To select the composition of the protective atmosphere used for heating steel without decarburizing of the surface layer or with a limited degree of decarburizing permitted, it is necessary to determine the effect of the composition of the protective gas on the equilibrium concentration of carbon in the steel and also on parameters characterizing the impoverishment of the surface layer in carbon — the depth of decarburizing, the distribution of carbon concentrations through the depth of the layer, and the amount of carbon burned out of the steel.

It is known [1] that the concentration of water vapor in the protective atmosphere has the strongest effect on decarburizing of steels during heating. A method of calculating the variation of the carbon potential of the protective atmosphere with the concentration of water vapor in the atmosphere was given in [2]. This work* concerns the effect of the humidity of an exothermal protective atmosphere of the PSO-09 type on the change in the depth of decarburizing of carbon steel and the amount of carbon burned out of the steel during heating.

The experiments showed that the variation of the reduction in weight with time due to burnout of carbon during oxidation-free heating in a dry PSO-09 atmosphere (dew point 20°C) is quadratic in character for steels 45 and U10A. It was assumed on this basis that the limiting stage of decarburizing is the diffusion

* V. I. Moroz assisted in this work.

Fig. 1. Calculated depth of decarburizing in relation to humidity of the atmosphere: —— steel U8 at 900°C; —— steel 45 at 900°C; —— steel 45 at 800°C. The holding times are given on the curves.

Fig. 2. Depth of decarburizing of steel 45 in exothermal atmosphere at 900°C with holding for 1 h: 1) calculated data; 2) experimental data.
of carbon in the metal. In this case the distribution of the carbon concentration in the surface layer of the steels and the amount of carbon burned out of the steel can be determined from the solution of diffusion equations with use of the respective boundary conditions. The carbon concentration in the steel \( C(x, \tau) \) in relation to holding time \( \tau \) and distance from the surface of the metal changes as

\[
C(x, \tau) = C_{\text{sur}} + (C_0 - C_{\text{sur}}) \text{erfc} \left( \frac{x}{2\sqrt{D\tau}} \right),
\]

where \( C_0 \) is the original carbon concentration of the steel; \( C_{\text{sur}} \) is the equilibrium concentration of carbon at the surface of the sample, i.e., the carbon potential of the atmosphere; \( \text{erfc} \) \( z = 2/\pi \int_0^z e^{-t^2} dt \) is the integral of the errors; \( D \) is the diffusion coefficient of carbon in the steel.

The amount of carbon \( M \) burned out of the steel in time is equal to

\[
M = 2(C_0 - C_{\text{sur}}) \sqrt{\frac{2\tau}{\pi}}.
\]

Formulas (1) and (2) include \( C_{\text{sur}} \), which depends on the humidity of the protective atmosphere \( w \). This makes it possible to determine the variation of the depth of decarburizing \( L \) and the amount of carbon burned out of the steel \( M \) and \( w \). Since the depth of decarburizing is usually taken as the distance from the surface at which the carbon concentration is 90% of the original value, the value of \( L \) can be determined from the numerical solution of Eq. (1) with \( x = L \):

\[
0.9C_0 = C_{\text{sur}} + (C_0 - C_{\text{sur}}) \text{erfc} \left( \frac{L}{2\sqrt{D\tau}} \right).
\]

Equation (3) was solved for \( L \) with use of the M-220 computer for four steels with different amounts of carbon (0.45, 0.80, 1.0, and 1.2%) at 800, 900, and 1000°C and holding times of 1, 4, 16, and 20 h. In each of the 48 cases considered (the possible combinations of \( C_0, T, \tau \)) the value of \( L \) was calculated for 6-12 (depending on \( C_0 \)) values of humidity \( w \), which varied in a range corresponding to the carbon potential from \( C_0 \) to zero.

The value of \( C_{\text{sur}} \) at given values of temperature \( T \) and humidity \( w \) was determined by solving the system of five equations describing chemical equilibrium in the gas-metal system and arbitrary limits (constant mass and pressure) applied to this system [2]. The program for determining \( C_{\text{sur}} \) was introduced as a subprogram in the program for the computer. The composition of the protective atmosphere (at +20°C) in the calculations of \( C_{\text{sur}} \) was taken as follows: 3.5% CO, 0.05% CO₂, 2.75% H₂, 0.05% CH₄, 0.001-0.1% H₂O, the remainder nitrogen.

The diffusion coefficient of carbon in austenite was determined [3] as

\[
D = (0.04 + 0.08C_0) \exp \left( -\frac{Q}{RT} \right),
\]

where \( Q \) is the activation energy of diffusion; \( R \) is the gas constant.

Figure 1 shows the variation of the depth of decarburizing with the humidity of the atmosphere for different steels, temperatures, and holding times. The results obtained indicate that drying of the PSO-09 exothermic atmosphere down to the critical humidity \( w_{\text{cr}} \), depending on the steel and the temperature, has little effect on the depth of decarburizing. However, with reduction of the humidity below \( w_{\text{cr}} \) the depth of decarburizing varies sharply with the concentration of water vapor in the atmosphere; with a small reduction of the concentration of water vapor the depth of decarburizing decreases greatly and at a certain value of \( w_0 \) the depth of decarburizing is equal to zero. The values of \( w_0 \) for carbon steels are given in Table 1.

The variation of the amount of carbon burned out of the steel \( M \) with the humidity of the atmosphere \( w \) was also determined by introducing a subprogram in the computer. The value of \( M \) was calculated for the same values of \( C_0, T, \tau, \) and \( w \) used in calculating the depth of decarburizing.

The analysis of the effect of humidity on decarburizing of carbon steel indicates that the minimal humidity of 0.15-0.20% (dew point -15 to -20°C) ordinarily attained in commercial furnaces is insufficient to