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# INFLUENCE OF THE OPERATING REGIMES OF A PLASMACHEMICAL REACTOR ON THE EFFICIENCY OF CONVERSION OF ETHANOL

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*The results of experimental investigations on optimization of the process of conversion of ethanol in a high-voltage atmospheric-pressure discharge have been presented. The influence of the structural features of the reactor on the yield and energy cost of conversion products has been investigated. The reactors' operating regimes ensuring the maximum values of the specific output and the minimum values of the energy cost of hydrogen have been established.*

Optimization of the processes of conversion of hydrocarbons in a high-voltage atmospheric-pressure discharge is a pressing problem at present [1–3]. Investigations of the process of steam-water conversion of methane have been described in [3] and the energy cost of production of hydrogen $Q_{H_2} \approx 3$ kW·h/m$^3$ which is minimum for this structure of the reactor has been determined. The production of hydrogen from an ethanol–air mixture in a high-voltage-discharge plasma has been investigated in [4]; the minimum energy cost for hydrogen was attained in operating regimes of the reactor near the lower bound of stable burning of self-sustained discharge and was $Q_{H_2} \approx 1.2$ kW·h/m$^3$; however the hydrogen output was low: $G_{H_2} = 170$ liters/h.

In this paper, we present results of experimental investigations on optimization of operating regimes of compact plasmachemical reactors with the aim of increasing the specific output and reducing the energy cost of hydrogen.

**Experimental Setup.** The setup for ethanol–hydrogen conversion in the plasma of a high-voltage atmospheric-pressure discharge is analogous to that described in [4]. It incorporates the following basic units: a plasmachemical reactor, a system for feeding reagents and preparing a working mixture, a high-voltage power supply, and a diagnostics system. We modified the previous structure of the reactor to maximize the efficiency of discharge energy (Fig. 1). Tube 2 of height equal to the maximum electrode spacing was slipped over cathode 1. A fill of ceramic spheres 4 with a diameter of 3 mm was placed between the internal 2 and external 3 quartz tubes. The external quartz tube was surrounded by the heat-insulation layer 5. The plasmachemical reactor operated as follows. Breakdown voltage was applied between the anode 6 and the cathode 1 for a nearly zero electrode spacing $d$. Next, we moved apart the electrodes and simultaneously increased the voltage up to a level sufficient for maintaining a self-sustained discharge. The ethanol–air mixture was allowed to pass through the fill layer 4, successively traversed channels 7, and arrived at the discharge zone. The discharge-radiation energy was absorbed through the wall of the internal tube 2 by the fill layer, where the efficient heat exchange between the fill and the arriving gaseous mixture occurred. Next, the preheated mixture was treated in the discharge zone, after which the conversion products were removed from the reactor via heat exchanger 8.

**Results of the Experiments and Their Discussion.** Since it is necessary to create a compact reactor of conversion of hydrocarbons, we introduce the specific output of the reactor $K_r = G_{H_2}/V$ as the ratio of the volume of hydrogen produced per unit time (output) $G_{H_2}$ to the volume of the reactor core $V$. By the reactor core we will mean the volume between the cathode's lower part and the anode, which is bounded by the external reactor tube (shown by the dashed line in Fig. 1). In the previous reactor, the specific output was $K_r = 6.8$ m$^3$/(h·liter) for the ethanol–air mixture with an equivalence factor $\gamma = 5.4$ for the electrode spacing $d = 5$ mm, $V = 0.025$ liter, and $G_{H_2} = 0.17$ m$^3$/h.

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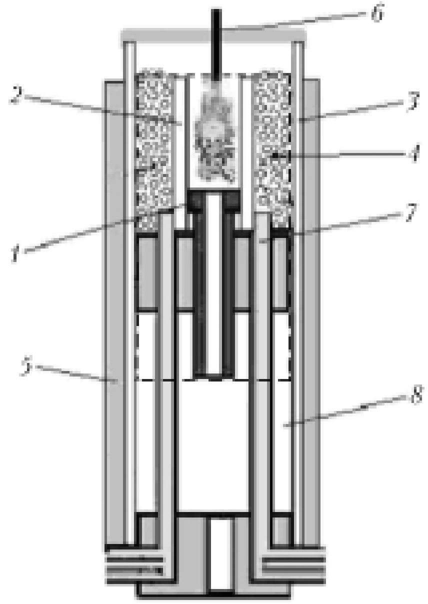


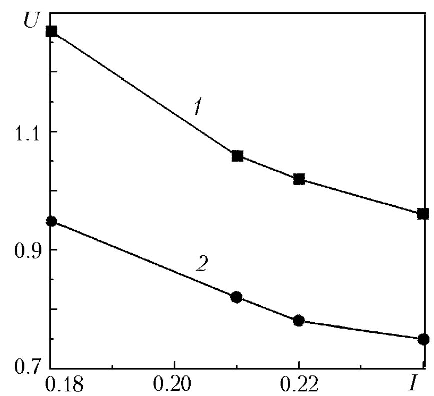




Fig. 1. Diagram of a modified reactor.

Fig. 2. Volt-ampere characteristics for discharges: 1) modified reactor; 2) initial reactor. $U$, kV; $I$, A.

