Torrefaction of food waste using a microwave plasma berner

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Abstract: The LPG microwave plasma burner was presented as a tool for torrefaction of food waste, which cause environmental problem. The plasma burner operates by injecting LPG as a hydrocarbon fuel into a microwave plasma and by mixing the resultant gaseous hydrogen and carbon compounds with air. The raw food waste has moisture and carbon compound content 83.9% and 9.48%, however after torrefaction treated the moisture and carbon compound content were 12.11% and 71.03%, respectively.

Keywords: Torrefaction, food waste, plasma, microwave, plasma burner

1. Introduction

In South Korea, food waste represents a sizeable and largely underutilized component of Municipal Solid Waste (MSW). It has become the primary cause of odour among MSWs in the country. Furthermore, it is responsible for many of the peninsula's municipal waste management-related environmental hazards. These include the formation of polluting leachate and methane gas under anaerobic conditions [1]. Energy supply and waste management are suffering from rapidly growing costs. At the same time, the public's awareness of environmental issues is similarly rising. Fortuitously, the conversion of food waste to energy is quickly becoming an economically viable practice [2]. Despite this, there has been alarming little discussion devoted to analyzing the prospects for food waste to become a viable source of solid fuel. Diverted food waste is traditionally and largely treated/managed using biological approaches. They include composting and anaerobic digestion. These techniques can greatly reduce greenhouse gas emissions that are associated with landfill. They also contribute to the generation of valuable resources (e.g., fertilizer, methane gas). However, the techniques required do involve a range of operational challenges. The most substantial is the problem of dealing with mixed waste [3,4].

In this study, the torrefaction of readily available food waste was carried out in a cylindrical reactor in which an LPG plasma burner was installed. The reason for the torrefaction limitation of microwave plasma is directly attributable to the relatively low volume of plasma and insufficiently high temperatures. Therefore, we built an LPG plasma burner that comprised a plasma reactor and a fuel injector connected in series to a torrefaction reactor. By utilizing the LPG plasma burner, the torrefaction experiments were conducted at 2 kW plasma power, with 6 LPM of LPG.

2. Experimental

The atmospheric microwave plasma burner system consists of a magnetron, waveguide components (WR340 for 2.45 GHz), a microwave plasma torch, a fuel injector, and plasma reactor. The typical power of the magnetron is maximum 5 kW at 2.45 GHz. We described the design and operation of an atmospheric microwave plasma torch in detail in previous literature [5-7]. Microwaves from a magnetron propagate toward the discharge tube through a waveguide, concentrating its power in the discharge tube, and generated a plasma torch with a temperature of ~ 6000 K and a plasma density of ~ $10^{13}/cm^3$ [8]. Figure 1 (a) photograph image of the experimental setup for torrefaction reactor with plasma burner system. Figure 1 (b) and (c) were showed the burner flame of LPG and plasma, respectively.

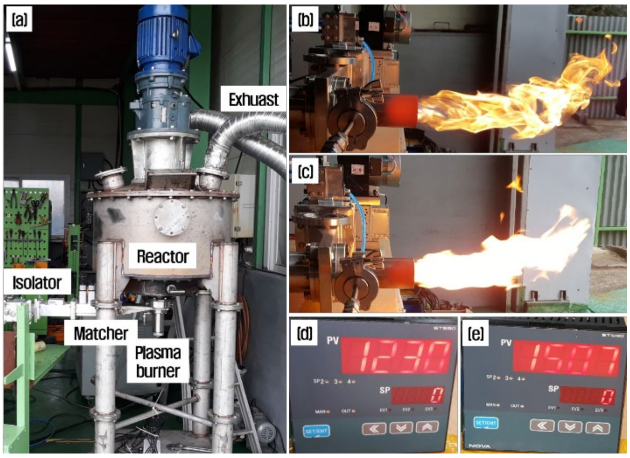

Fig. 1. Photograph images of (a) the torrefaction reactor with plasma burner system, (b) LPG burner flame, (c) LPG plasma burner flame, (d) temperature monitor of LPG burner, and (e) LPG plasma burner.

