THE THERMAL CHARACTERISTICS OF THAWING SILTS OF GLACIAL GENESIS

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The thermal conductivities and thermal diffusivities of frozen monodisperse silts of glacial origin, as functions of temperature, have been determined experimentally.

The thermophysical characteristics of porous rocks are subject to substantial changes, depending on structural–mechanical factors (the mineral composition of the particles, pore dimensions, or particle size), as well as the state of the rocks – porosity, temperature, moisture content.

The correct determination of the thermophysical characteristics of the rocks will enable us correctly to design methods of thawing and to evaluate the effectiveness of the proposed technological approaches to preparation for dredging operations in frozen soils, a primary element of which will doubtlessly be a thawing procedure.

Rocks of glacial origin – the so-called silts of glacial genesis – are widely encountered in most dredging operations. This is a monodisperse rock containing large amounts of ice, exhibiting a filtration factor of $k = 2\text{-}3 \cdot 10^{-3}$ m/day.

As a rule, these silts cover gold-bearing gravel, and they are further covered from above with alluvial glacier–gravel deposits with sandstone and sandy loam fillers.

We have every reason to assume that such rocks will present particular difficulty in thawing out. Moreover, this is confirmed by experience. Thus, in research involving the use of hydraulic probes, a control bore hole (in the center of a hydraulic-probe triangle, with the individual probes separated by 5 m), drilled through a segment in which the silt was six meters thick, showed that the volume of the unfrozen rocks is equal to the volume of those that remained frozen, with lengthening of the thawing period during the summer season producing no particularly desirable result. This is quite understandable, if we consider that the process of steady-state filtration in such rocks, even in a state of thawing, will be an infinitely prolonged affair.

We know that glacial deposits extend even into the frozen portions of the dredging ground. In the light of this, the problem of deciding on a thawing procedure under such conditions is quite urgent, and it is extremely necessary that we study the thermophysical, electrical, physicotechnical, and filtration properties of such rocks.

We will examine the thermophysical characteristics of frozen and thawed silts, produced on passage of a drill.

Two procedures were used in studying the specimen, whose structure remained unbroken, i.e., an intermittent procedure and a procedure following a regular regime.

In the first case, we employed a method of applying brief pulses from a linear heat source, developed by Vishnevskii [1]. The thermophysical characteristics – the thermal conductivity λ and the thermal diffusivity a – are calculated from the measurement results for the maximum of the temperature wave propagating through the material and from the time for the onset of this maximum, as well as from the power of the heat pulse.

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TABLE 1. Thermal Diffusivity of Frozen Rocks (Silts of glacial origin), Determined by the Regular-Regime Method

Experimental parameters	Depth of specimen sampling, m					
		8			9	
Cooling rate m	4,28	4,64	2,95	3,16	8,2	6,15
Form factor b	1,98	1,98	3,1	3,1	1,98	1,98
Initial specimen temperature, °C	—14,0	—13,0	—19,0	—26,0	—33,0	—18,0
Thermostat-fluid temperature, °C	—0,2	—0,2	—0,4	—0,7	—1,0	—0,8
Coefficient of thermal diffusivity, $a \cdot 10^4$	8,5	9,18	9,3	9,8	16,2	12,15
Moisture content, %		24,7			28,8	28,8

Pulse sensors were prepared, and these were imbedded directly into a specimen that had been sawed open. The sensors were made in the form of two parallel wires, 0.2 mm in diameter, one of which was made of constantan – 100 mm long – to serve as the pulse heater, while the other wire formed a copper –constantan thermocouple whose "hot" junction was separated through a distance R = 10 mm from the mid-section of the heater. The "cold" junction was located in a thermostat.

To determine a and λ, we fixed the time τ_{max} at which the maximum of the temperature wave passed through the thermocouple junction. Simultaneously, we established the amplitude of the thermal wave and the power of the heat source. A GZP-47 mirror galvanometer was used for the measurements.

The heat pulse was varied in time for 30 to 60 sec and was based in virtually every specific case on the "strength" of the temperature wave.

