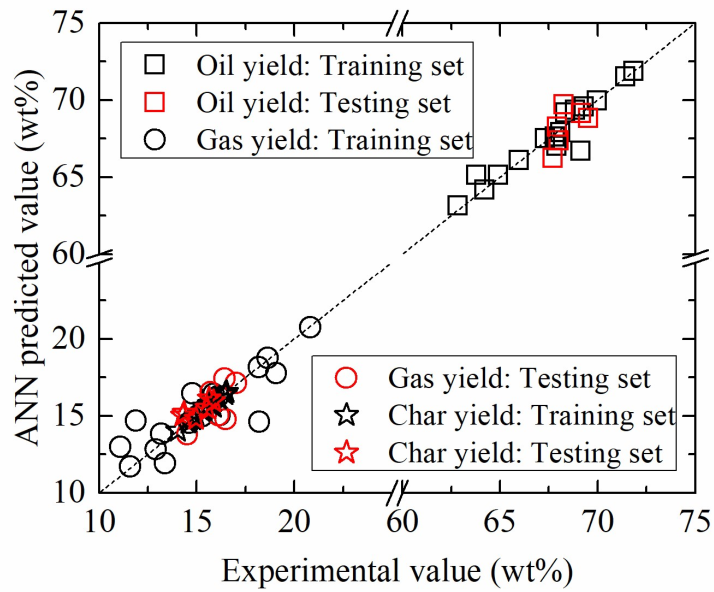


Figure 6. Experimental and ANN predicted co-pyrolysis product yields.

- The experimental **oil**, **gas**, and **char** yields varied from 60.0 wt% to 71.8 wt%, from 11.1 wt% to 20.8 wt%, and from 14.0 wt% to 16.5 wt%, respectively.
- The R-squared values between the experimental and ANN predicted co-pyrolysis product yields were **0.9986** in the **training** set and **0.9988** in the **testing** set.
- ANN predicted co-pyrolysis product yields are **accurate**.

- **Evaluating the WPP/WPS co-pyrolysis product yields**

➢ The ANN has established **mathematical expressions** to determine the WPP/WPS co-pyrolysis product yields by the PS mass fraction, temperature, and carrier gas flow rate.

➢ The parameters have **complicated interactions** on the co-pyrolysis product yields.

