Supplementary Information

# Rapid degradation of microplastics by catalyst-free gliding arc plasmatron

Chuanqi Shi<sup>ab</sup>, Yanhui Long<sup>a</sup>, Yunqing Zhou<sup>a</sup>, Shi Feng<sup>a</sup>, Zhenzhen Wu<sup>a</sup>, Hualiang Li<sup>ac</sup>,

Kaiyi Wang<sup>a</sup>, Zijiang Zhao<sup>a</sup>, Qunxing Huang<sup>a</sup>, Xiaodong Li<sup>a</sup>, Hao Zhang<sup>\*ac</sup>

<sup>a</sup> State Key Laboratory of Clean Energy Utilization, Institute for Thermal Power

Engineering, Zhejiang University, Hangzhou 310027, China

<sup>b</sup> Polytechnic Institute, Zhejiang University, Hangzhou 310027, China

<sup>c</sup> Ningbo Innovation Center, Zhejiang University, Ningbo 315100, China

## Contents

| Materials and methods  |
|--|
| Fig. S1. Time-resolved evolution of the gas composition in microplastics degradation |
| Fig. S2. Product distribution of liquid products from PP degradation using GC-MS7    |
| Fig. S3. Product distribution of liquid products from PE degradation using GC-MS8    |
| Fig. S4. Product distribution of liquid products from PS degradation using GC-MS9    |
| Fig. S5. Product distribution of gas products from PP degradation using MS10         |
| Fig. S6. Product distribution of gas products from PE degradation using MS11         |
| Fig. S7. Product distribution of gas products from PS degradation using MS12         |
| Table S1. Carbon balance for GAP-assisted degradation of various plastics            |

### Materials and methods

#### Materials

PP (30 mesh), PE (30 mesh), PS (30 mesh), and standard dry air were used for the GAP assisted MP degradation experiments.

### Experiment

The custom-designed GAP reactor comprises a cylindrical inner anode and a grounded outer cathode (stainless steel). During the experiments, the anode is powered by a high-voltage direct current power supply (TLP 2040, Teslaman), operating in constant-current mode. To limit and stabilize the discharge current, a 40 K $\Omega$  resistor is connected in series.

The feed gas (air) is introduced through three tangential inlets at the base of the cathode block, uniformly spaced at 120-degree intervals, creating a swirling flow within the reactor conducive to plasmatron formation. The gas flow rate is controlled by a mass flow controller (MFC, D07-11C, Sevenstar). During operation, the plasma arc is initiated at the narrowest gap between the two electrodes (2 mm) and is then propelled downstream, while rapidly rotating around the anode. The resultant plasma gas extends from the convergent outlet nozzle, forming a large three-dimensional torch-shaped plasmatron beyond the electrode region.

Downstream of the electrode assembly, a double-layered, cup-shaped quartz bed is installed to hold the MP samples and establish an enclosed plasma reaction zone for MP degradation. The quartz bed is surrounded by a layer of insulating cotton and features two outlets: a tangential outlet directly connected to the inner layer for thermocouple installation and temperature measurement, and a radial outlet connected solely to the outer layer for gas exhaust.

In a typical experiment, 200 mg of plastic was placed within the reaction zone inside a quartz bed. Dry air, serving as the carrier gas, was continuously supplied at a constant flow rate. The high-voltage power supply was set to maintain a constant output current of 0.2 A, with the output power ranging between 100 and 300 W, depending on the specific operating conditions. The plastic degradation process was completed within 2–4 minutes. No external heat source was employed during the degradation process; instead, the plastics were degraded solely by the GAP system. The outlet gases, mainly CO<sub>2</sub>, CO, H<sub>2</sub> and O<sub>2</sub> were monitored online using an NDIR gas analyzer (GASBOARD-3100, Wuhan cubic optoelectronic Co., Ltd.). Each experiment was repeated for 3 times and the averaged values with error bars are presented in the figures.

Two 250 mL gas washing bottles, immersed in an ice-water cooling bath and connected to the radial outlet of the quartz bed, are employed to collect the condensed liquid-phase products.

