Application of Microwave Plasma Torch to Power Plant

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Abstract

This presentation is a pure steam-plasma torch generated by microwave energy and uses it for coal gasification in a lightweight operating system. The high temperature of the steam torch when used for fast gasification reactions of low-grade coal ensures a compact reaction system for an electrical power plant.

Keywords : Microwave Torch, Coal Gasification, Power Plant

1. Introduction

Microwave plasmas operated at atmospheric pressure, especially waveguide-based torch plasmas, have been the object of increased attention over the last decade, since they can be sustained efficiently in a variety of gases without the need for a high-Q resonator [1-4]. Such an interest comes from their potential and actual use in diverse applications as a clean heat source for welding, cutting, and material processing [5,6], as an excitation source for elementary analysis [7], as a tool for remediation of gas effluents detrimental to environment [8,9], etc. The advantages include clean and wear resistant electrodeless operation for high throughput at atmospheric pressure. The efficiency of microwave to plasma coupling is close to 100%, and the availability of inexpensive sources at 2450 and 915 MHz are also an advantage. This report presents a pure steam-plasma torch generated by microwave energy and uses it for coal gasification in a compact operating system. This gasification system aims to gasify low-grade types of coal, which otherwise can lead to environmental problems. The proposed coal gasification system utilizing a microwave steam torch may serve as a moderately sized power plant due to its compact and lightweight design. This can be useful in rural or sparsely populated areas where access to a national power grid is not available.

2. Microwave Plasma Torch

The atmospheric microwave plasma system [1,10] consists of a microwave generator; waveguide components (WR-340 for 2.45 GHz) including an isolator, a directional coupler, and a three-stub tuner; and a microwave plasma torch that serves as a applicator of the wave fields. The waveguide used in the microwave plasma torch was tapered to a shorted cross-section (86 mm × 20 mm for 2.45 GHz) to increase the electric field intensity in the discharge tube. The discharge tube was inserted perpendicularly to the wide wall of the waveguide. The discharge tube was located 1/4 wavelength away from the shorted end of the waveguide. The typical power of the magnetron is only a few kW at 2.45 GHz. The microwave radiation generated from the magnetron passes through the three-stub tuner, is guided through the tapered waveguide, and enters the discharge tube which consists of fused quartz. The plasma generated inside the discharge tube is stabilized by injecting a swirl gas which enters the discharge tube sideways, creating a vortex flow in the tube and thus stabilizing the torch flame in the center of the tube, keeping the torch flame of 5,000°C off the discharge tube wall and protecting the wall from the torch heat. The temperature profiles are nearly flat in the largest measurable plasma radius with a maximum value of 6000K ± 200K on axis. The flame temperature at a radius of 10 mm for a 2.45 GHz torch is still 80% of its value on axis. The typical electron density n_e for an argon torch [11] is approximately 5.0 to 8.0 ($\times 10^{14}$cm^{-3}). The actual

value depends on the gas flow rate rather than on the microwave power. An increase in the microwave power causes an expansion of the plasma flame and an increase in the gas temperature with little change in the electron density. However, the electron density increased as the gas flow rate increased in this particular experiment, where the flow rate was several liters per minute (lpm) or more. Typical plasma torches generated by microwaves at 2.45 GHz are shown in Fig. 1 for several different working gases. Each gas has its own characteristic color of torch flame due to its atomic and molecular excitement levels. For example, the color of the oxygen flame at a flow rate of 40 lpm is bluish white.