The coefficients of thermal diffusivity a and thermal conductivity λ were calculated [2] from

$$a = \frac{R^2}{4\tau_c}\,\varphi_a,\ \ \mathrm{m^2/h}, \tag{1}$$

$$\lambda = \frac{Q_h}{4\pi L_c \Delta t_{max}}\,\varphi_\lambda,\ \ \mathrm{kcal/m \cdot h \cdot deg}, \tag{2}$$

where R is the distance between the electric heater and the hot junction of the thermcouple, in m; τ_h is the duration of the heat pulse, in h; φ_a and φ_λ are functions which depend on the ratio (τ_h/τ_{max}); τ_{max} is the time from which the heater is switched on to the onset of the temperature-wave maximum; L_c is 0.1 m, which represents the working length of the heater; Q_h is the thermal power of the linear heater and is given by

$$Q_h = 0.86IU = 0.86I^2 r_h,\ \ \mathrm{kcal/h}, \tag{3}$$

I is the current strength in the heater circuit, in A; r_h is the heater resistance, in Ω; Δt_{max} is the maximum excess temperature, in °C.

The regular-regime method [3] was used exclusively to determine the coefficient of thermal diffusivity. A calorimeter in the form of a hollow cylinder was fabricated. The center section of the calorimeter contained a mercury thermometer. The inside cavity of the calorimeter was filled with rock of natural structure. The experiments were performed at a negative initial temperature ranging from –13° to –33° and the thermostat-fluid temperature ranged from 0.2-1.0°C.

The purpose of the experiment was to establish the temperature during the heating of the frozen rock specimens and to plot the curve for $\ln|t°| = f(\tau)$. The tangent to the angle of inclination for the rectilinear segment of the curve was then calculated, i.e., the heating rate m for the calorimeter. The thermal diffusivity for the specimen was determined from the formula

$$a = mb,\ \ \mathrm{m^2/h}, \tag{4}$$

where b is the form factor for the calorimeter.

Below we present the results from the determination of the thermophysical characteristics.

The speed of the intermittent method enabled us to achieve a sharply delineated and stable relationship between the thermal conductivity λ and the thermal diffusivity of the frozen rock relative to the temperature (see Fig. 1). This relationship is most evident for the thermal diffusivity. This is explained by

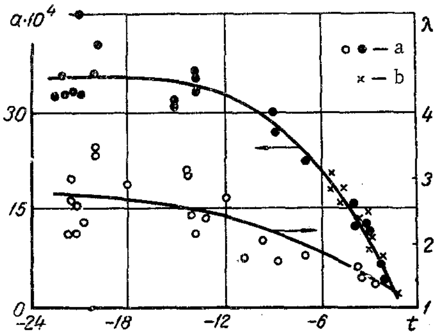

Fig. 1. The relationship of a (m^2/h) and λ (kcal/m · h · deg) to t (the rocks were formed of silts of glacial origin; W = 25%; γ = 1.65 g/cm^3): a) depth, 9 m; b) 8 m.

the fact that the thermal conductivity of the frozen rocks increases with a drop in temperature, while the heat capacity diminishes. The main reason for this is the fact that a certain relationship exists between the temperature and the phase composition of the water in the frozen rocks [4]. The silt rocks are therefore completely frozen at a temperature below −20°C, while in the temperature range from 0 to −10°C the thermal characteristics of these rocks are subject to substantial changes (see Fig. 1).

The thermal characteristics of thawed silts, in the range of interest to us, are virtually independent of temperature. The thermal diffusivity of thawed silts is found in the range a = (12-17) · 10^{-4} m^2/h; the thermal conductivity is λ = 1.1-1.5 kcal/m · h · deg; and the heat capacity is c = 650-920 kcal/m^3 · deg.

The results from the determination of the thermal diffusivity for the silts by the regular-regime method are presented in Table 1. Because of the great interval between the initial specimen temperature and that of the thermostat fluid, we obtained only averaged quantities, but nevertheless these results indirectly indicate the relationship between a and temperature, as well as its relationship to the moisture content.

The resulting temperature relationship for the thermal characteristics of silt rocks indicates the need for investigating the phase composition of the water in these rocks as a function of temperature, which is of great significance in view of the high overall moisture content in the determination of the amount of ice present. At the same time, the resulting relationships serve as a basis for specifying the ice content. Indeed, silts can be classified on the basis of their properties to the class of clays, which also completely freeze at a temperature below −20°C. For clays a phase composition of water [4] has been established, and this can thus be used to classify the amount of ice in silt rocks.

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