#### **Performance evaluation**

The selectivity of  $CO_2$  and CO in the products and the carbon balance were calculated using the following equations.

$$CO_2 \, selectivity \, (\%) = 100 \, \% \, \times \, \frac{\int_0^t \eta_{CO_2} \times F_{out} \, dt}{R \, \times \, n_{CH_x}} \tag{1}$$

$$CO \ selectivity \ (\%) = 100 \ \% \ \times \ \frac{\int_{0}^{t} \eta_{CO} \ \times \ F_{out} \ dt}{R \ \times \ n_{CH_{\chi}}}$$
(2)

Carbon balance (%) = 100 % × 
$$\frac{n_{CO} + n_{CO_2}}{n_{CH_x}}$$
 (3)

Where  ${}^{\eta_{CO_2}}$  is the volume fraction of CO<sub>2</sub> in the exhaust gas, vol%;  ${}^{\eta_{CO}}$  is the volume fraction of CO, vol%;  ${}^{F}_{out}$  denotes the gas flow rate, L min-1;  ${}^{n_{CO_2}}$  is the amount of CO<sub>2</sub>, mol;  ${}^{n_{CO}}$  is the amount of CO, mol;  ${}^{n_{CH_x}}$  is the amount of C in the initial plastic, mol; t is the treatment time, s. R corresponds to the molar volume of an ideal gas at standard temperature and pressure, 22.4 L mol<sup>-1</sup>. Given the variation in CO<sub>2</sub>/CO concentration over time, an integral approach was employed to calculate the total amounts of CO<sub>2</sub>/CO generated.

It should be noted that the carbon balance calculation does not account for the inevitable polymer loss to coke formation. Therefore, the actual carbon balance is expected to be slightly higher than the reported values.

The maximum  $CO_2$  yield (ml min<sup>-1</sup>) indicates the rate of  $CO_2$  generation during the degradation of MPs, which partially reflects the degradation rate of the MPs.

The energy efficiency  $(E; mg kJ^{-1})$  was determined using the following equation:

$$E = \frac{m_{MP_s}}{P \times t} \tag{4}$$

Where  ${}^{m_{MP}}s$  represents the mass of the unreacted MP, mg, P is the discharge power of GAP, W, and t is the treatment time, s.



Fig. S1. Time-resolved evolution of the gas composition in microplastics degradation.

Experimental conditions: 200 mg of microplastics at a carrier gas flow rate of 8 L min<sup>-1</sup>.



Fig. S2. Product distribution of liquid products from PP degradation using GC-MS.



Fig. S3. Product distribution of liquid products from PE degradation using GC-MS.



Fig. S4. Product distribution of liquid products from PS degradation using GC-MS.



Fig. S5. Product distribution of gas products from PP degradation using MS.



Fig. S6. Product distribution of gas products from PE degradation using MS.



Fig. S7. Product distribution of gas products from PS degradation using MS.

The observed Ar and  $C_3H_6O$  spectra lines in Figs. S5-S7 are attributed to the carrier gas and the absorbent in the cold trap for the products.

| Sample | Gas flow<br>rate<br>(L min <sup>-1</sup> ) | C in plastic<br>(mmol) | CO <sub>2</sub> product<br>(mmol) | CO product<br>(mmol) | C balance<br>(%) |
|--------|--|------------------------|-----------------------------------|----------------------|------------------|
| PP     | 4  | 14.3                   | 11.6                              | 2.2                  | 96.7             |
|        | 6  |                        | 13.5                              | 0.4                  | 97.5             |
|        | 8  |                        | 13.8                              | 0.2                  | 98.3             |
| PE     | 4  |                        | 13.5                              | 1                    | 101.2            |
|        | 6  | 14.3                   | 14.2                              | 0.3                  | 101.6            |
|        | 8  |                        | 14.1                              | 0.2                  | 99.8             |
| PS     | 4  |                        | 13.4                              | 0.7                  | 92.1             |
|        | 6  | 15.4                   | 14.1                              | 0.4                  | 94.4             |
|        | 8  |                        | 13.8                              | 0.7                  | 93.7             |
| PP&PE  | 4  |                        | 12.5                              | 2.1                  | 102.4            |
|        | 6  | 14.3                   | 14.3                              | 0.4                  | 102.2            |
|        | 8  |                        | 15                                | 0.3                  | 107.5            |
|        | 4  |                        | 13                                | 1.1                  | 95.3             |
| PP&PS  | 6  | 14.8                   | 14.1                              | 0.6                  | 99               |
|        | 8  |                        | 13.7                              | 0.6                  | 97.1             |
|        | 4  |                        | 12.8                              | 1.1                  | 94.1             |
| PE&PS  | 6  | 14.8                   | 13.7                              | 0.6                  | 96.7             |
|        | 8  |                        | 14                                | 0.3                  | 96.2             |

 Table S1. Carbon balance for GAP-assisted degradation of various plastics.