



# The catalytic pyrolysis of food waste by microwave heating



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## HIGHLIGHTS

- Microwave pyrolysis with catalysts was a feasible method to handle food waste.
- MgO, Fe<sub>2</sub>O<sub>3</sub>, MnO<sub>2</sub>, CuCl<sub>2</sub> and NaCl can lower bio-oil yields and enhance gas yields.
- The optimal microwave power to maximize bio-oil yield during pyrolysis was 400 W.
- Chloride salts promoted formation of acidic compounds in the bio-oil's lower layer.
- CuCl<sub>2</sub> was the most effective among the tested catalysts, followed by MnO<sub>2</sub>.

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## ABSTRACT

This study describes a series of experiments that tested the use of microwave pyrolysis for treating food waste. Characteristics including rise in temperature, and the three-phase products, were analyzed at different microwave power levels, after adding 5% (mass basis) metal oxides and chloride salts to the food waste. Results indicated that, the metal oxides MgO, Fe<sub>2</sub>O<sub>3</sub> and MnO<sub>2</sub> and the chloride salts CuCl<sub>2</sub> and NaCl can lower the yield of bio-oil and enhance the yield of gas. Meanwhile, the metal oxides MgO and MnO<sub>2</sub> can also lower the low heating value (LHV) of solid residues and increase the pH values of the lower layer bio-oils. However, the chloride salts CuCl<sub>2</sub> and NaCl had the opposite effects. The optimal microwave power for treating food waste was 400 W; among the tested catalysts, CuCl<sub>2</sub> was the best catalyst and had the largest energy ratio of production to consumption (ERPC), followed by MnO<sub>2</sub>.

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## 1. Introduction

With the parallel rise in population and living standards that is occurring in China, the generation of municipal solid waste (MSW) is also increasing rapidly, at an annual rate of 8–10%. In 2007, the total national amount of MSW reached 152 million tons (Lai et al., 2011). MSW is composed mainly of food waste, paper, slag, ceramics, plastics, glass, metals, textiles and wood – among these components, food waste currently represents the greatest share at more than 40% of the weight of solid waste (Luo et al., 2010; Zhao et al., 2009). Appropriate handling of this great amount of food waste has become a serious social and environmental issue. Especially, the gutter oil, the concomitant of food waste, which is illegally used to cook food in many restaurants in China, causing serious health problems. In light of these problems, the disposal

of food waste has been receiving more and more public and research attention.

Today, the main methods of disposing food waste are landfill, incineration and composting. The dumping of food waste in landfill sites causes some environmental impacts, including the generation of landfill leachate, methane gas, and offensive odours (Ahmed and Gupta, 2010). When food waste is incinerated together with other combustible wastes, dioxins may be produced because of the high moisture content (Vavouraki et al., 2013). Composting is a popular solution to treat food waste (Caton et al., 2010) because it produced nutritious fertilizer, yet it can discharge harmful byproducts such as leachate, NH<sub>3</sub>, and greenhouse gases, creating secondary environmental pollution (Yang et al., 2013). Therefore, there is a strong need for effective methods and treatment processes for food waste that have fewer environmental impacts.

Caton et al. (2010) found that dried food waste contained more energy than wood, which is a more typical biomass fuel. Tanaka et al. (2008) studied the basic characteristics of steam gasification of food waste, and found it to be an effective method that not only reduced the final amount of waste, but also produced gas that was

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useful as fuel. Ahmed and Gupta (2010) argued that waste food offers a good potential feedstock for power generation via gasification. In spite of the similarity between pyrolysis and gasification, the research on pyrolysis of food waste has been limited.

Pyrolysis is one of the promising methods for application of biomass-to-energy, and it has been widely employed in the disposal of municipal solid waste (Velghe et al., 2011; Nurul Islam et al., 2005). So far, pyrolysis mainly includes microwave pyrolysis and conventional pyrolysis. Compared to the conventional pyrolysis, microwave pyrolysis has some advantages, such as rapid heating, generation of fewer hazardous compounds, prevention of undesired secondary reactions, and higher heating efficiency (Domínguez et al., 2003; Miura et al., 2004). It has been used to treat biomass (Huang et al., 2010; Miura et al., 2004; Zhao et al., 2013), and sewage sludge (Menéndez et al., 2005; Tian et al., 2011). However, not all materials have the high absorption capacity that is necessary for effective microwave pyrolysis, so in order to improve the efficacy of this method, many researchers have experimented with adding various microwave absorbers or catalysts to the raw materials, such as metal oxides (Hu et al., 2012; Li et al., 2013; Wan et al., 2009), salts (Li et al., 2013; Wan et al., 2009), activated carbon (Bu et al., 2011; Hu et al., 2012), and acids (Wan et al., 2009).

Our objective was to investigate the effect of microwave power levels and catalysts on the effectiveness of food waste pyrolysis. Temperature profiles, three-phase products characteristics, and the energy ratio of production to consumption (ERPC) were analyzed to determine the optimal conditions for this waste treatment process.

