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# Near-Zero Emissions Combustor System for Syngas and Biofuels

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*Abstract*— **A multi-institutional plasma combustion team was awarded a research project from the DOE/NNSA GIPP (Global Initiative for Prolifereation Prevention) office. The Institute of High Current Electronics (Tomsk, Russia); Leonardo Technologies, Inc. (an American-based industrial partner), in conjunction with the Los Alamos National Laboratory are participating in the project to develop novel plasma assisted combustion technologies. The purpose of this project is to develop prototypes of marketable systems for more stable and cleaner combustion of syngas/biofuels and to demonstrate that this technology can be used for a variety of combustion applications – with a major focus on contemporary gas turbines. In this paper, an overview of the project, along with descriptions of the plasma-based combustors and associated power supplies will be presented.**

**Keywords: plasma assisted combustion, gas turbine**

## I. INTRODUCTION

Worldwide, it is recognized that a variety of combustion fuels will be required to meet the needs for supplying gas-turbine engines (electricity generation, propulsion), internal combustion engines (propulsion, transportation), and burners (heat and electricity generation) in the 21st Century. Biofuels and biofuel blends have already been applied to these needs, but experience difficulties in modifications to combustion processes and combustor design and the need for flame stabilization techniques to address current and future environmental and energy-efficiency challenges. In addition, municipal solid waste (MSW) has shown promise as a feedstock for heat and/or electricity-generating plants. However, current combustion techniques that use such fuels have problems with achieving environmentally-acceptable air/exhaust emissions and can also benefit from increased combustion efficiency.

This project involves a novel technology (a form of plasma-assisted combustion) that can address the above issues. Plasma-assisted combustion (PAC) is a growing field that is receiving worldwide attention at present. The project is focused on research necessary to develop a novel, high-efficiency, low-emissions (near-zero, or as low as reasonably achievable), advanced combustion technology for electricity and heat production from biofuels and fuels derived from MSW. For any type of combustion technology, including the advanced technology of this project, two problems of special interest must be addressed: developing and optimizing the combustion chambers and the systems for igniting and sustaining the fuel-burning process. For MSW in particular, there are new challenges over gaseous or liquid fuels because solid fuels must be ground into fine particulates (~ 10 $\mu$m diameter), fed into the advanced combustor, and combusted under plasma-assisted conditions that are quite different than gaseous or liquid fuels.

The principal idea of the combustion chamber design is to use so-called reverse vortex gas flow, which allows efficient cooling of the chamber wall and flame stabilization in the central area of the combustor (Tornado chamber). Considerable progress has been made in designing an advanced, reverse vortex flow combustion chamber for biofuels, although it was not tested on biofuels and a system that could be fully commercialized has never been completed.

## II. EXPERIMENTAL SETUP

Schematic of the experimental installation is shown in Fig. 1. A gas discharge in plasmatron burns between the inner electrode 1 and the outer electrode 2 due to a voltage applied from the power supply *PS*. A gas flow (in general cases, an air/fuel mixture) is delivered in the plasmatron nozzle via a swirling unit so that the plasma torch is generated in the vortex gas inside the plasmatron cavity and at its exit. The air/fuel composition is used up partly as a result of the burning process directly in the plasmatron nozzle. The rest of the composition burns in the combustion chamber 3. An inner diameter of the combustion chamber is 78 mm, and its length is 300 mm. The total expenditure of air/fuel composition in the system is up to 5 g/s. The chamber envelope is equipped with a water cooling system and with auxiliary windows 5 for diagnostics of flame and flue gas. In a case of necessity, we can add air or air/fuel mixture directly into the chamber through the feed pipes *II* and *III* as shown in Fig. 1. Then, the torch flame forms in the chamber. Depending on the chamber design, the gas flow velocity, and the gas composition, the torch flame can be localized inside the chamber or can propagate up to the unit for flue gas diagnostics 4. One of the subjects of the investigations is to elucidate a correlation between the regimes of discharge burning in the plasmatron and the properties of the plasma torch and torch flame, since the gas-discharge regimes determine the conditions of complete hydrocarbon combustion or its partial oxidation with obtaining $H_2$ and CO.

