Fuel consumption reduction achievement by using the dielectric barrier discharge (DBD) plasma on Bunsen burner

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Abstract: In this paper, the reduction of fuel consumption in the Bunsen burner was investigated by using a dielectric barrier discharge plasma as the fuel activator. Based on the experiments, about 20% reduction in fuel consumption achieved by applying 40 watts power to the DBD. The results also indicate that the flame length and heat capacity have increased.

Keywords: Plasma, Combustion, Dielectric barrier discharge, Fuel consumption, Bunsen burner

1. Introduction

Natural gas, one of the cleanest fossil fuels, composed of mostly methane (CH_4) has widespread use in the variety of industrial and automotive combustion devices. Natural gas is a non-renewable energy source and emits some quantities of greenhouse gases such as carbon dioxide (CO_2) into the atmosphere that causes global warming. Having better combustion, less fuel consumption and less polluting emissions have created the need for new high-efficiency combustion devices and auxiliary procedures. Plasma-assisted combustion is a promising way to achieve success in this area[1, 2]. Non-Thermal Plasmas (NTPs) improve the ignition of fuel/air mixtures, increase flame propagation speed, enhance flame stabilization and extend flammability limits. Non-thermal plasmas are generated by a variety of electrical discharges such as Direct Current (DC) Glow Discharges, Corona, Dielectric Barrier Discharges (DBD) and etc. This group of plasmas also known as "Cold Plasmas" or "Non-Equilibrium Plasma" because the electron temperature is high on the order of few electron volts, but ions have a temperature near the room temperature[3]. The presence of energetic electrons, that produce in turn ions and highly active chemical reactive species without the excessive heat generation, makes NTPs suitable for plasma chemistry purposes. In this research the fuel consumption in the Bunsen burner was investigated by using a DBD reactor as the fuel activator, The effect of plasma was also studied on flame parameters and burning process.

2. Materials and Methods

The investigated burner was composed of an inner stainless-steel tube (external diameter, d_{ext} = 6 mm) and a coaxial quartz tube (internal diameter, D = 10 mm; external diameter = 13 mm) as shown in Fig.1. The steel tube was connected to the ground, acting as the grounded electrode. A steel mesh was placed on the outer surface of the quartz tube and connected to the HV, acting as the second electrode. The mixing region is the zone between the top ends of the two coaxial tubes, which the reactants (air and fuel) mix; Air passes through the central electrode and enters the mixing zone, and the fuel mixed with air after passing through the plasma region.

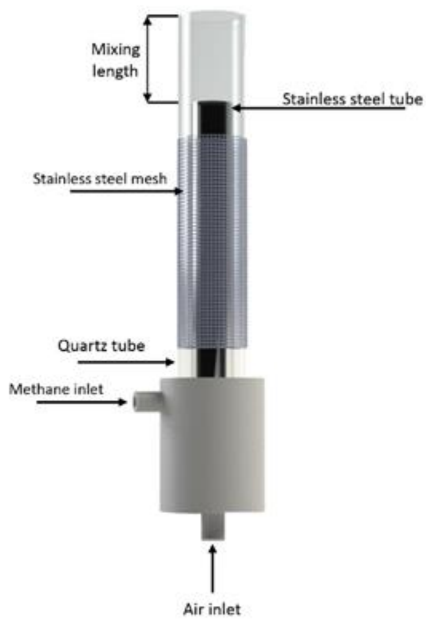

Figure 1. Sketch of the burner geometry

The amount of fuel and air entering is adjusted on the basis of burning stoichiometric equations and is controlled by mass flow controllers (ALICAT MC-500SCCMPM) into the DBD reactor. According to the methane burning equation, each mole of methane will need 2 moles of oxygen for complete burning, and since the air has 21% oxygen, then to burn any mole of methane requires 10 moles of air. As a result, all methane/air ratios are considered 1 to 10 in all experiments. Plasma was produced by using a variable voltage power supply at a fixed frequency of 21 KHz. Also, according to the circuit shown in Fig.2, two voltage probes, an oscilloscope, and a capacitor with a capacity of 21 nanofarad are used to obtain the amount of power consumed by the system[4].

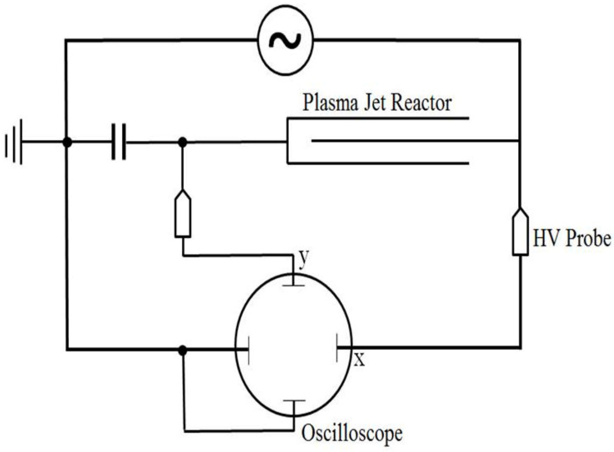

Figure 2. Sketch of the circuit

Lissajous curve which indicates the system's power consumption is shown in Fig.3.

