METHOD OF TEMPERATURE CONVERSION FOR EQUILIBRIUM ISOTHERMS OF SPECIFIC MOISTURE CONTENT

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Temperature conversion of the specific moisture content at equilibrium at subzero temperatures is demonstrated, and a new method is proposed for temperature conversion of isotherms of that moisture content.

In connection with the intense development of northern regions of the country and the buildup of an infrastructure, as a consequence, there has arisen the need to determine the hygroscopic characteristics of various materials in the range of natural low temperatures, for the purpose of predicting their physicomechanical characteristics in service under severe climatic conditions of the Far North.

In the range of above-zero temperatures there are available experimental methods of determining the specific moisture content at equilibrium (tensometric, dynamic, vacuum-adsorption methods [1, 2]) as well as methods of converting an original isotherm to other temperatures [3, 4]. This is why extensive experimental data have been accumulated, and then extended [5, 6], pertaining to above-zero temperatures.

There are, however, no experimental methods now available for large-scale determinations of isotherms of the specific moisture content at equilibrium in the subzero temperature range. There are also no methods available for converting original isotherms to this temperature range. It must be pointed out, at the same time, that extrapolation of data given for above-zero temperatures into the subzero temperature range is incorrect, because upon transition to temperatures below the melting point of the adsorbate in the bulk phase there occurs a transition of the stable phase of the adsorbate from liquid to solid state while in both temperature ranges the adsorbate is adsorbed and accumulated in the liquid state. Accordingly, the conditions under which sorption processes occur are different in the two temperature ranges. In the case of water, for instance, at $T < T_0$ the pressure of saturated water vapor is well known to be much lower above ice than above supercooled liquid and, consequently, the sorption volume of this substance undersaturates, i.e., the amount of sorbed vapor decreases with decreasing temperature. This agrees with results of experimental studies [7-9].

Upon transition through temperature T_0, therefore, the temperature dependence of the isotherms changes its trend substantially: Instead of increasing W_e with decreasing temperature at $\varphi = \text{const}$, which is characteristic of the $T < T_0$ range, W_e decreases with decreasing temperature in the $T < T_0$ range at $\varphi = \text{const}$.

In this study there will be made an attempt to develop a method of temperature conversion for equilibrium isotherms of the specific moisture content, not only in the above-zero range but also in the subzero range.

As the basis for such a method will serve the well known Clapeyron–Clausius equation

$$\frac{d\ln p}{dT} = \frac{L}{RT^2}, \tag{1}$$

which, when integrated over the temperature range from T_1 to T_2 with $L = \text{const}$, yields

$$\ln p(T_2) - \ln p(T_1) = \frac{L}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right). \tag{2}$$

Equation (2) will be subsequently used for describing the temperature dependence of the saturated-vapor pressure above water, ice, and the adsorbate at $W_e = \text{const}$. The quantities

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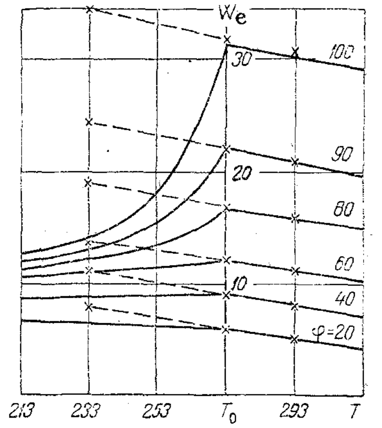

Fig. 1. Temperature dependence of specific moisture content at equilibrium in wood: solid lines represent our calculations; dash lines represent published data [5]. T (°K), W_e (%), φ (%).

L_s (heat of sublimation of ice), L_v (heat of evaporation of water), and Qa (differential heat of adsorption) are then assumed to be constant, with an error not exceeding 11% [10-12].

The relative humidity of air φ at temperatures $T \geq T_0$ is defined as the ratio of partial pressure to saturation pressure of water vapor above the water surface, and at temperatures $T \leq T_0$ it is defined as the ratio of partial pressure to saturation pressure of water vapor above the ice surface, the latter being the stable phase in the subzero temperature range.

As input data for solving this problem one needs the $W_e = f(\varphi)_{T_1 \geq T_2}$ isotherm and the differential heat of adsorption $Q_a(W_e)$. The isotherm can then be converted according to the following procedure.

a) $T \geq T_0$: We write Eq. (2) for the adsorbate and for water

$$\begin{aligned} \ln p_a(T_1) - \ln p_a(T) &= \frac{Q_a}{R}\left(\frac{1}{T} - \frac{1}{T_1}\right), \\ -\ln p_w(T_1) + \ln p_w(T) &= -\frac{L_v}{R}\left(\frac{1}{T} - \frac{1}{T_1}\right). \end{aligned} \tag{3}$$

Adding the left-hand sides and the right-hand sides, respectively, we obtain

$$\ln\frac{p_a(T_1)}{p_w(T_1)} - \ln\frac{p_a(T)}{p_w(T)} = \frac{Q_a - L_v}{R}\left(\frac{1}{T} - \frac{1}{T_1}\right) \tag{4}$$

or

$$\ln\left(\frac{\varphi_1}{\varphi}\right)_{W_e} = \frac{q_a}{R}\,\frac{T_1 - T}{T_1 T}. \tag{5}$$

With the aid of Eq. (5) it is now possible to convert $\varphi(T_1)$ to $\varphi(T)$ at W_e = const and thus calculate the $W_e = f_1(\varphi)\,T$ isotherm.