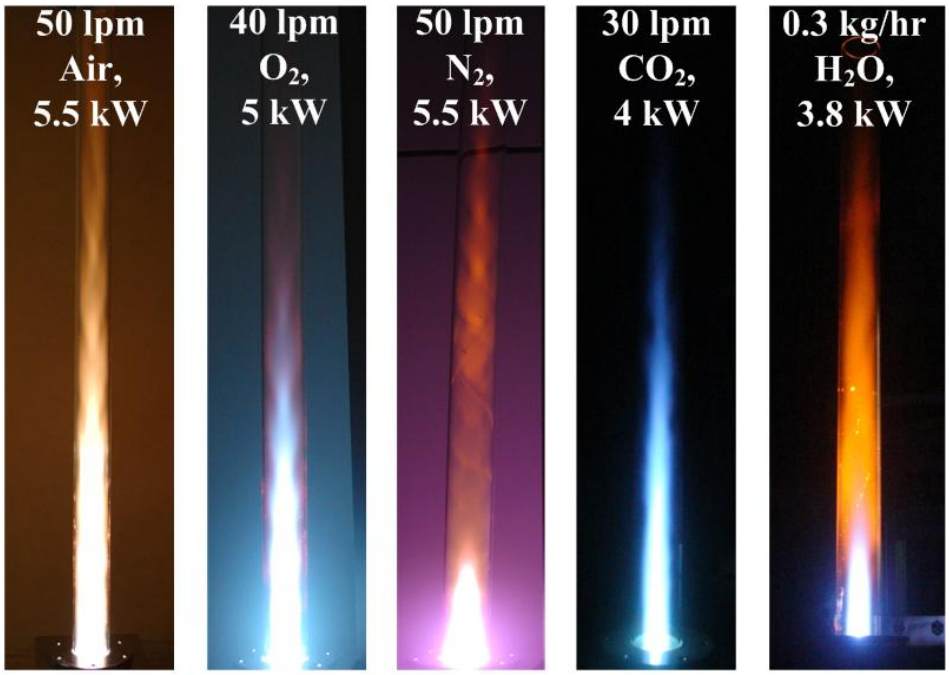
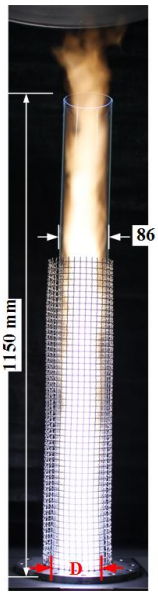


Figure 1. Typical plasma torches generated by microwaves at 2.45 GHz for several different working gases.

Figures 2(a) and (b) are the typical microwave torch plasmas generated in airflows at 915 MHz and 2450 MHz, respectively, revealing the discrepant difference in plasma volumes. Only a part of the quartz tube was set and the quartz tube for 915 MHz microwave plasma was surrounded by a steel mesh owing to concerns of microwave leakage. Because we had worried about the possible leakage of microwaves, we measured the leakage power from the air plasma corresponding to Fig. 2(a) by using a microwave survey meter with a model number of HI-1600 (ETS-Lindgren L. P. Company). The leakage power was less than one mW/cm^2 at the position of 50 mm away from the upper wide waveguide wall outside the mesh. Even on the top of quartz tube, it was almost zero, indicating that the plasma consumes microwave powers almost completely. We also expect that instead of metal mesh, a metal cylindrical tube may shield the leakages better if there is any. As shown in Fig. 2, the plasma flames are very stable and reproducible. The large-volume plasma flame in Fig. 2(a) was confined inside the quartz tube with the inner diameter of 80 mm and the length of 1100 mm. It was generated at 150 liters per minute (lpm) airflow and at the incident power of 20 kW. Then the reflected power was less than 0.1 kW, as measured by the directional coupler. The length of microwave plasma flame is beyond the long quartz tube, displaying a flame pillar in its appearance. On the other hand, the plasma flame excited by a 2450 MHz microwave in the quartz tube with internal and external diameters of 27 and 30 mm was sustained at 50 lpm airflow and 5 kW (without reflected power). From the comparison of two photographs, it was confirmed that the scale-up proportional to the wavelength could result in an enlargement of the plasma source based on waveguide and in the increasing of the plasma volume at 915 MHz.



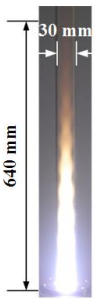


Fig. 2. (a) Fig. 2. (b)

