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# PREDICTION OF THE PLASMA REACTOR EFFICIENCY[1]

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A method of predicting the efficiency of a d.c. arc plasmatron, generating an argon plasma stream, was elaborated. Together with the model of heat exchange in the reaction chamber and the course of chemical reaction, it is possible to predict the reactor thermal efficiency as well as the substrate degree and unit energy consumption.

## О ПРОГНОЗИРОВАНИИ ТЕРМИЧЕСКОГО КПД ДЛЯ ПЛАЗМОХИМИЧЕСКОГО РЕАКТОРА

В работе предложен метод определения КПД плазмотрона постоянного тока, работающего на аргоне. Наряду с моделью теплообмена и протекания химической реакции в реакторе оказалось возможным определить термический КПД реактора, степень превращения метана в ацетилен и величину удельного потребления энергии.

## I. INTRODUCTION

Three steps can be distinguished in the process of the acetylene preparation from methane: generation of a plasma stream; mixing of the substrate (methane) with the plasma stream and the course of the chemical reaction of a simultaneous energy exchange through the reaction chamber walls; rapid cooling (freezing) of the reaction products. The chemical process in the reaction chamber is affected decisevely by the energy of the plasma stream and the amount of gas introduced into the plasmatron [1—3].

The energy of the plasma stream is directly connected with the discharge power and the thermal efficiency of the plasmatron. This indicates that prediction of the thermal efficiency of the plasmatron by a tentative modelling of the chemical process is necessary.

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## II. METHODS AND RESULTS

It was assumed that in the plasmatron, similarly as in the arc discharge, under static conditions the amount of energy evolved on the electrodes depended on the discharge current intensity.

For static conditions the energy evolved on the anode $E_A$ is equal to [4]:

$$E_A = I\left(V_A + \varphi_e + \frac{2kT}{e}\right) \quad (1)$$

where $I$ is the discharge current intensity, $V_A$ the anodic voltage drop, $\varphi_e$ the surface potential barrier.

In the plasmatron PL-100 the nozzle-anode is intensively cooled with water. The formula can be assumed to be represented in the form

$$E_A = aI. \quad (2)$$

The energy losses of the plasmatron cathode are considerably lower than those for the anode. Experimental results indicate the relation to exist in the form

$$E_{kt} = b \ln I. \quad (3)$$

For the plasmatron PL-100, in which an argon plasma stream is generated, the following regression equation describing the heat losses has been obtained on the basis of experimental data:

$$E_s = 0.0103\,I + 0.4386 \ln I - 1.61. \quad (4)$$

The equation is valid for the discharge current 100—500 A, the argon consumption 1.5—5 $m^3/h$, the nozzle diameter 3—10 mm. A correlation between the current intensity and the potential difference of the electrodes $U$, the nozzle diameter $d$, and the argon consumption $G$ was determined in the form of the so-called generalized characteristics [5]

$$\lg\frac{Ud}{I} = \lg b - \beta \lg\frac{I^2}{Gd} \quad (5)$$

where $b$, $\beta$ are the empirical coefficients.

After transformation of equation (5) and submitting the coefficient values ($\lg = 0.292$, $\beta = 0.492$) found experimentally we obtain

$$I = \left(\frac{E_a d^{0.508}}{G^{0.492}}\right)^{0.985} \quad (6)$$

where $E_a$ is the energy of the arc discharge in the plasmatron.



Equations (6) and (4) make it possible to evaluate the thermal efficiency of the plasmatron

$$\eta = 1 - \frac{E_s}{E_a},$$

the energy of a plasma stream

$$E_{pl} = E_a - E_s.$$

In Fig. 1 the calculated values of the thermal efficiency of the plasmatron PL-100 are presented. The calculated relations between arc voltage and power are given in Fig. 2. The possibility of the prediction of plasmatron efficiency and plasma energy

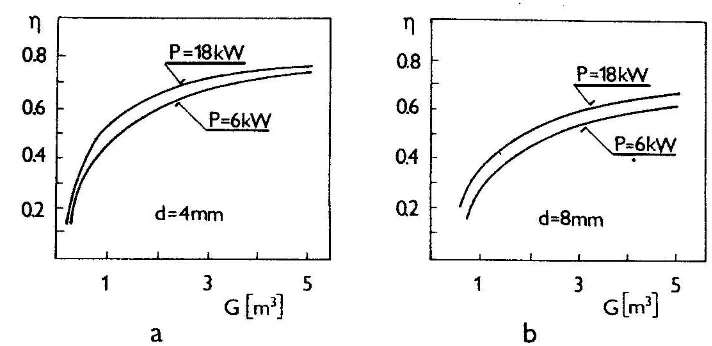


Fig. 1. Effect of the argon flow and the discharge power on the thermal efficiency of the plasmatron. a) diameter of the nozzle-anode — 4 mm; b) diameter of the nozzle anode — 8 mm.

