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Investigation of the influence of the dependence of the gas heating on the geometric parameters of the heating element of the cold spraying technology

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Currently, in mechanical engineering, in order to increase the service life of products, increased requirements are imposed on the materials used for the manufacture of parts and structures [1, 2, 3]. One of the promising directions is to improve the characteristics of materials by applying functional coatings, including increasing the corrosion resistance of the material, wear resistance and protection from mechanical damage, as well as providing the possibility of local repair of products without dismantling the structure [4]. At the same time, preference is given to technologies that do not have a negative impact on the applied surface. The technology of cold spraying (CS) is the most dynamically developing method for applying protective coatings and imparting various functional properties to materials [5, 6].

In the work of Wenya Li [7], an experiment was carried out and a 2D model of the entire process of cold spraying technology was constructed, however, numerical modeling of the gas heating element was not performed. Nitrogen is most often used as a working gas. Numerical simulation of the gas heating process will allow you to set the optimal parameters of the heated element to reduce the gas heating time, and, accordingly, optimize the process in the complex.

Nitrogen is an inert diatomic gas without color and odor, the chemical formula of the diatomic molecule N_2, molar mass 28.01 kg/kmol, the most common element on Earth. The nitrogen content in the atmospheric air is about 78.09% by volume. It is used in technological processes as an inert sealing medium, for example, for dry gas mechanical seals and sealing complexes, in the chemical industry for the synthesis of ammonia. Liquid nitrogen is used as a refrigerant in mechanical engineering for the assembly of non-removable tight joints (cooling of the covered part). Nitrogen is used in special technological processes for applying a thin layer of wear-resistant coating – titanium nitride on the surface of steel parts; in combination with silicon, it forms a wear-resistant promising ceramic material, silicon nitride Si_3N_4 [8].

The working gas is nitrogen (N_2), which is supplied to the tube at room temperature, 293–298 K (20–25 °C), and a pressure of 2 to 10 MPa. The tube walls are maintained at a constant temperature of 1273 K (1000 °C). The inner diameter of the tube is fixed and is 0.008 m, and the wall thickness is 0.002 m. The diameter, number of coils, and length of the tube are parameters that need to be determined for efficient gas heating.

This task was considered in the software product "Thermoviscous fluids: a hydrodynamic simulator for modeling flow in annular channels with heat exchange" [9].

The flow of incompressible nitrogen in a flat channel was considered. The channel diameter was fixed, and the channel length varied from 1 m to 50 m. The modeling environment used was the own software product "Thermoviscous fluids: a hydrodynamic simulator for modeling flow in annular channels with heat exchange", which was adapted to solve this problem. Data: the inner diameter of the tube — 0.008 m; the length of the tube — from 1 m to 50 m; the pressure drop — 1 Pa; the initial temperature of the gas — 293 K; the temperature of the tube walls — 1273 K.

To solve the problem of the incompressible flow of nitrogen in a flat channel, the control volume method was chosen. This approach allows solving the Navier-Stokes equations with high accuracy, which is critical for obtaining reliable results.

The geometric dimensions of the tube, the properties of nitrogen, the boundary conditions for velocity and pressure at the inlet and outlet of the tube, and the temperature at the tube walls were used as input data for modeling.

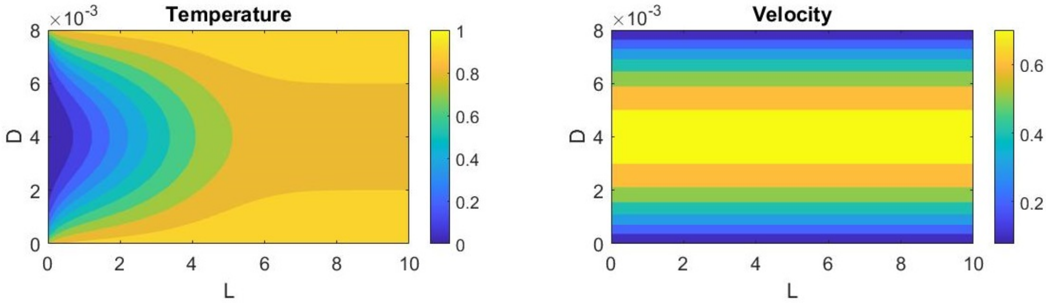

Figure 1: Distribution of temperature and velocity in the computational domain at $\mathrm{d}p = 104$ Pa

Based on the calculations, the results for the distribution of velocity, pressure, and temperature along the length of the tube were obtained.

The study results showed Fig. 1 that as the channel length increases to 10 meters and the pressure drop to 104 Pa (equivalent to 0.1 atm), the nitrogen is heated closer to the middle of the channel. The maximum nitrogen velocity in the channel is 0.7 m/s.

The graph shows the distribution of temperature and velocity along the length of the channel in a dimensionless form. From the obtained results, it follows that the distribution of the nitrogen velocity along the length of the channel has a parabolic shape. The maximum velocity is reached in the middle of the channel and decreases to zero at the tube walls.

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