2. P. Shneider, Engineering Problems of Heat Conduction [Russian translation], IL, Moscow (1960).
3. G. Z. Gershuni and E. M. Zhukhovitskii, Convective Stability of Incompressible Fluids, Halsted Press (1976).
4. S. S. Kutateladze and V. M. Borishanskii, Handbook of Heat Transfer [in Russian], Énergiya, Moscow (1959).
5. V. P. Isachenko, V. A. Osipova, and A. S. Sukomel, Heat Transfer [in Russian], Énergiya, Moscow (1975).
6. O. G. Martynenko and Yu. A. Sokovishin, Free-Convective Heat Transfer [in Russian], Nauka i Tekhnika, Minsk (1982).

EXPERIMENTAL STUDY OF THE PROCESS OF THE FILLING OF A CONTAINER WITH COMPRESSED AIR

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Certain laws governing the process of the filling of a container with compressed air are determined experimentally.

In engineering practice it is sometimes necessary to fill containers with compressed air. This is usually done from stationary high-pressure accumulators or by means of a compressor. Complex gasdynamic and thermal processes take place in the container being filled, and these processes are accompanied by an increase in the temperature of the gas. The amount of this heating depends on the heat exchange between the gas and the wall of the container, as well as on many other factors.

As the test container 3 (Fig. 1) we used a standard cylinder having a length of 1.33 m. The outside diameter of the cylindrical part was 0.226 m, while the wall thickness was 0.008 m. The cylinder was made of steel 5. The working gas was air, which was admitted through a headpiece 4 from an air ramp under a constant pressure of 8-15 MPa. The axis of the headpiece coincided with the axis of the cylinder. We used two types of headpieces. The first took the form of sonic nozzles with a minimum diameter d_0 equal to 2, 3, and 5 mm. The gas passed through these nozzles into the container in the form of an axisymmetric jet. The second type was also a sonic nozzle, but here a flat, circular screen was positioned normally with respect to its axis. The flow was deflected in its interaction with the screen and flowed into the container in the form of a V-shaped stream. The test unit permitted the container to be oriented different ways: horizontally, vertically, etc.

We measured the following parameters during the tests: the temperature of the gas and the temperature of the outer surface of the wall at different stations along the cylinder, the gas pressure in the container and the ramp, and the total pressure and temperature of the gas ahead of the headpiece. The temperature was measured with Chromel–Alumel thermocouples with wires 0.3 mm in diameter. Pressure in the container was measured with an MD 400T potentiometric transducer. The recording element in the measurement system was an N-700 light-ray oscillograph equipped with M001-1 galvanometers. The transducers for measuring gas temperature and pressure in the container were installed at three stations located distances from the headpiece edge x = 0.15, 0.65, and 1.15 m, respectively. The transducers for measuring the temperature of the outside surface was placed at six stations x = 0.11, 0.37, 0.49, 0.62, 0.84, and 1.18 m.

The experiment was conducted in the following sequence. After the recording equipment was turned on, we injected air into the container through electric valve 1. When the pressure in the container reached the pressure value in the ramp, the injection main was cut off by the same valve. The parameters of the gas in the container were subsequently measured

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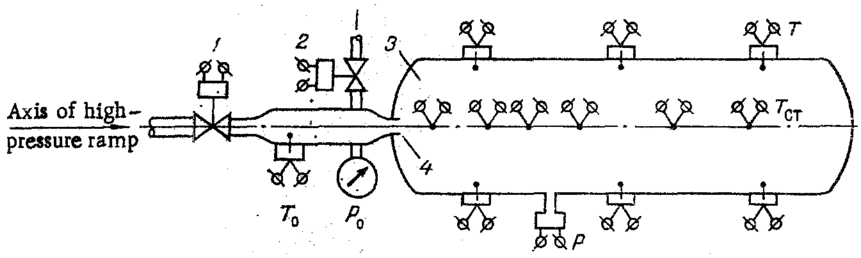

Fig. 1. Basic diagram of unit.

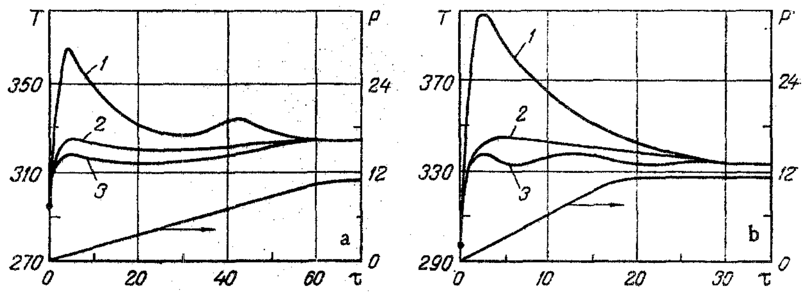

Fig. 2. Change in the parameters of the gas in the container during its filling: P_0 = 11 MPa; *a*) d_0 = 0.002 m; b) 0.005 m; 1) x = 1.15 m; 2) 0.65; 3) 0.15 T, K; P, MPa; τ, sec.

