Development of high-power plasma reformer and power supply for large scale applications

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Abstract: The modern technology of non-thermal gliding arc for large scale industrial processes demand a high power plasma system that consist of high voltage power supply and Gliding Arc plasmatron (GA).

Plasma system for gliding arc including a modular design 10 kW power supply and Gliding Arc plasmatron with cylindrical non-cooled electrodes was developed. The power supply is designed as a switching mode electronic power supply, based on pulse width modulation technology. Results of investigation of the electrical and thermal characteristics of the dual jet gliding arc plasmatron system depending on inner geometry and flow rates are presented.

Keywords: Plasmatron, Gliding Arc Discharge

1. Introduction
Non-equilibrium gliding arcs (GA) at low power level (0.5-1kW) are prove to be highly efficient plasma stimulators of hydrogen/syngas generation from biomass, coal and organic waste. The advantage over conventional catalytic technology is due to its ability to convert any hydrocarbons (without sensitivity to specifics of the feedstock) to syngas without any catalyst, at low temperature, no thermal inertia, and no sulphur restrictions [1]. This plasma-catalytic technology, developed at the A. J. Drexel Plasma Institute at Drexel University has already attracted significant attention of such companies as Chevron, ConocoPhillips, Ceramatec and Accelbeam. Large-scale application and commercialization of this technology requires scaling-up of the non-equilibrium GA to a single unit power of 10-30kW, which corresponds to H₂/syngas production on the power level up to 1-3MW (taking into account that plasma energy consumption is 1-2% of fuel heating value). The scaling-up is the primary objective of this research project.

2. Experimental methods
The test setup consisted of dual-jet gliding-arc plasmatron (Figure 1) and modular design high voltage power supply. Plasmatron system [2] which consisted of two identical Gliding Arc plasmatrons with cylindrical, non-cooled electrodes was used. The plasmatrons were connected serially: high voltage was supplied to the cathode of the first plasmatron and ground was connected to the anode of the second plasmatron.

Figure 1. Dual-jet gliding arc plasmatron.

The power supply was specially designed for the plasmatron system to supply high voltage up to 2kV. The maximum power provided by the power supply
was about 12kW. The power supply designed as a switching mode electronic power supply based on pulse width modulation technology. The power supply consists of several identical modules connected in parallel and regulated by control processor unit (CPU). The power supply provides negative polarity high voltage.

All described experiments were done using air at atmospheric conditions. To initiate the discharge an igniter was used for each gap.

3. Results and Discussion

Figure 2 shows Voltage-Current (V-I) characteristics of the power supply at different loads. At maximum load the power level provided by the power supply reached up to 10kW.

Figure 3 presents V-I characteristics of the plasmatron system for different air flows. As air flow increases, the voltage rises at the same current in comparison to lower air flow. Each curve can be divided into several regions which correspond to different operating modes of the plasmatron system. For example, the lower air flow (89.59 L/min, blue curve) can be divided to 4 regions: $AB$, $BC$, $CD$ and $DE$ as denoted on Figure 3. In the first region, $AB$, the voltage drops when the current increases. This region corresponds to the stage where the arc in each plasmatron is extending from the gap toward the electrode edge, but has not reached the edge yet. This regime is shown in Figure 4 (a) and Figure 5 (a). In the second region, $BC$, the voltage remains constant while current increases. In this region the gliding arc has reached both ends of the electrodes and arc length remains relatively constant with a constant flow rate. In this region voltage remains constant during current increase that results in linear V-I characteristic. This region is shown in Figure 4 (b) Figure 5 (b). In region $CD$ the voltage is sharply increased As the arcs begin to merge, but remain unstable. Finally, both arcs merge and form one joint arc as shown in Figure 4 (c) and Figure 5 (c) and this corresponds to region $DE$ in Figure 3.

Figure 2: V-I characteristics of the power supply at different loads.

Figure 3: V-I characteristics of the plasmatron system for different air flow rates.

Figure 4: Different stages of gliding arc development in dual jet plasmatron system.
Figure 5: photographs of plasmatron regimes: (a), (b), and (c) corresponding to stages (a), (b) and (c) of Fig.4. Exposure time of photographs a. and b. was 1/8000s.

Figure 6 demonstrates the power dependance on the voltage for the plasmatrons (dash lines) and power supply (solid lines). The gray area (voltage 1.5-1.7kV) in Figure 6 denotes working zone in the regime of high power (up to 9kW). An air flow rate larger than 120 L/min is required for optimal power (9kW). Lower flow shows lower voltage and results in instability.

Figure 7 shows power-current characteristics for the plasmatrons (dash lines) and power supply (solid lines). The gray area in the picture (current after 5 A) shows the zone of stable plasma system operation at maximum power.

4. Conclusions

An innovative system consisting of a dual-jet, gliding arc plasmatron and 10kW power supply was successfully developed and tested. The system is simple, robust, doesn’t require liquid cooling and can operate at high power levels (9-12kW) for long period of time. Comparison of V-I characteristics of the power supply and plasmatron system shows a zone of stable plasma system operation. Different modes of operation of the plasma system were observed and attempt to explain the phenomena was made. Future work needs to be done to improve
efficiency and operation stability of the plasma system in wide range of parameters.

References