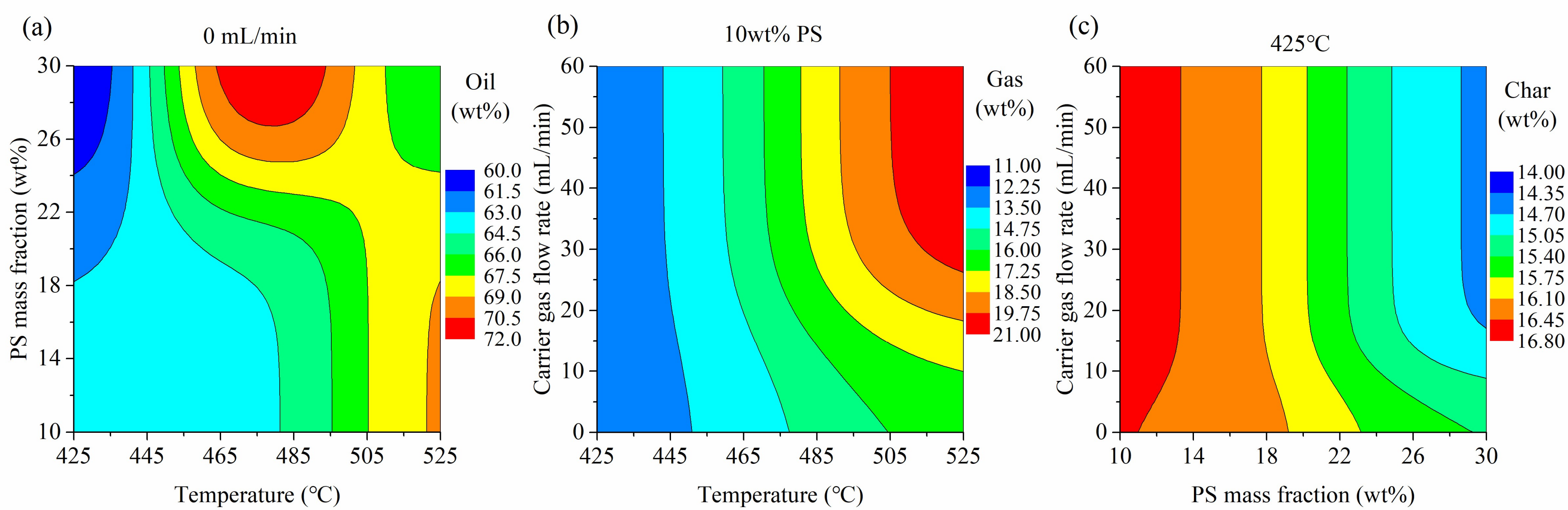


Figure 7. Interactive effects of operating conditions on (a) oil yield at 0 mL/min, (b) gas yield at 10 wt% PS, and (c) char yield at 425 °C.

• Optimization of product yields by ANN-GA

- The highest **oil** yield of **71.90 wt%** was obtained at **478 °C**, **30 wt% PS**, and **0 mL/min**.
- The highest **gas** yield of **20.75 wt%** was achieved at **525 °C**, **10 wt% PS**, and **60 mL/min**.
- The highest **char** yield of **16.54 wt%** was recovered at the lowest temperature of 425 °C, the lowest PS mass fraction of 10 wt%, and the highest carrier gas flow rate of 60 mL/min.

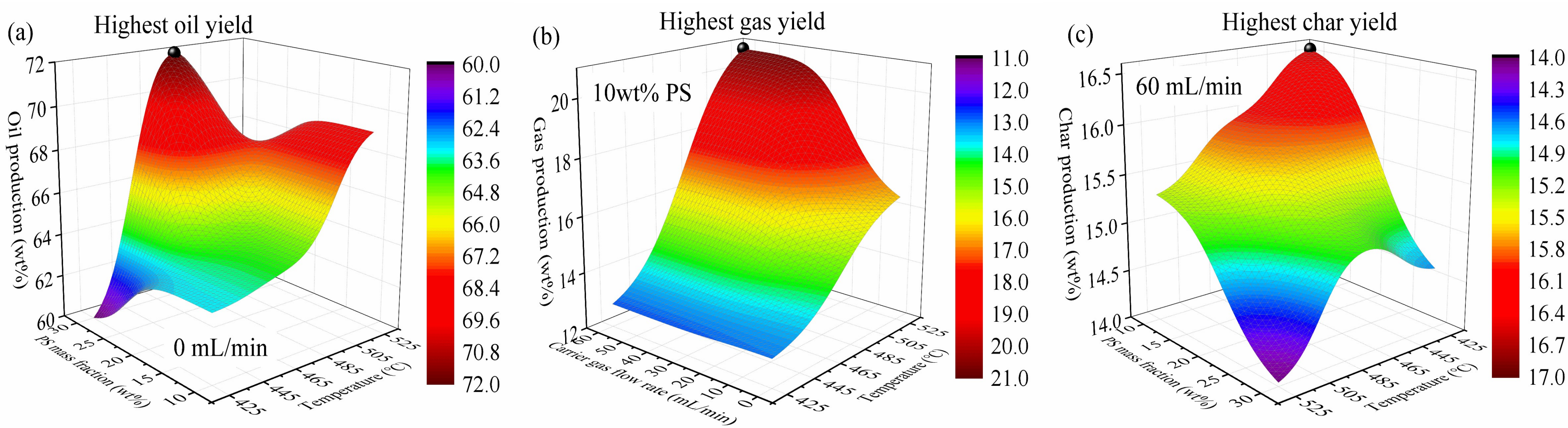


Figure 8. ANN-GA optimized (a) oil yield, (b) gas yield, and (c) char yield.