b) $T \leq T_0$: We write Eq. (2) for the adsorbate, water, and ice as

$$\begin{aligned} \ln p_a(T_1) - \ln p_a(T) &= \frac{Q_a}{R}\left(\frac{1}{T} - \frac{1}{T_1}\right), \\ \ln p_w(T_0) - \ln p_w(T_1) &= \frac{L_v}{R}\left(\frac{1}{T_1} - \frac{1}{T_0}\right), \\ \ln p_i(T) - \ln p_i(T_0) &= \frac{L_s}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right). \end{aligned} \tag{6}$$

Adding the left-hand sides and the right-hand sides of these equations, respectively, considering also that $p_w(T_0) = p_i(T_0)$, we obtain

$$\ln\varphi_1 - \ln\varphi = \frac{Q_a(T_1 - T)}{RT_1T} + \frac{L_v(T_0 - T_1)}{RT_1T_0} + \frac{L_s(T - T_0)}{RT_0T} \tag{7}$$

or
$$\ln\left(\frac{\varphi_1}{\varphi}\right)_{W_e}=\frac{q_a(T_1-T)}{RT_1T}-\frac{L_f\,(T_0-T)}{RT_0T}. \tag{8}$$

Equation (8) provides the means for solving the problem.

Usually the latent heat of adsorption is unknown. With data on two original isotherms available, however, one can convert these isotherms without knowing the heat of adsorption.

Let us assume that the original isotherms have been determined at temperatures T_1, $T_2 > T_0$. Then, upon insertion of the data from these isotherms into Eq. (5), one can obtain q_a explicitly as

$$q_a=\frac{RT_1T_2}{T_1-T_2}\ln\left(\frac{\varphi_1}{\varphi_2}\right)_{W_e}. \tag{9}$$

Now inserting the value (9) into Eqs. (5) and (8), for conversion, we obtain

$$\ln\left(\frac{\varphi_1}{\varphi}\right)_{W_e}=\frac{T_2(T_1-T)}{T(T_1-T_2)}\ln\left(\frac{\varphi_1}{\varphi_2}\right)_{W_e},\ T\geqslant T_0, \tag{10}$$

$$\ln\left(\frac{\varphi}{\varphi_1}\right)_{W_e}=\frac{L_f\,(T_0-T)}{RT_0T}-\frac{T_2(T_1-T)}{T(T_1-T_2)}\ln\left(\frac{\varphi_1}{\varphi_2}\right)_{W_e},\ T\leqslant T_0. \tag{11}$$

Owing to the lack of data on the heat of adsorption, Eqs. (10) and (11) are of most practical value for conversion of isotherms.

For illustration, we have performed a temperature conversion of isotherms characterizing wood as a representative of capillary-porous colloidal materials. The results are shown in Fig. 1 in the form of curves depicting the temperature dependence of the equilibrium moisture content at φ = const. On the same diagram have also been plotted data from another study [5]. The graph indicates that for $T \geq T_0$ the results of our calculations agree with published data, namely that the equilibrium moisture content at φ = const increases linearly with decreasing temperature. For the $T < T_0$ range, however, there is a wide disagreement: W_e at φ = const continues to increase with decreasing temperature according to the data in study [5], but changes its trend drastically upon transition through temperature T_0 according to our calculations, which indicates that at a high air humidity the amount of adsorbed moisture decreases sharply with decreasing temperature.

It is thus evident that the results of our calculations for $T < T_0$ agree with known anomalies of the temperature dependence of those isotherms. The data in study [5] on W_e at φ = const in the subzero temperature range have evidently been obtained by extrapolation, which is incorrect.

The decreasing of the sorption capacity of a material with decreasing temperature in the $T < T_0$ range has been confirmed by the results of tensometric tests on specimens of sand and grade KSK No. 1 silica gel, performed by this author in the underground laboratory at the Permafrost Institute, Siberian Branch of the Academy of Sciences of the USSR in Yakutsk. Those results agree qualitatively with the experimental data on various soil specimens obtained by Votyakov [9].

NOTATION

T, temperature; T_0, melting point of ice; R, universal gas constant; p_w, p_i, p_a, pressures of saturated vapor above water, ice, and the adsorbate, respectively; L_f and L_s, heat of fusion and the heat of sublimation of ice; L_v, heat of evaporation of water; Q_a and q_a, respectively, differential and pure differential heat of adsorption; W_e, specific moisture content at equilibrium in a material; and φ, relative humidity of air.

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PRODUCTION OF A FLUIDIZED BED MOVING ALONG AN INCLINED GAS-DISTRIBUTING GRID

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Results are presented from analytical and experimental studies on how the height of a fluidized bed is dependent on the major parameters when it moves up an inclined gas-distributing grid.

It is very promising in many technological processes [1-4] to move a fluidized bed along a gas-distributing grid with a flow of fluidizing gas oriented in the direction of motion by the grid. One of the most important parameters of this process is the bed depth, which has a quite definite relation to the gas flow speed, the angle of entry of the gas into the fluidized bed, the density and particle size of the solid phase, the grid inclination, and various other parameters. Here we consider how the bed depth is related to these parameters.

Preliminary experiments and published data show that gas jets curve in the direction of least resistance in a fluidized bed (Fig. 1).

If we neglect the interaction between particles, the projection G_x of the mass of a particle on the X axis at the surface of the bed at $y = h$ should be equal to the projection of the aerodynamic resistance force N_x. Particles in the range $y > h$ roll down along the layer since for these $G_x > N_x$. Therefore, a necessary condition for the existence of a moving fluidized bed of depth h is $G_x \leq N_x$ for $0 < y < h$, with the sign of equality corresponding to the upper boundary of the bed.

To determine h, we first have to establish the gas-velocity distribution in the bed. As the treatment is one-dimensional, we take the gas as incompressible and write the equations of continuity and the Navier-Stokes ones for the gas phase:

$$\frac{dv}{dy} = 0; \tag{1}$$

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