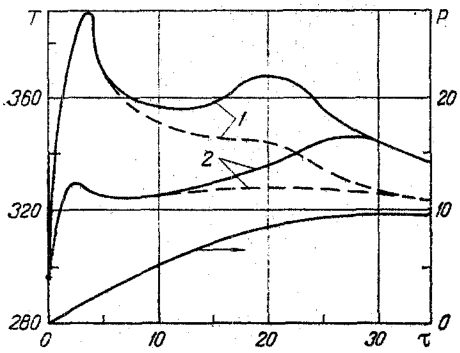

Fig. 3

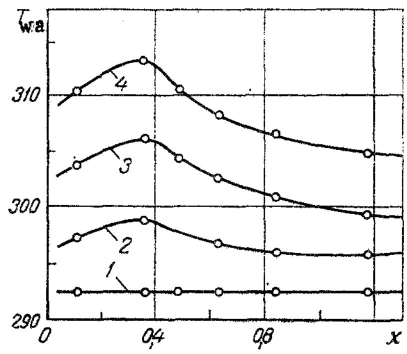

Fig. 4

Fig. 3. Change in gas parameters at different stations along the container: d_0 = 0.003 m; P_0 = 9.5 MPa.

Fig. 4. Change in the temperature of the outside surface of the wall along the container: d_0 = 0.003 m; P_0 = 13.4 MPa; 1) τ = 0; 2) 2-20 sec; 3) 40; 4) 60. T_{wa}, K; x, m.

over a period of 5-10 min. Pressure in the container was decreased by releasing air into the atmosphere through electric valve 2. The initial pressure in the container in all of the tests was equal to atmospheric pressure. The container was positioned horizontally in most of the tests.

The test showed that the container-filling process is accompanied by an increase in gas temperature and is characterized by significant nonuniformity of the temperature distribution along the container. This nonuniformity is particularly evident during the initial part of the filling period (Fig. 2). The maximum heating is seen at the rear end of the container, while the minimum heating is seen at the front end, where there is more intensive mixing of the incoming gas with the gas already in the container. It is also evident from the figure that the degree of nonuniformity depends on the dimensions of the headpiece through which the gas is admitted. With an increase in the diameter of the minimum cross section of the headpiece, higher values of gas temperature are seen at the rear end of the container. However, the temperature of the gas along the container equalizes by the end of the filling process. The installation of the deflecting screen ahead of the sonic nozzle reduces the intensity of mixing of the gas in the container and increases the degree of nonuniformity of the tempeature distribution along the container. In this case, as measurements showed, higher values of temperature are reached in the rear end of the container.

The character of the gas-temperature distribution in the different cross sections of the container can be judged from Fig. 3, which shows the change in gas temperature in the upper (solid line) and lower (dashed line) parts of the container at two stations: $x = 1.15$ m (curves 1) and $x = 0.65$ m (curves 2). It is apparent that the gas temperature at the different stations is roughly the same during the initial part of the filling, but then the gas temperature obtains a layered distribution: hot gas accumulates above, cold gas below. This change in the temperature field of the gas in the container over time is explained by the fact that during the initial filling period, with a supercritical regime of flow through the headpiece, flow in the container is characterized by high velocities and intensive mixing, which equalizes the temperature field. The velocity of the forced gas flow into the container subsequently drops, and natural convection begins to predominate.

Figure 4 shows the change in the temperature of the outer surface of the container wall at different moments of time. It is apparent that the wall-temperature distribution along the container is extremely nonuniform and has a characteristic maximum. The maximum heating of the wall occurs near the front end and is attributable to the higher gas velocities in this region and, thus, to higher values of heat flux to the wall. The increase in the temperature of the outside surface of the wall, as can be seen from Fig. 4, reaches 20°K. This heating will obviously be more significant for containers with a lesser relative wall thickness.

Similar tests were performed with the container positioned vertically. Comparison of these results with the test results for the horizontal container showed that during the initial filling period the gas-temperature field and wall-temperature distribution are roughly the same in both cases. However, due to different directions of free convection, the temperature fields for these cases are quite different by the end of the filling. The greatest layering of the gas with respect to its temperature is seen by the end of filling when the container is positioned vertically, particularly in the case where the gas is injected from below.

NOTATION

d_0, diameter of minimum cross section of the injection-nozzle headpiece; x, distance from headpiece end to site of installation of transducer; P, T, pressure and temperature of the gas in the container, respectively; P_0, T_0, total pressure and temperature of the gas at the headpiece inlet; T_{wa}, temperature of outside surface of container wall.