IV. Optimization for WPP/WPS co-pyrolysis oil fractions

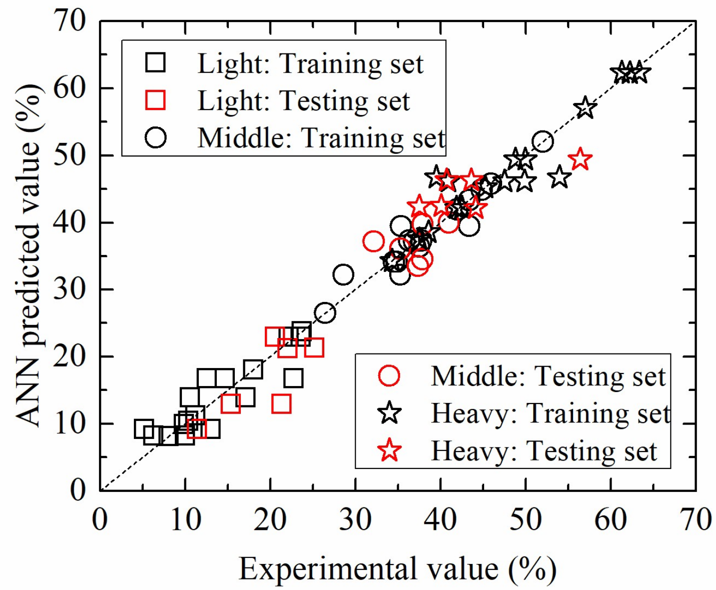


Figure 9. Experimental and ANN predicted co-pyrolysis product yields.

- The experimental **light (C7-C11)**, **middle (C12-C20)**, and **heavy fractions (>C20)** varied from 5.20% to 25.21%, from 26.48% to 52.02%, and from 34.30% to 63.35%, respectively.
- The R-squared values between the experimental and ANN predicted co-pyrolysis oil fractions were **0.9747** in the **training** set and **0.8775** in the **testing** set.

- **Evaluating the WPP/WPS co-pyrolysis oil fractions**

➢ An increase in temperature leads to a decrease in light and middle fractions and an increase in heavy fraction.

➢ Higher carrier gas flow rates can enhance the light fraction in oil.