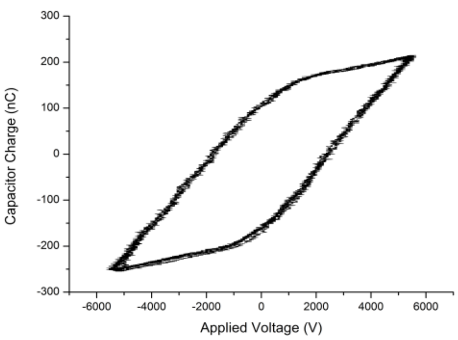

Figure 3. Lissajous curve

The flame temperature is measured by a k-type thermocouple connected to a thermometer. This measurement indicates an increase of 20-70 ° C in flame temperature (As a function of temperature and gas flux). In addition, flame appearance is investigated on the various input powers. Fig.4 shows the length and stability of the flame at plasma off condition, plasma input power 10, 20, 30, 40, and 50 respectively. The experiments were performed at 15, 30 and 40 Watts of plasma. Also, by changing the air and fuel flows to 100, 150, 200, and 300 ml/min the gas flow effects were investigated.

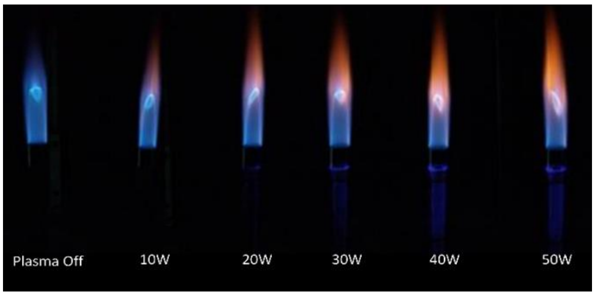

Figure **4**. Flame appearance in different plasma powers from 0 to 50 watts

3. Results and Discussion

The experiments indicate the positive effect of using plasma to reduce fuel consumption in the methane burning process as shown in Table 1.

Table 1. Fuel consumption of different methane flows by different applying powers to the DBD

Fuel consumption reduction (%)	Time (s)	Power (W)	Gas Flow (ml/min)
0	197	0	100
4.6	188	15	
9.73	178	30	
13.1	165	40	
0	151	0	150
13.2	131	15	
17.2	125	30	
21.7	118	40	
0	113	0	200
5.2	106	15	
11.3	98	30	
17.4	90	40	

While plasma is applying, the needed time to increase the temperature of 50 ml of water, inside the balloon placed on the flame, from 20 to 80 ° C is measured. Finally, by using this time and the time of the plasma off condition, fuel consumption obtained, the results show that at the 150 ml/min gas flow rate condition, about 21% fuel consumption reduction will be achieved. The temperature and flame appearance investigations also indicate the positive effect of the plasma on the Bunsen burners. When the plasma is turned on, the minimum increase in flame temperature is about 20 (^{o} C) and the flame length will clearly increase about 2-4 centimeters. The results of the analysis of OES in plasma off condition and when plasma is on and its power adjusted on 30W, is shown in Fig. 5. It indicates that the presence of plasma and its effects on methane and air have led to the formation of active species like N_2^+, O, etc. these active species improve the burning process and therefore, led to form a flame with higher temperature and size [5-7].

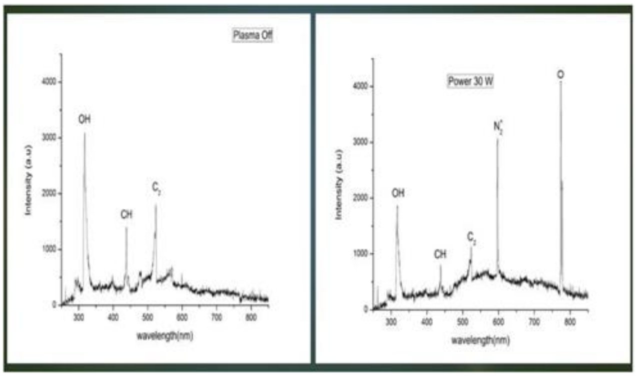

Figure 5. OES graph for plasma off (left) and plasma on (right)

4. Conclusions

The plasma breaks down methane bonds and produce various active species and molecules with better burning capability such as hydrogen. This effect leads the combustion process towards complete burning and subsequently higher efficiency. As the result more energy availability, less pollutants production and also fuel consumption reduction will be achieved by plasma presents. By a DBD reactor with 2 mm electrodes gap and 150 ml/min gas flow better results were obtained in comparison with the other gas flows. In this condition, due to the proper density and sufficient residence time of gas molecules in the plasma reactor, probability of collision between the active species of the plasma and the gas molecules will be more.

References

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