## 2. Methods

### 2.1. Sampling and preparation of materials

Food waste was collected from a residential quarter in Guangzhou, Guangdong Province, China. Once fruits, plastic and shells were removed from the raw food waste, the remaining, three main components were white rice, vegetable leaves, and meat/bones, with proportions of 32.69%, 44.23% and 23.08%, respectively, according to a previously published survey of domestic food residues (Ma et al., 2009). The samples were dried at 105 °C for 24 h, and then broken, ground and screened. The sizes of all resulting particles were less than 4 mm. The ultimate analysis, proximate analysis and lower heating value (LHV) of food waste (dry basis) were analyzed, and the results were shown as follows: C, 42.34 wt.%; H, 7.54 wt.%; O, 33.50 wt.%; N, 3.68 wt.%; S, 0.31 wt.%; volatile matter, 81.63 wt.%; fixed carbon, 5.74 wt.%; ash, 12.63 wt.% and LHV, 18.92 MJ/kg.

Metal oxides (CaO, MgO, CuO, Fe<sub>2</sub>O<sub>3</sub> and MnO<sub>2</sub>) and chloride salts (CuCl<sub>2</sub>, NaCl and MgCl<sub>2</sub>) were added to the ground food waste as catalysts. Catalysts were first dried in the oven at 105 °C for 24 h, then milled and sieved to obtain uniform particles smaller than 250 μm. The amount of food waste used in each experiment was 30 g, and the content of catalysts for each addition was 5% (mass basis).

### 2.2. Experimental procedure

A sketch of the experimental apparatus used for microwave pyrolysis of food waste is shown in Fig 1. The microwave oven had a frequency of 2450 MHz and the power could be regulated continuously, up to 4000 W. In order to maintain anoxic conditions, N<sub>2</sub> flow rate was kept at 500 mL/min for 20 min before the experiment, and then reduced to 300 mL/min during the experiment. An appropriate microwave power was entered on the

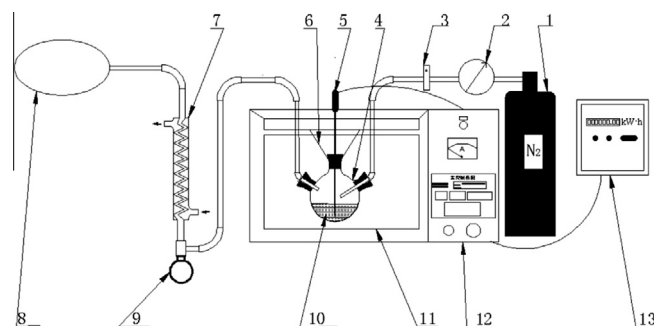


Fig. 1. The diagram of pyrolysis system: (1) nitrogen bottle; (2) pressure reducing valve; (3) float flowmeter; (4) quartz reactor; (5) thermocouple; (6) cotton thread; (7) condenser; (8) gas collecting bag; (9) liquid collecting bottle; (10) materials; (11) microwave oven; (12) touch screen; (13) electronic energy meter.

MT6070iH touch screen (Weinview Science Stock Co., Ltd., Guangdong Province, China), and the oven was then started. During the experiment, the sample temperature was measured with a thermocouple, and the data were saved automatically on the touch screen, while electric energy consumption was recorded with an electronic energy meter. The condensable volatiles emitted during treatment were collected using a condenser filled with flowing, cooling water, and the non-condensable gases were collected in a gasbag; the process was left to continue until no further volatiles were observed, at which point the oven's power was stopped. After the sample had cooled to ambient temperature, the liquid collecting bottle and quartz reactor were removed, and the mass of bio-oil and solid residue was measured. The weight of gas production was calculated based on the difference, using the mass balance. All experiments were repeated three times and mean results are reported, in order to the accuracy of the experimental results.

### 2.3. Evaluation method

To evaluate the cost-effectiveness of microwave pyrolysis and to determine the optimal conditions for the procedure, we calculated an energy ratio, the ERPC, which we defined as:

$$\text{ERPC} = \frac{\text{Production energy}}{\text{Energy consumption}} \quad (1)$$

The main cause of energy consumption during the process was the use of electric energy for pyrolysis. The energy produced included the energy of solid residue, bio-oil and gas production, whereas the gas proved difficult to use as fuel because it contained a large amount of carrier gas (N<sub>2</sub>). Therefore, Eq. (1) was refined as follows:

$$\text{ERPC} = \frac{\text{LHV}_{\text{solid residue}} \cdot M_{\text{solid residue}} + \text{LHV}_{\text{bio-oil}} \cdot M_{\text{bio-oil}}}{\text{Electric energy consumption}} \quad (2)$$

where LHV<sub>solid residue</sub> is the lower heating value of solid residue (MJ/kg); M<sub>solid residue</sub> is the mass of solid residue (kg); LHV<sub>bio-oil</sub> is the lower heating value of bio-oil (MJ/kg); M<sub>bio-oil</sub> is the mass of bio-oil (kg).

## 3. Results and discussion

### 3.1. Characteristics of pyrolysis under different microwave powers

#### 3.1.1. Temperature rise

The rise in temperature is one of the most important characteristics of microwave pyrolysis (Huang et al., 2010), as it may affect the loss of mass and the distribution of products (Zhao et al., 2010).

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