# Peculiarities of Hydrogen Electric Arc AC Plasma torch and Its Usage in Environmental Applications

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The paper deals with the results of studies of a hydrogen electric arc alternating current plasma torch with gas-vortex stabilization of the arc. The design features of the device are shown, the results of experiments are presented, characteristic oscillograms and volt-flowrate characteristics are given.

**Keywords:** plasma torch, alternating current, hydrogen, methane.

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Environmental protection is one of the key objects of scientific research and requires the most advanced methods and technologies. The priority goal is to reduce atmospheric emissions of harmful substances, which have a fairly diverse composition: carbon dioxide; chlorofluorocarbons; toxic and carcinogenic gases; nitrogen oxides ($NO_x$); sulfur oxides ($SO_x$); metal oxides; ash; soot; and solid particles of various sizes, chemical composition, and morphology. These substances often enter the atmosphere as products of combustion processes. Therefore, it is necessary to introduce environmentally friendly technological processes and low-waste closed-cycle technologies, which factor in the type and properties of emissions and the principles of their formation, at manufacturing enterprises.

The use of hydrogen plasma-chemical technologies (specifically, in the power industry and mining) may be one of the options for increasing production efficiency and reducing the amount of waste [1,2]. Hydrogen is one of the common working media used directly in plasma-chemical reactions as a reaction gas or a high-enthalpy coolant.

The results of several decades of development of hydrogen plasma torches [3–6] are summarized in the table. The following characteristic design features may be identified by analyzing literature data: plasma torches of a linear or end-type design with vortex longitudinal flow-around, a porous wall, and an interelectrode insert. Even a cursory review suggests that the use of electric-arc hydrogen plasma torches at power plants holds much promise due to their capacity to provide the highest possible density of energy transfer to working gas, maintain high heat content of this gas, and, consequently, accelerate chemical processes in the gas phase. Most of the examined plasma torches are designed for DC operation, which entails certain operational features (e.g., in designs with a self-adjusting arc length). When discussing the practical use of plasma systems, one definitely needs to take into account all aspects that affect their efficiency. Work on the design of AC plasma torches capable of operating with both oxidizing and reducing media has been ongoing for quite some time at the Institute for Electrophysics and Electric Power of the Russian Academy of Sciences [7]. With due regard to the accumulated knowledge and experience, an experimental model of a hydrogen single-phase AC plasma torch capable of operating with inert gases, argon, methane, hydrogen, and their mixtures was constructed. Its distinguishing feature is the lack of ballast gases (except at the moment of ignition, which is currently performed using argon), which makes it especially well-suited for purification of natural gas from impurities, hydrocarbon pyrolysis products, etc.

The AC plasma torch shown in Fig. 1 features two housings *1* made of heat-resistant alloys. Each of them contains water-cooled electrode unit *2* and replaceable graphite output insert *4*. The electrode unit has a water-cooled body and an electrode with tip *3* fixed to its end. Depending on the purpose of the plasma torch, the tip may be made of tungsten, graphite, or copper. The body has a channel for tangential supply of plasma-forming gas *5*. A spiral gas-vortex flow formed in the channel cools and stabilizes the plasma channel. Flange *6* is secured to the nozzle cluster, and a cavity is formed between the body and the inner wall for water supply to ensure heat removal from the arc ignition zone. The electrode channels are positioned on the same axis and connected to reaction chamber *7*. The chamber operates as a plasma-chemical reactor when the processed material is supplied.

The plasma torch is switched on by a high-voltage power source at a voltage of 6–10 kV. A breakdown of the air gap between the channel wall and the electrode tip element occurs first. An arc is then ignited and moves under the influence of the gas flow. Arcs develop in each channel, reach the ends of electrodes, and close with each other outside them.

