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Electrical and Thermodynamic Characteristics of Non-transfer Arc and Electric Direct Current Plasma Torch with Air Working Gas

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ABSTRACT: Industrial and research use of thermal plasma technology for a wide range of applications such as material processing, gasification, and disposing of hazardous waste. In this research, we have designed and manufactured a plasma torch for the gasification of liquid carbon-based materials. In particular, these materials must be sprayed at a certain angle into the plasma. The plasma torch is one of the components of a liquid waste gasification device, in this research, we have only studied the thermodynamic and electrical characteristics of the plasma torch. The plasma torch has been tested in two cases Finally, the electrical and thermodynamic characteristics of the plasma torch were measured and compared to each other. According to the results, the plasma torch has a maximum electrical voltage of 210 V and thermal efficiency of 86.2%. The maximum plasma enthalpy value is 21.5 MJ/kg and the maximum plasma jet temperature at the nozzle outlet is 3400 K. Plasma torch at a distance of 20 mm from the nozzle outlet has a temperature above 3000 degrees Celsius, which can be completely gasified the organic compounds and carbonaceous materials.

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1- Introduction

Industrial and research use of thermal plasma technology for a wide range of applications such as material processing, gasification, and disposing of hazardous waste. Nikita Obraztsov et al [1] The characterization of AC plasma burners has been investigated, which were used for processing organic materials. Nishikawa et al. [2] direct current plasma torch with the flow of steam and air gas have been investigated and Also, and the effect of plasma torch gas on carbon chain decomposition rate in the gasification process has been studied. Guohua et al. [3] studied the characterization of direct current plasma torch with steam working gas for materials processing and gasification applications. Chau et al. [4] studied the characterization of direct current plasma torch with steam working gas with tubular electrodes. In this research, we have designed and manufactured a plasma torch for the gasification of liquid carbon-based materials. This liquid residue should be sprayed into the plasma at a specified angle. Therefore, several parameters in characterizing the plasma torch are important for this application, which are: 1- Suitable plasma width at a distance of 20 mm from the nozzle outlet, 2- Temperatures above 3000K plasma at a distance of 20 mm from the nozzle outlet, 3- High plasma enthalpy, 4- Thermal efficiency of the torch, 5- Atomic radicals in plasma. As an assumption, the waste should be injected at a distance of 20 mm from the nozzle outlet, we have considered this distance as our effective distance. Accordingly, Plasma temperature and plasma width were measured at this distance. In this research, we have only studied the thermodynamic and electrical characteristics of the plasma torch.

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2- Methodology

Fig. 1 Part B, describes the arrangement of the test components that include: A DC power supply, cooling water tank, gas supply, oscilloscope, optical emission spectrometer, barometer, and thermometer. Fig. 1 Part A, shows a view of a 25-kW air plasma torch that has been sampled.

The method of the experiments is defined as follows; Plasma torch characteristics have been investigated for two different cases. In the first case, the working gas pressure is kept constant at 2 bar and the electric current is increased from 50 to 100 amps. In the latter case, the electric current was kept constant at 100 amps and the working pressure was increased from 2 to 3 bar, and the characteristics of the Plasma torch parameters are inscribed for each case.

3- Results and Discussion

The torch voltage variation is shown in Fig. 3.

Thermal efficiency as one of the studied parameters of plasma torch is defined as follows:

$$\eta = \frac{I.V - (A\varepsilon\sigma(T_s^4 - T_\infty^4) + Ah(T_s - T_\infty) + 4.18c_{cw}.q_{cw}(T_2 - T_1))}{I.V} \quad (1)$$