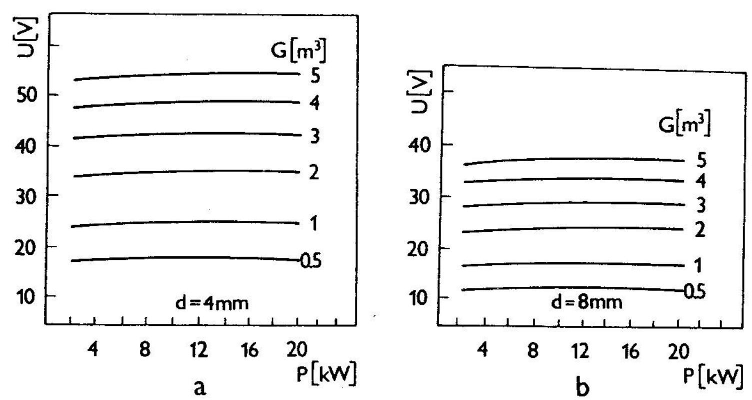


Fig. 2. Effect of the power and the argon flow on the voltage. a) diameter of the nozzle-anode — 4 mm; b) diameter of the nozzle-anode — 8 mm.

Table 1

Comparison of predicted values with those obtained experimentally

| Parameter | exp | calcul. | exp | calcul. | exp | calcul. | exp | calcul. | exp. | calcul. |
|---|---|---|---|---|---|---|---|---|---|---|
| $E_{pl}$ [MJ] | 24.23 | 23.56 | 24.16 | 23.14 | 24.19 | 23.26 | 24.19 | 23.11 | 23.98 | 23.00 |
| $\eta$ | 0.63 | 0.60 | 0.63 | 0.60 | 0.64 | 0.60 | 0.63 | 0.60 | 0.63 | 0.60 |
| $\eta_r$ | 0.41 | 0.44 | 0.41 | 0.44 | 0.43 | 0.44 | 0.42 | 0.44 | 0.41 | 0.43 |
| $T_{in}$ [K] | 4500 | 4400 | 4650 | 4550 | 4500 | 4400 | 4650 | 4550 | 4650 | 4550 |
| $T_{out}$ [K] | 2000 | 1950 | 2100 | 2100 | 2000 | 1950 | 2000 | 2100 | 2100 | 2100 |
| $u$ | 0.75 | 0.73 | 0.71 | 0.81 | 0.66 | 0.87 | 0.74 | 0.79 | 0.80 | 0.80 |
| $Z$ [MJ/m$^3$] | 108.1 | 111.2 | 120.3 | 105.7 | 122.5 | 92.4 | 117.4 | 110.0 | 107.2 | 107.7 |

úxp — experimental value
calcul. — calculated value



makes it possible, taking into consideration the heat exchange in the reaction chamber, to calculate the thermal efficiency of a chemical plasma reactor, the methane conversion degree, and the unit energy consumption.

For the synthesis of acetylene from methane [6] the calculation involved, solving of the equation system (7—13),

$$E_{pl} = G\int_{T_0}^{T_{in}} c_{pAr}\,dT + M\int_{T_0}^{T_{in}} c_{pCH_4}\,dT \tag{7}$$

$$E_{pl} - E_r = 0.5\,Mu\int_{T_0}^{T_{out}} c_{pC_2H_2}\,dT + 1.5\,Mu\int_{T_0}^{T_{out}} c_{pH_2}\,dT + \\ +(1-u)M\int_{T_0}^{T_{out}} c_{pCH_4}\,dT + G\int_{T_0}^{T_{out}} c_{pAr}\,dT + 0.5\,Mu\,\Delta H_0 \tag{8}$$

$$u = \frac{\sqrt{x^2 + 4(1+0.75\sqrt{3/K_p})\,(1+x)} - x}{2(1+0.75\sqrt{3/K_p})}, \tag{9}$$

$$\ln K_p = -\frac{\Delta G}{RT_{out}} \tag{10}$$

$$E_r = (T_{in} + T_{out})0.5\,a + b \tag{11}$$

$$\eta_{rch} = 1 - \frac{E_r}{E_{pl}} \tag{12}$$

$$Z = \frac{E_a}{0.5\,M_u} \tag{13}$$

where $T_0$ is the reference temperature, $T_{in}$, $T_{out}$ the gas temperature at the reaction chamber inlet and outlet, $c_p$ the specific heat reaction chamber, $u$ the methane-to-acetylene conversion degree, $M$ the methane flow rate, $\eta_{rch}$ the thermal efficiency of the chemical chamber, $Z$ the unit energy consumption, $x = G/M$, and $\Delta H_0$ the heat effect of the reaction $CH_4 \rightarrow 0.5\,C_2H_2 + 1.5\,H_2$. In Table 1 a comparison of the predicted and experimental values [1] is given.

## III. DISCUSSION

In the method of prediction of the plasmatron thermal efficiency and current-voltage characteristics presented above, the effect of pressure in the interelectrode area as well as of the electrode material were not taken into account. In the experiments performed the pressure in the interelectrode area did not exceed 2500 hPa; copper-made anodes were used. For 130 experimental results the linear correlation coefficients equal to 0.877 were obtained between the experimental and the calculated values of the plasmatron thermal efficiency.

It seems that also the results given in Table 1 indicate a significant correlation between the experimental and the calculated values.


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