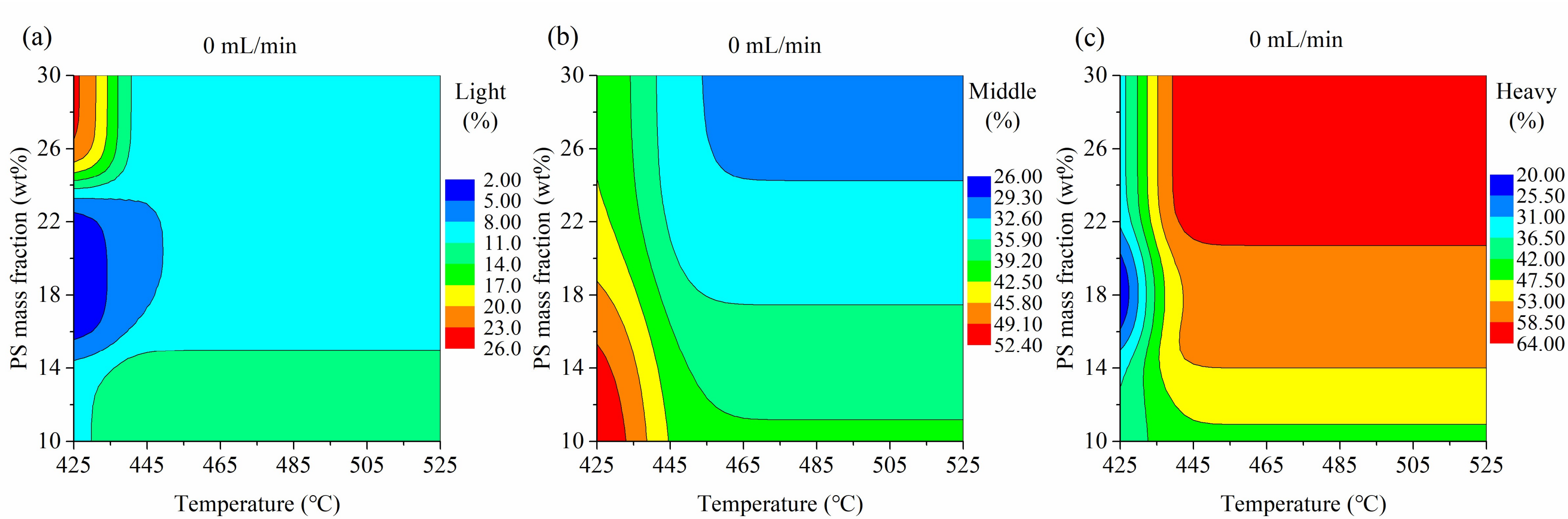


Figure 10. Interactive effects of operating conditions on (a) light fraction at 0 mL/min, (b) middle fraction at 0 mL/min, and (c) heavy fraction at 0 mL/min.

- **Optimization of oil fractions by ANN-GA**

  - The highest **light** fraction of **23.71%** was achieved at **425 °C**, **30 wt% PS**, and **0 mL/min**.
  - The highest **middle** fraction of **52.02%** was obtained at **425 °C**, **10 wt% PS**, and **0 mL/min**.
  - The highest **heavy** fraction of **62.34%** was recovered at the highest temperature of 525 °C, the highest PS mass fraction of 30 wt%, and the non-sweeping atmosphere of 0 mL/min.

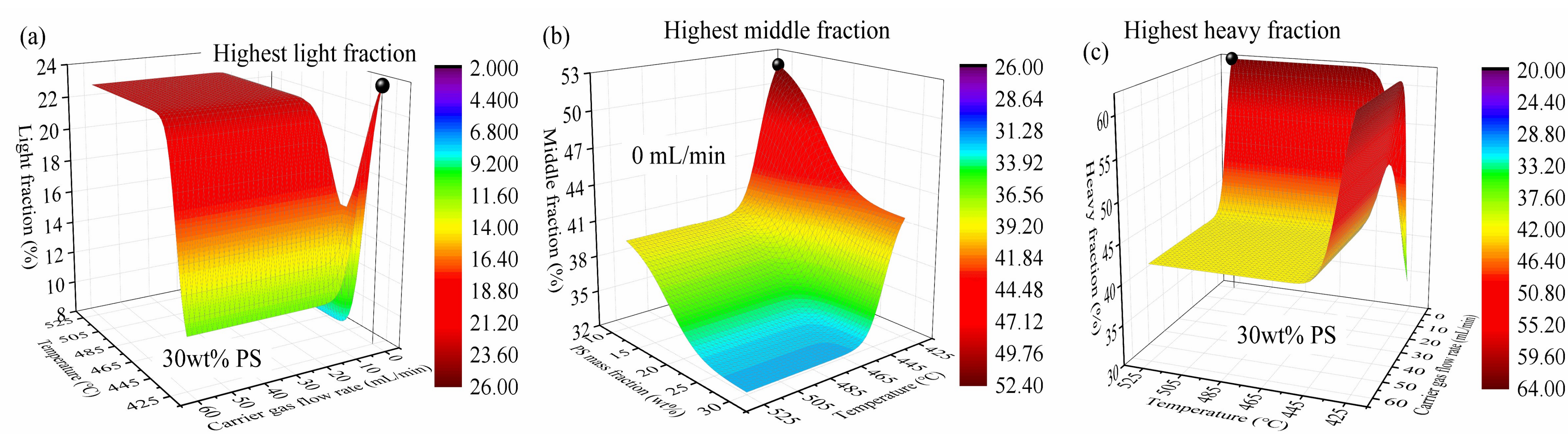


Figure 11. ANN-GA optimized (a) light fraction, (b) middle fraction, and (c) heavy fraction.

V. Conclusions

- ANN-GA coupled with a central composite design was adopted to evaluate the WPP/WPS co-pyrolysis oil production.
- ANN-GA was qualified to optimize the oil yield and fractions.
- The highest oil yield of 71.9 wt% was obtained at 478 °C, 30 wt% PS, and 0 mL/min by ANN-GA.
- The highest light fraction of 23.71% was achieved at 425 °C, 30 wt% PS, and 0 mL/min; and the highest middle fraction of 52.02% was obtained at 425 °C, 10 wt% PS, and 0 mL/min.