The research data were obtained using an experimental setup with an AC plasma torch, a power source, a system for cooling liquid and plasma-forming gas supply, and a measurement system. The parameters required for practical

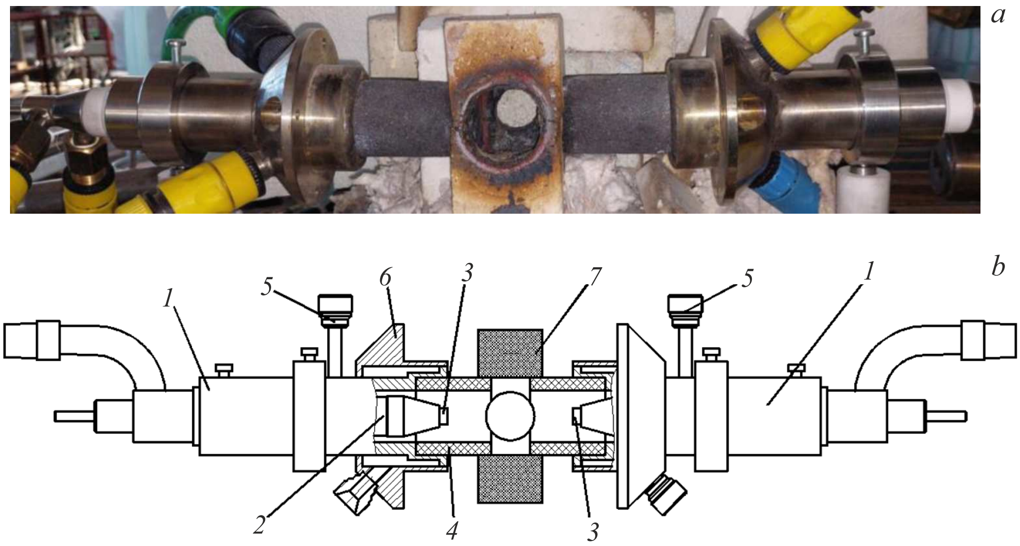


**Figure 1.** *a* — External view of the plasma torch. *b* — Diagram (top view). *1* — Housing, *2* — electrode unit, *3* — tip, *4* — graphite insert, *5* — gas supply, *6* — flange, and *7* — reaction chamber.

Characteristics of hydrogen plasma torches

| Plasma torch type | Power, kW | Flow rate, g/s | Voltage, kV | Current, A | Reference |
|---|---|---|---|---|---|
| Axial design with a porous interelectrode insert | $1.18 \cdot 10^3$ | 30 | 3 | 400 | [3] |
| Linear design | 48–64 | 0.9–1.2 | 0.9 | 600 | [4] |
| Vortex with longitudinal flow-around and a sectional interelectrode insert | $5 \cdot 10^3$ | 35–70 | 2–2.4 | 600–940 | [5] |
| Linear with vortex stabilization | 200 | 2 | – | 800 | [6] |

application of plasma torches were determined at this stage. The dependence of the arc-drop voltage on current and the flow rate of various plasma-forming gases is an important characteristic in this context. Operating modes stable with respect to the flow rate, the ratio of gases in the mixture, etc., were identified. The hydrogen flow rate was varied up to 0.25 g/s in the experiments, and the methane flow rate was adjusted up to 0.01 g/s; the plasma torch power fell within the 6–10 kW range. Electric and energy characteristics within a wide range of parameters were obtained as a result. The dynamics of arc burning is characterized by the corresponding oscilloscope records shown in Fig. 2.

The temporal variation of current is sinusoidal, and the voltage curve has pronounced peaks of ignition and extinction on crossing zero. The full period of voltage variation may be divided into three sections. The first and third sections (lateral sides of a trapezoid) are the sections of voltage rise and fall in the interelectrode gap. The arc does not burn between the electrodes at this time. The second section is characterized by voltage fluctuations about the average value; in certain half-periods, a slight increase in voltage is observed toward the middle of the second section (this is the arc burning section). Depending on the gas type, the range of variation of peak voltages falls within 1200–4000 V. Figure 3 shows the dependence of voltage on hydrogen flow rate, which has a pronounced increasing nature.

A degree of methane conversion up to 89% [8] was found when the chemical composition of effluent gases for a plasma-forming gas mixture consisting of $H_2$ with a flow rate of 0.008 g/s and $CH_4$ with a flow rate of 0.01 g/s was analyzed in preliminary experiments.

