Heat Balance in the Positive Column of a Glow Discharge

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Abstract. According to classical concepts, a cylindrical positive column (PC) of the glow discharge (GD) is a luminous volume of ionized gas that fills up the whole space in the discharge chamber (DC) and which parameters are indiscrete, i.e. they do not vary along the axis of the chamber. In this case, the heat balance of the PC is that the electric power released in the discharge is expended on the heat flux to the wall of the discharge chamber (DC) due to heat transfer; also, a certain fraction of energy is carried away due to heat transfer by radiation. In case of an open system when gas flows through the area of the PC, it is possible to change the discharge parameters along its axis, and it is necessary to take into account heat transfer by convection in the energy balance. It is important to have knowledge of heat balance and its components both for gas discharge physics and for any DC designed for various applications. This paper is devoted to a comprehensive experimental study of the distribution of potential, electric field intensity, and gas temperature in the longitudinal GD. The gas pressure P, its flow rate G, the discharge current I and its voltage U varied accordingly in the following ranges: P = (2–9) kPa, G = (0–0.05) g/s, I = (30–80) mA, U = (1–2) kV. The obtained distribution of potential, electric field intensity, and gas temperature make it possible to calculate all the heat fluxes in the plasma of the discharge PC.

1. Introduction

The non-equilibrium nature of GD when the electron temperature is much higher than that of the neutral component makes this type of discharge attractive for use in a variety of technologies to produce new types of materials, apply coatings by cathode sputtering, to generate ozone that can be used to sterilize medical products, etc.[1-6]. Another feature of GD is a significant cathode potential drop that ensures knockout of electrons from the cathode due to the kinetic energy of incident ions. This allows to make devices with a cold cathode and to create uniformly luminous surfaces of the required configuration. A new round of interest in GD has emerged with the development of gas lasers where it is used as an active medium. To use effectively all the advantages of GD, it is necessary to understand the regularities associated with GD in the gas flow, in DCs with different geometries. Analytical formulas based on the equations of charge continuity and Ohm's law in integral form, the energy equation was obtained in [7-10]. The temperature fields of neutral particles, the heat balance were calculated in [11-17]. Experimental studies of the gas temperature were carried out in [18-22]. The objective of this work is to further study the heat balance in the PC of GD.
2. Experiment
The scheme of the experimental situation is shown in Fig. 1.

Copper electrodes located at a distance of \( l = (0.08 - 0.1) \text{ m} \), are located in the side branches of the glass tube with a diameter of 0.01 m. The thermocouples are arranged in such a way that from the measured values of the gas temperature it is possible to calculate the heat flux to the wall due to thermal conductivity, as well as convective energy transfer from the region of the PC of the discharge. The arrows show the direction of the gas flow. Also, to study the distribution of the potential, the electric field strength along the discharge chamber, probes were inserted into the guiding capillaries instead of thermocouples 2, 4 and 6. Cylindrical probes made of platinum with a diameter of 0.1 mm and working lengths of 2 mm were used. The non-working part of the probes was isolated by a quartz capillary with a diameter of 0.2 mm. To measure the potential, static voltmeters of the C50 type of accuracy class 1.0 with measurement limits of 300, 1000, 1500 and 3000 V were used. All measurements of the potential of the electric field were made with respect to the grounded anode. The procedure for measuring gas temperatures by chromel-alumel thermocouples and other discharge parameters is described in [19].

3. Results
Fig. 2 shows the distribution of the potential \( \varphi \) along the axis of the discharge chamber in the air flow. In these graphs, the origin of coordinates \( Z = 0 \) corresponds to the right edge of the cathode, whose potential is assumed to be zero.
Figure 2. The potential distribution in the glow discharge: P = 4.6 kPa, 1- I = 50 mA, 2- I = 30 mA, 3- I = 20 mA, to the left- G = 0, to the right- G = 0.04 g / s.

The magnitude of the potential from the cathode to the anode increases approximately linearly and therefore the average electric field strength remains almost constant. With increasing current, the magnitude of the potential decreases, this corresponds to the dropping current-voltage characteristic of the discharge. For a more accurate verification of the variation or constancy of the electric field strength along the DC axis, it is necessary to place more probes along the axis or use a mobile probe, which introduces additional errors. The average electric field strength was calculated from the gradient of the potential. Dependences of the electric field strength on the discharge current are shown in Fig. 3 (left).

Figure 3. Dependences of the electric field strength E and power density N on the discharge current I: 1,2,3 - P = 4.7 kPa, 4 - P = 6.1 kPa; 1, 4-G = 0.04 g / s; 2-G = 0; 3- G = 0.05 g / s; 1,2-air; 3-argon; 4-helium.
As can be seen, the electric field strength decreases with increasing current. Under identical discharge conditions, the electric field strength in the air is greater than that in argon and helium. From a comparison of curves 1 and 2, it can be seen that the air flow rate leads to an increase in the electric field strength. For calculating the heat balance of the PC, it is necessary to know the value of the power density, which is dependent on the discharge current, as is shown in Fig.3 (right). With equal flow rates and currents, the discharge power density for air is approximately twice as large as for helium. This is due to the large value of the electric field strength in the molecular gas. The results of measurements of the gas temperature are shown in Fig.4.

![Figure4](image)

Figure4. Dependences of temperatures 2 and 3 on discharge current, G = 0.007 g / s; •, x - P = 2.5kPa; e, + - P = 3.9 kPa; Δ, □ -P = 5.5 kPa.

The gas temperature decreases along the radius of the DC and increases in the direction of gas flow. The temperature at the axis of the DC increases with increasing current, discharge power and gas pressure. The effect of air consumption on the temperature distribution and the shape of the positive column of the discharge are also revealed.

4. Conclusions
This paper presents the results of the comprehensive experimental research on energy properties of a longitudinal GD. The gas potential and temperature distributions in the longitudinal and transverse directions are obtained. The dependencies of the electrical field strength and power density on the discharge current for air, argon and helium are obtained. The obtained distributions and dependencies allow you to calculate the heat balance in the PC of GD.

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