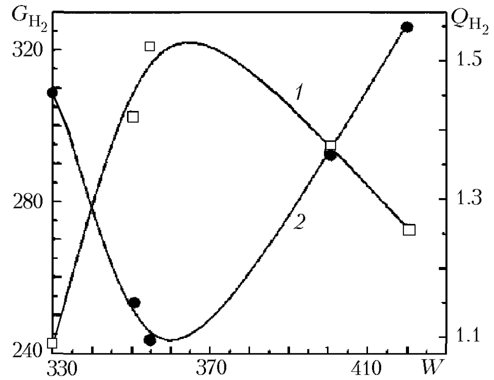
Despite the increase in the reactor volume, the specific output substantially increased with increase in the electrode spacing to $d$ = 15 mm and was equal to $K_r$ = 8.9 m$^3$/(h·liter). However, the minimum energy cost increased from $Q_{H_2} \sim$ 1.2 kW·h/m$^3$ for $d$ = 5 mm to $Q_{H_2} \sim$ 1.7 kW·h/m$^3$ for $d$ = 15 mm. Thus, the specific output and the energy cost of the hydrogen produced grew with electrode spacing. This was due to the competition of the processes of increase in the output $G_{H_2}$ with increase in the volume of the mixture treated and growth in the radiation loss; therefore, we modified the structure of the previous reactor to decrease this loss.

Figure 2 gives the volt-ampere characteristics of the discharge in reactors of the initial and modified structures for an electrode spacing $d$ = 15 mm (working gas air, flow rate 500 liters/h). It is seen that the curve for the discharge with a ceramic fill lies substantially higher, since a higher voltage is required to maintain the plasma in the reactor with a fill at the same current; the reason is that heat transfer from the discharge to the gas is higher and more power must be put into the discharge [5].

In the modified reactor, we were able to realize a discharge with substantially higher flow rates of the ethanol–air mixture than those in the reactor of the previous structure. This enabled us to increase the hydrogen yield. Thus, for $d$ = 15 mm the hydrogen yield was $G_{H_2}$ = 320 liters/h with its energy cost $Q_{H_2}$ = 1.1 kW·h/m$^3$ and specific output $K_r$ = 9.88 m$^3$/(h·liter).

Further investigations of the conversion of an ethanol–air mixture showed that the general physical principles of the process of conversion remained the same. It was established that the optimum values of the energy cost of hydrogen are realized near the lower bound of stable burning of the discharge. Figure 3 plots the yield of hydrogen and its energy cost as functions of the power out into the discharge. It is seen that as the power input increases to 360 W, the hydrogen yield grows, which is followed by a drop. The optimum values of the energy cost of the hydrogen produced are realized for a power input of 350 to 380 W. Unlike a reactor of the previous type [5], the limiting values of the hydrogen yield and the optimum values of the energy cost in this reactor are realized in a close power range.

Figure 4 shows the change in the specific output and the energy cost of hydrogen for different electrode spacings. It is seen that the highest value of the hydrogen yield in the reactor with recuperation was attained for the electrode spacing $d$ = 30 mm at $K_r$ = 10.1 m$^3$/(h·liter) and was $G_{H_2}$ = 450 liters/h for the energy cost $Q_{H_2}$ = 1.36 kW·h/m$^3$. From the viewpoint of optimization of the energy parameters, the regimes implemented for electrode spacings of 15 to 30 mm are the most acceptable for reactor operation, since the energy cost of hydrogen changes in these regimes only slightly with increase in the specific output.



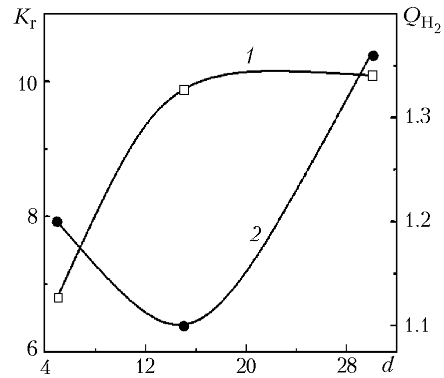




Fig. 3. Volume yield of hydrogen (1) and its energy cost (2) vs. discharge power for a modified reactor. $G_{H_2}$, liters/h; $Q_{H_2}$, kW·h/m$^3$; $W$, W.

Fig. 4. Values of the specific output of the reactor (1) and the energy cost of hydrogen (2) at different electrode spacings. $K_r$, m$^3$/(h·liter); $G_{H_2}$, liters/h; $d$, mm.

Thus, during the investigations of the process of conversion of ethanol in the plasma of a high-voltage atmospheric-pressure discharge in the reactor with a recuperation system, we have obtained the following optimum values: maximum hydrogen output $G_{H_2}$ to 450 liters/h, minimum energy cost of production of hydrogen $Q_{H_2} \approx 1.1$ kW·h/m$^3$, and specific output $K_r = 10.1$ m$^3$/(h·liter). The results of this work can be used in creating compact, low-inertia plasmachemical reactors of conversion of hydrocarbons.

## NOTATION

$d$, electrode spacing, mm; $G_{H_2}$, hydrogen output, liters/h; $I$, current strength, A; $K_r$, specific output of the reactor, m$^3$/(h·liter); $Q_{H_2}$, specific energy consumption to produce hydrogen, kW·h/m$^3$; $U$, voltage, kV; $V$, volume of the reactor core, liters; $W$, power, W; $\gamma$, equivalence factor. Subscript: r, reactor.

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