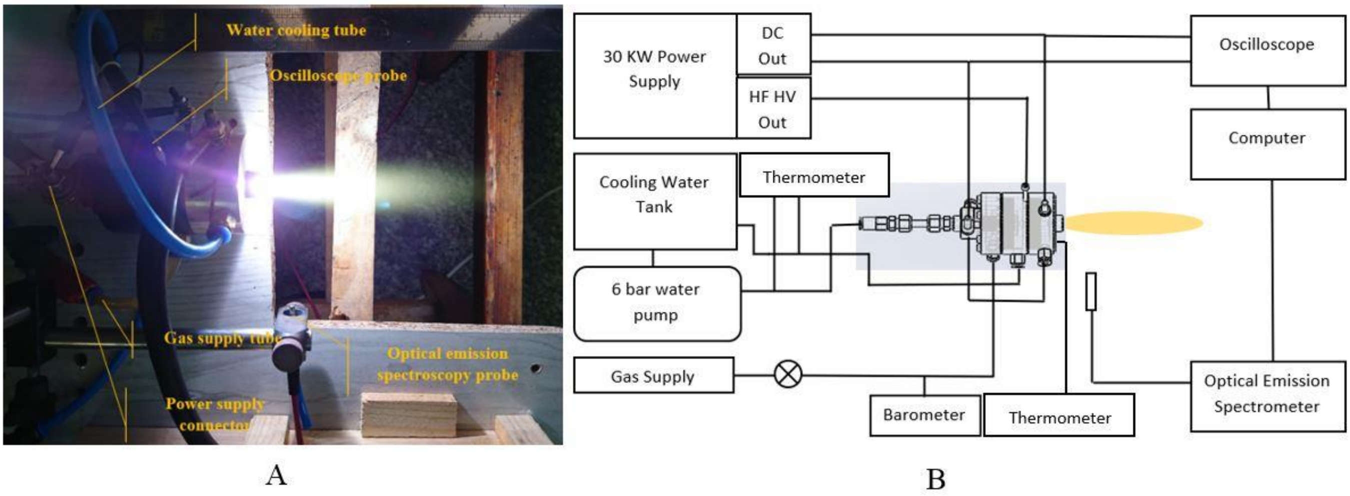

Fig. 1. A: Top view of the plasma torch that displayed in working mode. B: Schematic diagram of the experimental setup is described.

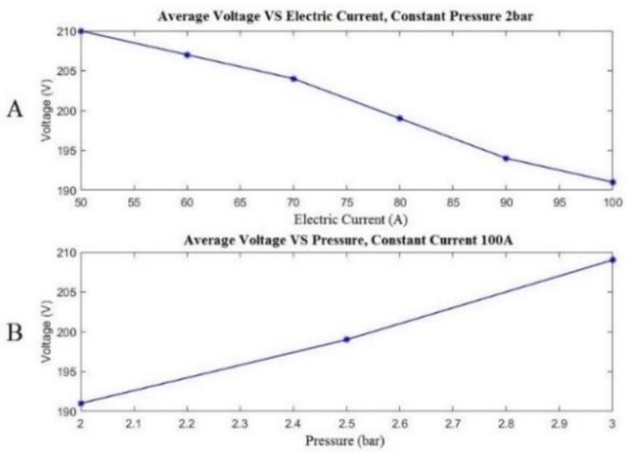

Fig. 2. Diagram A, shows the voltage variation to the electric current, and Diagram B, shows the voltage changes to the working gas pressure.

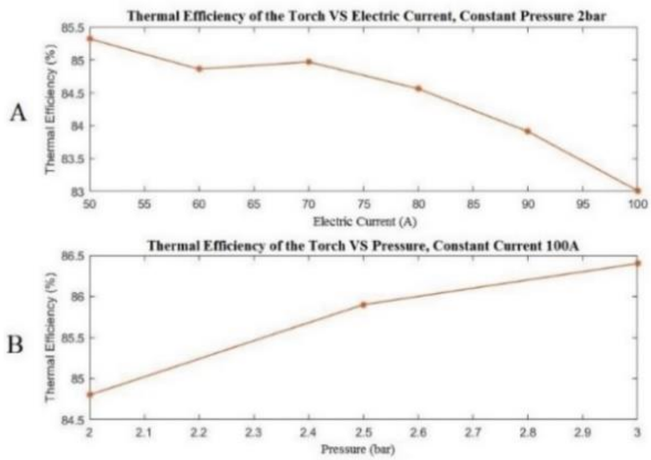

Fig. 3. Diagram A, shows the thermal efficiency variation to the electric current, and Diagram B, shows the thermal efficiency changes to the working gas pressure.

Which η is the thermal efficiency, I is the arc current, V is the arc voltage, A is the outer surface area of the torch, ε is the emissivity of the torch surface, σ is the Stefan–Boltzmann constant, h is the torch–environment convective heat transfer coefficient, T_∞ is the ambient temperature that is equal to 300K, T_s is the temperature of the torch outer surface, c_{cw} is the specific heat of water, q_{cw} is the volume flux of cooling water, and T_1 , T_2 are the water temperatures at the inlet and outlet of the torch, respectively. The thermal efficiency variation is shown in Fig. 3.