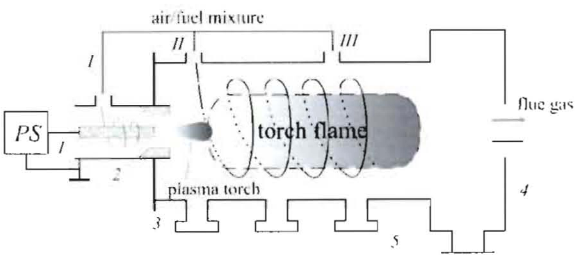



Fig. 1 Schematic arrangement of a system for plasma assisted combustion. *1* – inner electrode of a nonsteady-state plasmatron (cathode); *2* – grounded outer electrode of plasmatron (anode); *3* – combustion chamber; *4* – unit for flue gas diagnostics; *5* – auxiliary windows.

The operation regimes of the plasmatron demand specific rating characteristics of the power supply *PS* for the discharge sustainment. Based on the results of the discharge investigations, the prototype of power supply which does not need the use of external ballast resistor has been constructed and tested. Simplified circuit diagram is shown in Fig. 2. The industrial voltage (110 V, 60 Hz, single phase) is rectified and, after that, is converted to a bipolar voltage with a frequency of 50 kHz. This high-frequency voltage is enhanced by means of a high voltage transformer and rectified after the secondary coil of the transformer. The current limitation at a level of 0.1–0.2 A is achieved due to internal inductance of the electrical circuit. The power supply delivers not a constant dc voltage but a rectified pulsing voltage. Nevertheless, a pulsation frequency is rather high. It is selected from the condition that a characteristic time of gap deionization be much larger than the period of voltage oscillations. Then, even though, at certain short time interval, the voltage at the gap becomes close to zeros, this time is not large enough for the discharge plasma to be decayed.

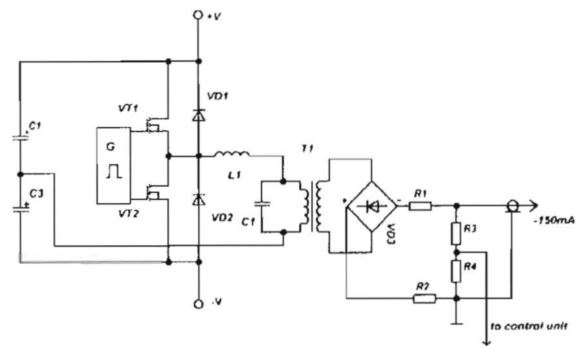



Fig. 2 Simplified electric circuit for the very first prototype of the power supply.

## III. Results and Discussion

Examples of waveforms with the gas-discharge load are shown in Fig. 3, where we can define the noncompleted glow-to-spark transitions at the instants $t_1$ and $t_2$. It is understandable that the voltage and current modulation appears not due to gas-discharge phenomena but due to pulsating voltage of power supply. The power supply is able to operate with a short circuit load. On the other hand, when the resistance of the load becomes extremely large, the power supply generates a voltage of up to 10 kV due to the resonant processes in inner *LC* circuit. This voltage is sufficient to provide the very first breakdown or the repeated breakdowns in the gap in the case of current interruption.

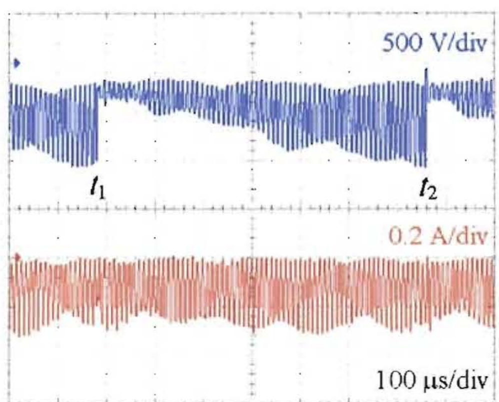



Fig. 3 Typical voltage and current waveforms for the power supply loaded to the nonsteady state plasmatron. $t_1$ and $t_2$ are the instants of the glow-to-spark transition.