The obtained results provide a basis for the design and construction of a multiphase hydrogen plasma torch with a power of up to 50 kW. Such facilities may find use in development of plasma-chemical processes, including those utilized in resource industries. The range of applications of plasma torches of this kind is rather extensive. In addition to simple heating of various materials, these include purification and pyrolysis of natural gas, its processing, etc. Owing to a high thermal efficiency, the possibility to use

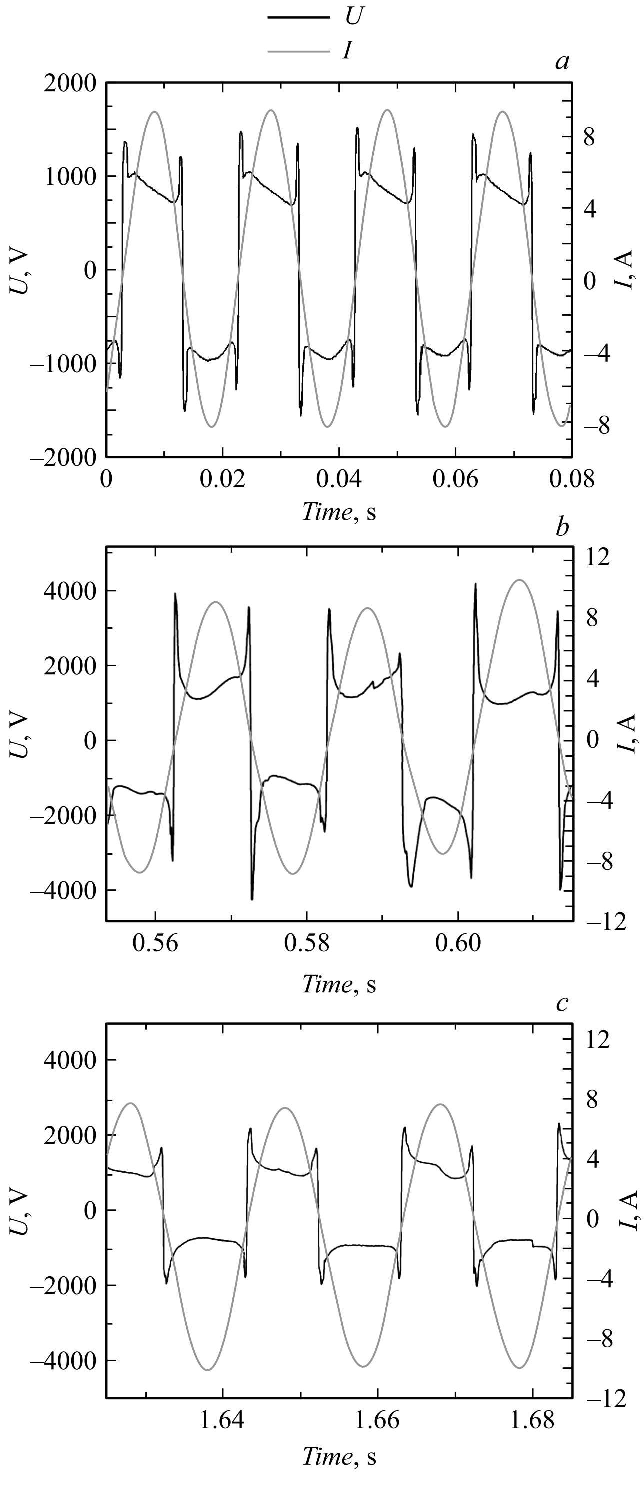


**Figure 2.** Typical oscilloscope records of voltages and currents. $a$ — 0.01 g/s of $CH_4$, $b$ — 0.03 g/s of $H_2$, and $c$ — 0.01 g/s of $CH_4 + 0.03$ g/s of $H_2$.

natural gas as a plasma-forming one, the lack of transport and ballast gases, the simplicity of the plasma torch design, and the reliability of its power supply system, the industrial use of such generators may turn out to be advantageous and promising from both technical and economic points of view.

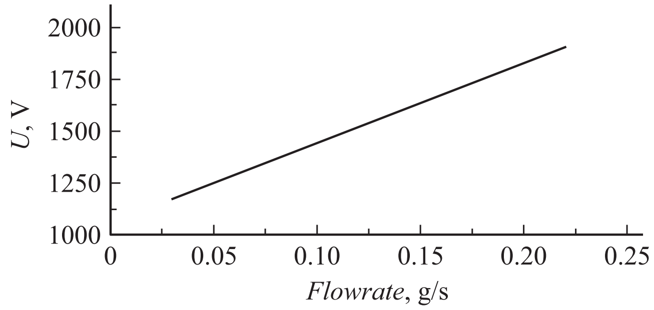


**Figure 3.** Dependence of voltage on the $H_2$ flow rate.

### Conflict of interest

The authors declare that they have no conflict of interest.

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