Another important characteristic of a plasma torch is the enthalpy, or in other words, the quantity of energy transferred to the plasma. The specific enthalpy value of the output plasma in the torch is defined as follows:

$$h_p = \frac{I.V - (Q_{rad} + Q_{conv} + Q_{cw})}{Q_{wp}} + h_0 \tag{2}$$

In the above equation h_p is the specific enthalpy of the plasma, Where $I.V$ total electric power of torch, h_0 is the specific enthalpy of the plasma-working gas before entering the plasma torch, Q_{wp} is the mass flow rate of the plasma working gas, Q_{rad} is the energy loss due to heat radiation by the torch surface to ambient air, Q_{conv} is the energy loss due to convection between the torch surface and ambient air and Q_{cw} is the energy loss due to cooling water for the torch body. In Eq. (2), the term of kinetic energy contributing to the net power of the torch is completely neglected due to the low plasma velocity at the torch exit. The Specific enthalpy variation is shown in Fig. 4.

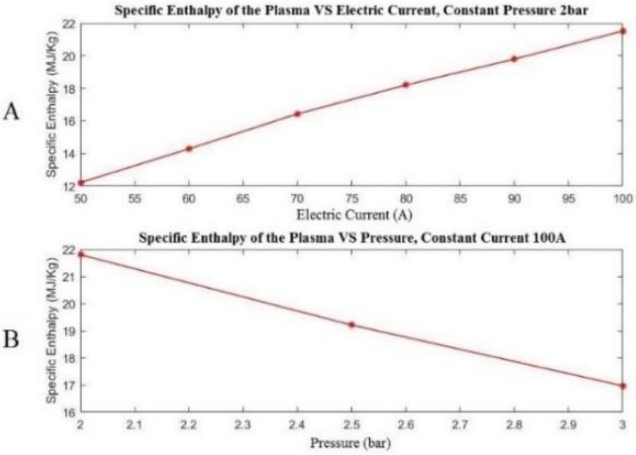

Fig. 4. Diagram A, shows the Specific enthalpy variation to the electric current, and Diagram B, shows the Specific enthalpy changes to the working gas pressure.

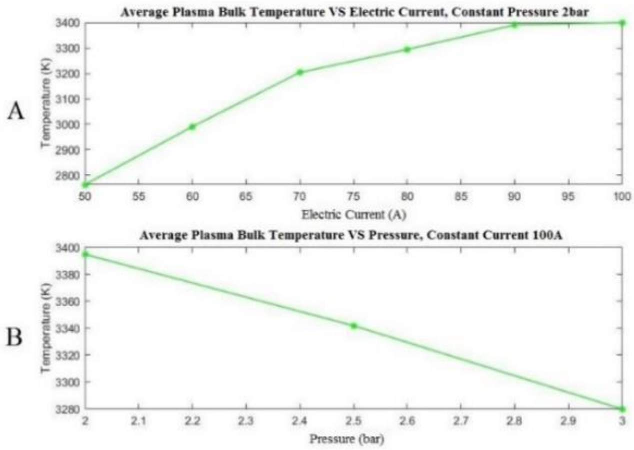

Fig. 5. Diagram A, shows the average plasma bulk temperature variation to the electric current, and Diagram B, shows the average plasma bulk temperature changes to the working gas pressure.

Plasma bulk emission spectroscopy was used to estimate the nozzle outlet plasma jet temperature. For low-temperature plasma conditions (below 5000K), we used the molecular transition OH (A-X) of branches R and P to determine the plasma temperature. The average plasma temperature of the nozzle outlet is shown in Fig. 5. The recorded temperature is considered from the center of the nozzle axis and at a distance of 20 mm from the nozzle outlet.

4- Conclusion

The results of the above experiments and studies are as follows, the plasma torch in electrical characterization has a maximum voltage of 210 volts and a minimum voltage of 191 V. In thermoelectric characterization, the maximum thermal efficiency of the torch was 86.2% and the minimum thermal efficiency was 83%. The maximum plasma enthalpy was 21.5 MPa/kg and the minimum enthalpy was 16.9 MPa/kg. The maximum plasma jet temperature is measured at the nozzle outlet of 3400K. according to the obtained results, the plasma torch at a distance of 20 mm from the nozzle outlet has a temperature above 3000 degrees Celsius and a convenient enthalpy of 21.5 MJ/kg, Which can complete the gasification process of base carbon compounds.

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