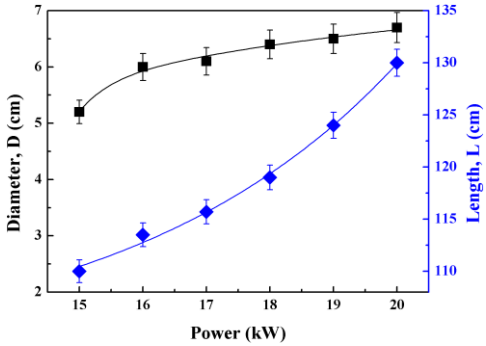


Figure 3

Figure 3 discloses the length *L* and diameter *D* of air plasma at 150 lpm airflow and at variable powers for 915MHz. In Fig. 3, *L* and *D* of the plasma flame were measured from and on the upper waveguide, respectively. When the applied power increases from 15 to 20 kW, *L* increased from 110 to 130 cm and *D* also increased from 5.2 to 6.6 cm almost linearly. In fact, *L* can be longer than the measured values if the length of the quartz tube used in this test is long enough relative to the plasma flame length. In addition to the 2450 MHz microwave plasma torch reported previously, *D* and *L* in the 915 MHz plasma torch significantly depends on the amount of swirl gas. For example, in introducing 100 lpm air into the 20 kW plasma torch, the plasma could fill the whole radial cross-section of the discharge tube with the damage on it. Therefore, by appropriately controlling the input power and the gas flow rate, the stable plasma can be obtained reproducibly.

3. Coal Gasification

A high-temperature steam torch may be used for hydrocarbon fuel reforming at one atmospheric pressure. The main object of this study is the gasification of coal, which is a prime concern in the current energy economy. Coal gasification may be carried out according to $C + H_2O \rightarrow CO + H_2$. Shown in Fig. 4 are plots of the relative concentrations of synthesized gas species versus the ratio of steam to coal. If there is insufficient steam, the dominant synthesized gas is carbon dioxide because the oxygen of the coal powder carrier produces an abundant amount of CO_2. The relative hydrogen concentration increases and the carbon dioxide concentration decreases as the ratio of steam to coal increases. The carbon monoxide concentration also increases slightly.

The relative concentrations of synthesized gases at a ratio of 0.55 of steam to coal is 52% of hydrogen, 23% of carbon monoxide and 25% of carbon dioxide, as shown in Fig. 4. Most of the steam molecules were consumed during gasification at this steam-to-coal ratio. Therefore, a simple calculation indicates 90 moles of hydrogen, 40 moles of carbon monoxide and 43 moles of carbon dioxide per hour in this experiment. The carbon dioxide concentration may be reduced by eliminating the oxygen feeding as a carrier gas. The relative concentrations of the synthesized gases at a ratio of 0.55 of steam to coal are suitable for operation of a gas-engine generator for the production of electric power.

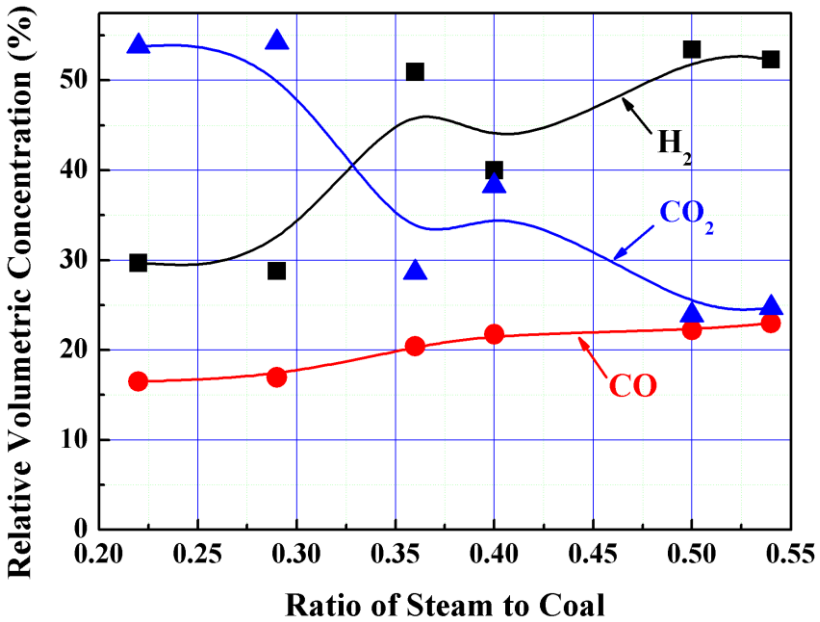


Figure 4. Relative concentrations of synthesized gas species versus the ratio of steam to coal

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