Heat and mass transfer in confined jet plasma reactor with peripheral vortex flow

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Abstract. A fundamentally new solution for the creation of a peripheral vortex flow is proposed: by the means of rotation of a rotor placed in a reactor. Experimental studies have been performed based on which the distributions of the heat fluxes to the wall of the plasma reactor were obtained by creating a vortex flow by a rotating rotor. It is established that the presence of a vortex flow leads to a significant change in the distribution of heat and mass flow to the reactor wall. The presence of a vortex flow leads to a change in the distribution of the isotherms in the mixing zone of the high-temperature paraxial flow with the gaseous medium of the reactor.

1. Introduction
Complex non-isothermal flows in channels in which a high-temperature paraxial jet and a peripheral vortex flow of cold gas are present are widely used for high-temperature flow zone stabilization, for reducing scattering intensity due to the decrease in the turbulent velocity pulsations (laminarization of the flow) and, accordingly, increasing presence time of reagents in this zone [1-8].

Usually peripheral vortex flow created by the injection of an additional amount of gas, the mass flow of which can significantly exceed the flow rate of the axial flow, what can create certain difficulties caused by a decrease in the final concentration of the target components in real plasma technological processes, resource costs for additional gas and instrumentation of the process.

A fundamentally new solution of creating a peripheral vortex flow by using the rotation of a rotor located in a reactor outside the high-temperature zone is proposed [9].

2. Experimental
Experimental studies were carried out on a plasma reactor with a total length of 1200 mm, a diameter of 200 mm, and with a rotating rotor located outside the high-temperature zone of the reactor. Part of the reactor is sectioned (figure 1), which allows temperature measurements at various points along the length of the reactor and an estimation of the density of heat and mass flows to the reactor wall, based on the amount of heat of the transferred to cooling liquid and powder disposed for each individual section.
As the source of plasma, an electric arc plasma torch with a power of 25 kW was used.
Experimental studies were carried out with a change in the operating parameters of the reactor in the following ranges:
— Plasma-forming gas — nitrogen, nitrogen-argon (17% vol. Ar) mixture;
— plasma-forming gas flow rate — 1.3-2.2 Nm$^3$/h (normal conditions);
— Plasma torch power — 10–20 kW;
— Plasma jet enthalpy — 1.7–8.5 kW/Nm$^3$ (normal condition);
— Precursor — WO$_3$ (<40 μm);
— Consumption of disperse raw materials — 3.0 g/min;
— Transporting gas — nitrogen;
— Transporting gas flow rate — 0.4 Nm$^3$/h
— Rotor speed — 0, 1000, 2000, 3000 rpm.

3. Results and Discussion
It is established that the presence of a vortex flow created by a rotating rotor leads to a significant change in the distribution of the heat flux to the reactor wall (figure 2).
In the absence of rotation of the rotor, the distribution of the heat flux to the reactor wall have is extreme with a maximum at a distance of 0.3 m from the reactor inlet. When the rotor rotates at a speed of 1000 rpm, a bimodal distribution with maxima in the vicinity of the regions located at a distance of 0.2 and 0.75 m from the entrance to the reactor is established for enthalpy values of 7.6-8.1 kWh/m$^3$.

![Figure 2](image)

**Figure 2.** Change in the distribution of the density of heat flow to the reactor wall when the rotor speed is changed from 0 rpm to 3000 rpm. The enthalpy of the plasma jet is 7.6-8.1 kWh/m$^3$.

When the rotor speed is increased to 2000 rpm and higher, the maximum of the heat flow is located at a distance of more than 1 m from the entrance to the reactor, and its value is practically independent of the speed of rotation of the rotor. It follows from the obtained results that the vortex flow created by the rotating rotor blocks the heat transfer to the reactor wall in the initial part, ensuring stabilization of the high-temperature axial flow.

As a result of the experiments carried out, it was also found that with increasing speed of rotation of the rotor creating counterpropagating vortex flow, the maximum distribution of the mass flows of the powder deposited on the reactor walls, as well as the maximum thermal flux density, shifts from the middle region of the reactor to its final part, where the rotor is located (figure 3).

The obtained data on the values of the measured temperatures are given without radiation corrections and are used only for qualitative estimates of the change in mixing zones.

It has been experimentally established that a vortex flow created by a rotating rotor leads to a change in the location of the isotherms in the mixing zone of the high-temperature axial flow with the gas medium of the reactor (figure 4). With increasing rotation speed of the rotor, the size of the "cold" zones increase, which indicates the inhibition of the scattering of the high-temperature flow in the reactor volume. This pattern is typical for the enthalpy values of the flow as 1.9 kWh/m$^3$, and 8 kWh/m$^3$. 
Figure 3. The distribution of the density of the mass flux of particles on the reactor wall at different rotor speeds.

Figure 4. Isoterm distribution in the reactor volume change for different rotation speeds of the rotor: to the left - 0 rpm, to the right - 3000 rpm.
4. Conclusions
It has been experimentally confirmed that the vortex flow created by the rotating rotor ensures the stabilization of the high-speed jet at the high-speed jet, while the deceleration of the jet dispersion is determined by the speed of rotation of the rotor. The presence of a vortex flow created by a rotating rotor inhibits radial mixing of the gas, which leads to the appearance of a temperature gradient along the radius and an increase in the gas temperature in the vicinity of the reactor axis.

The rotational vortex gas flow radically changes the distribution of heat flow density to the reactor wall. In the absence of rotation of the rotor, the distribution of the density of the heat flux is extreme, with a maximum in the initial zone of the reactor at a distance of about 0.15–0.3 m from the inlet. In the presence of rotation of the rotor (at a speed of more than 2000 rpm), the maximum heat flux density is removed from the reactor inlet, but further increase in the rotational speed to 3000 rpm practically does not affect the heat transfer characteristics on the reactor wall, while the maximum thermal flow is characteristic of the outlet zone of the reactor.

The dependence of the density distribution of the mass flow of particles on the reactor wall along its length in the absence of rotation of the rotor is extreme and the maximum flux density is located at a distance of about 0.35 m from the entrance to the reactor. When the rotor speed is increased to 2000–3000 rpm, the dependence character changes and the maximum density of the mass flow is shifted to the reactor end.

The results of the experiments indicate that the creation of a vortex flow by a rotating rotor significantly changes the heat transfer characteristics in the reactor, allowing the length of the high temperature zone along the length of the reactor to be increased.

Acknowledgment
The work was carried out with the support of the Russian Foundation for Basic Research (Grant No. 16-08-00491) and within the state task No. 007-00129-18-00

5. References
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