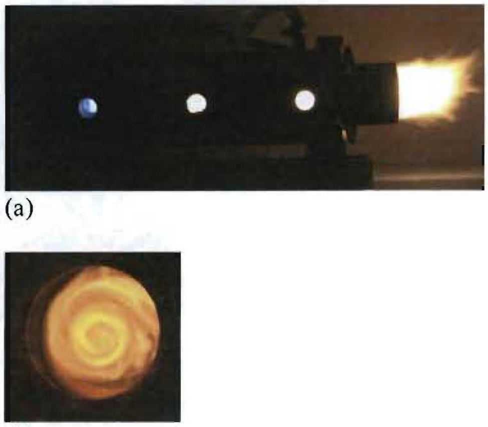
The experimental conditions for the waveforms differ from each other by a percentage of propane in air/propane mixtures, which is characterized by parameter $\alpha$. This parameter shows a ratio of air expenditure to propane expenditure in accordance with the relation

$$\alpha = 0.065 \times G(\text{air})/G(\text{propane}) \quad (1)$$

where *G* is the gas flow velocity in grams per second. Then, proceeding from the reaction of propane oxidation

$$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$$

it can readily be seen that the air-to-fuel ratio $\alpha = 1$ corresponds to the stoichiometric blend.



(a)

(b)

Fig. 4 Photograph of the plasma torch and torch flame (a). Structure of the torch flame, side view (b). Propane expenditure $G = 0.1$ g/s, Air expenditure is close to stoichiometric blend.

The regions of external parameters that characterize different regimes of the propane burning are shown schematically on diagram in Fig. 5. The area 1 spans the conditions of high propane percentage or high air percentage in the mixtures. The discharge is sustained mainly in air ($\alpha >> 1$) or mainly in propane ($\alpha << 1$). In both cases, we can speak of a noncomplete propane oxidation here.

As for the area 2, the process of partial propane oxidation in the plasma torch takes place, and this process determines the torch surface appearance. However, the propane combustion is sustained if only the gas discharge is available in plasmatron. If we switch the plasmatron power supply off, the burning process ceases.

The area 3 is distinctive due to the following reason. The propane completely burns in the plasma torch in these conditions. When we switch off the plasmatron power supply, the burning process does not stop, and the green color flame at the exit is running in a regime of self-sustaining. Let us now discuss the data for the experiments when we add airflow in the combustion chamber 3 via the feedpipe *1* on the wall (Fig. 1). The most illustrative case would be if the mixture that flows across the plasmatron nozzle has an excess of propane. In particular, the point *A* in Fig. 4 is related to the conditions of $\alpha = 0.2$. From the earlier discussion, it is evident that there is a shortage of air for propane oxidation. When airflow is additionally delivered via the feedpipe on the chamber wall, the torch flame arises inside the chamber 3.

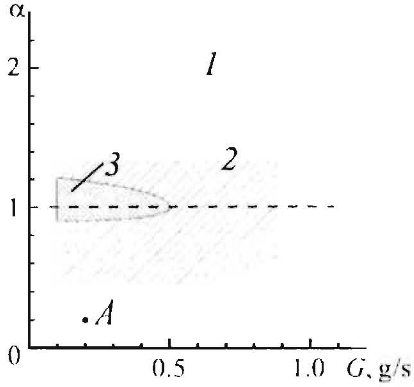



Fig. 5 Schematic diagram demonstrating different regimes for sustainment of the plasma torch at plasmatron exit.

## IV. Conclusion

This paper has described the experimental installation for plasma-assisted combustion in air/hydrocarbon mixtures and the results of experiments. The system is based on the so-called nonsteady-state gas-discharge plasmatron. The essence of discharge regime in the plasmatron can be characterized as a kind of glow with the random transitions from glow to spark. This regime has demonstrated an efficient ignition and flame control in air/propane mixtures with a wide range of equivalence ratio.

Proceeding from the results of discharge investigations, the special power supply for plasmatron powering has been developed and tested. In fact, this is a unit that is untended for generating a predetermined current value at a level of 0.2 A independently on a value of the gas-discharge load. The main idea of the technical solution is that the power supply delivers not a constant dc current but a rectified pulsing current. However, a pulsation frequency is selected from a condition that a characteristic time of gap deionization be much larger than the period of current oscillations. Then, in spite of the fact that, at certain time intervals, the voltage at the gap becomes close to zeros, these time intervals are not large enough for the discharge plasma to be decayed.

## Acknowledgement

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