As shown in Fig. 1(b) and (c), the LPG plasma burner flame was much brighter than LPG burner. Therefore, the temperature of LPG plasma burner is approximately 300 ℃ higher than only LPG burner, as shown in Fig. 1(d) and (e). The temperature is higher than LPG burner despite adding less fuel of LPG plasma burner. Also, the comparative experimental conditions of LPG burner and LPG plasma burner were described in table 1.

Table 1. The comparative experimental condition.

	LPG	Discharge air	Add air	Plasma power	Temp. (℃)
LPG	8 LPM	20 LPM	80 LPM	0 W	1232
LPG Plasma	6 LPM	20 LPM	80 LPM	700 W	1510

Generally, the plasma column length in the microwave plasma torch depends on the amount of swirl gas. In previous literature [5], the plasma column length was about 20~30 cm for 1 kW microwave power, for a discharge tube with 27 mm inner diameter and for 20 LPM of air discharge swirl gas. The LPG fuel was reacted instantaneously by the plasma column with its center temperature of about 6000 K [8] inside the waveguide excitation region and burns immediately with oxygen in air. In this context, the microwave plasma burner can be used for bulky treatment waste gas streams and for thermal sources such as incineration and thermal wind drying, etc [7]. The torrefaction reactor consists of a double cylindrical chamber type, and food waste is inserted into the inner cylindrical chamber to heat by thermal wind of LPG plasma burner. The volume of the inner chamber is approximately 50 L. Also, the inner surface of outer cylindrical chamber is insulated of a fire resistant ceramic material, which can sustain up to 1600 ℃. The thermal wind of LPG plasma burner from the microwave system where installed at bottom of torrefaction reactor enters the side way of inner chamber.

3. Results and discussion

The LPG was injected into the microwave plasma through the fuel injector, which is attached to a plasma reactor made of a stainless steel tube and is in contact with the upper waveguide. The combustion process of LPG containing many hydrogen atoms/radicals and OH radicals can convert most hydrocarbons in a plasma are turned into CH radicals, which provide a reduction mechanism. In fact, hydrocarbon-fuel injections with abundant oxygen lead to an explosive burning that requires special attention. In this sense, the Fig. 2(a) and (b) shows the LPG microwave plasma burner flame in operation at atmospheric pressure and inside of the torrefaction reactor, respectively.

Fig. 2. Photograph images of LPG plasma burner flame at (a) 2 kW power and (b) in the reactor, and (c) before and (d) after food waste of torrefaction.

Fig. 2(c) and (d) shows the before and after torrefaction treated of food waste images, respectively. The moisture content before torrefaction treatment food waste was analysed at 83.91 %, the Cl content was 0.68%, because diluted to water, and very low. The element analysis data is shown in Table 2.

Table 2. Results of elements analysis of food waste.

Elements	Before (%)	After (%)
Moisture (%)	83.91	12.11
Al (%)	1.98	-
As (mg/kg)	0.05	0.24
Cd (mg/kg)	0.05	0.08
Cr (mg/kg)	2.95	4.50
Cu (mg/kg)	4.87	19.25
Ni (mg/kg)	0.31	1.65
Zn (mg/kg)	4.81	67.72
Hg (mg/kg)	-	-
Cl (%)	0.68	1.99
C-compounds (%)	9.48	71.03

The raw food waste 30kg was torrefaction treated for 1 hour with 2 kW of plasma power, 6 LPM of LPG, 40 LPM of plasma discharge gas, and 140 LPM of add air for the fuel oxidation. The temperature of the torrefaction reactor was approximately 480 ℃. As shown in Fig. 2(c) and (d), the raw food waste was changed in colour and shape by torrefaction treatment. Also, the content of carbon compound was very high at 71.03% as shown in Table 2. The inception of torrefaction can be observed at temperatures around 200 ℃, upon the pyrolysis of the organic ingredients contained within the food waste. The thermal degradation of the food waste was completed at a temperature of approximately 500 ℃ [1].

4. Conclusion

We presented the new torrefaction tool using a plasma burner with LPG fuel and generating a high temperature plasma flame. The LPG microwave plasma burner operated at 6 LPM LPG and 2 kW plasma. The microwave plasma burner is much more cost effective, compact, and economic in comparison with other fuel burner. Also, as the result of element analysis, the carbon component is as high as more 70%, whereby the plasma burner can exhibit a high effect on the torrefaction treatment.

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5. References

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