Application of the Scanning Calorimetry Method to Determine the Specific Heat Capacity of Soils

A M Timofeev¹, O N Kravtsova², N I Tappyrova³

¹Department of heat and mass transfer processes, V.P. Larionov Institute of Physical-Technical Problems of the North Siberian Branch of the Russian Academy of Science, Oktyabrskaya st, 1, Yakutsk, 677890, Russia
²Department of heat and mass transfer processes, V.P. Larionov Institute of Physical-Technical Problems of the North Siberian Branch of the Russian Academy of Science, Oktyabrskaya st, 1, Yakutsk, 677890, Russia
³Department of heat and mass transfer processes, V.P. Larionov Institute of Physical-Technical Problems of the North Siberian Branch of the Russian Academy of Science, Oktyabrskaya st, 1, Yakutsk, 677890, Russia

E-mail: pnadya.iptpm@mail.ru

Abstract. The specific heat is an important characteristic of soils at their application as the bases of buildings and engineering structures. The article presents the experimental data on specific heat of the Amginsky deposits clay soil in the Republic of Sakha (Yakutia) in the range from sorption humidity to upper limit of plasticity obtained by the differential scanning calorimetry Sensys Evo TG-DSC. The specific heat measurements were carried out on samples of clay soil taken directly from the deposit and samples of the same soil, but previously cleaned of impurities. It is established that for clay soil the dependence of the specific heat capacity on humidity is not monotonous but has a maximum

1. Introduction
The intensive development of construction in areas of the Arctic coast has led to the need to study the physical and mechanical properties of soils. For long lasting accident-free operation of buildings and engineering structures it is required a thorough technical calculation and mathematical modeling of heat and mass transfer processes in soils and building materials at the initial stages of design. For this it is necessary to know the totality of thermophysical and mass transfer characteristics.

The wrong choice of thermal characteristics in the design calculations in some cases can lead to a decrease in performance and to emergency situations in the operation of engineering structures. And on the contrary, the proper use of thermophysical characteristics of soils can significantly reduce the cost of construction and installation works.

Forecast management of changes in the temperature regime of soils is a necessary element of engineering-geological justification and design of engineering structures in the Arctic.

To calculate the temperature regime of soils such thermophysical characteristics as heat capacity and thermal conductivity of soils are usually used [1]. If the thermal conductivity of different types of soils is a well-known and quite a certain (well-known dependence of heat conductivity on humidity, density, temperature), the situation with the specific heat of the soil is different [2]. The specific heat
capacity is an additive value [3], and at experimental measurements the specific heat capacity of pore solution makes the main contribution to the heat capacity of soil. The measurement of soil's heat capacity represents a difficult task: the device should be high sensitive.

In the last few years, with the improvement of measuring equipment it is possible to measure the specific heat with high accuracy and in a wide temperature range [4]. One of these methods for determining the specific heat is a method using the differential scanning calorimetry with temperature modulation. It is a fast and fairly simple method to determine the specific heat of materials. At the same time, the error of determination is 1%.

This paper presents the results of determining the specific heat of clay soil depending on humidity and temperature.

For the experiments, we used soil samples from the Amginsky deposit located at 0.5 km to the North-East from Amga village which is an administrative center of the Amginsky district of the Sakha Republic (Yakutia).

The granulometric composition of soil (%): fraction 0.25 mm – 0.01 mm – 79.1; fraction 0.01 mm - 0.005 mm – 8.0; fraction 0.005 mm - 0.001 mm – 11.3; fraction less than 0.001 mm – 1.0.

2. The measurement results of clay soil’s specific heat

Measurements of specific heat were carried out on samples of clay soil taken directly from the field and samples of the same soil but which were previously purified from impurities at three different temperatures (20, 30, 40°C) and in the range of humidity from sorption to the upper limit of plasticity.

The sorption humidity was determined according to GOST 24816-81 [5]. Values of sorption moistures for two types of studied soils are presented on figure 1.

Sorption humidity at a given relative humidity [I] was calculated with an error of up to 0.1% as the arithmetic mean of the test results of 3 samples.

![Figure 1. Sorption humidity of clay soils. x – purified clay soil, ♦ - crude clay soil.](image)

The use of this method allows determining the sorption humidity of material with a relative error of not more than 2%.

The limits of plasticity were determined according to GOST 5180 – 2015 [6] by three parallel tests, the discrepancy in the results did not exceed 0.02%. Lower and upper limits of plasticity for purified clay soil are 16.73% and 38.77% respectively, and for untreated clay soil – 20.15% and 37.91% respectively.

The specific heat of two types of clay soil was determined by the SENSYS EVO TG-DSC differential scanning calorimeter figure 2. Due to the fact that milligram quantities of soil are used for
measurements, it is necessary to make sure that a homogeneous sample of the test material is used for measurements.

Figure 2. SENSYS EVO TG-DSC measurement unit.

In the DSC method [7] heat is determined through the heat flux. Heat flow is measured by the temperature difference at two points of the measuring system at one moment of time. Measurements were carried out in a dynamic mode with programmable changing of temperature of the shell (heater): from 20°C to 40°C. For obtaining reliable values we carried out at least three independent measurements of heat capacity and processed the results statistically. The error of determination of the specific heat capacity of wet clay soils was 6-10%. Measurement results of the specific heat are shown in figure 3–4.

Figure 3. Dependence of specific heat capacity of clay soil treated from humidity. ▲ – 40°C, x – 30°C, ● - 20°C.
Within the sorption humidity, for two types of clay soil the values of specific heat capacity have a maximum, and then to the lower limit of plasticity there is a decrease in values. And starting from the lower limit of plasticity, with increasing of humidity and temperature the specific heat values increase. The specific heat values of the treated clay soil are greater than for untreated. This is due to the fact that in the untreated clay soil there are impurities (sand particles, etc.) that affect specific heat values. Usually, the greater the content of the clay component, the greater the value of soil’s specific heat [8].

The results were obtained on the equipment CF FRC.

3. References

[1] Deryagin B V 1989 Water in disperse systems ed B V Deryagin, N V Churaev et al (Moscow: Chemistry) 288
[2] Starostin E G and Lebedev M P 2014 Properties of bound water in dispersed varieties Part 1 Viscosity, permittivity, density, heat capacity, surface tension Cryosphere of the Earth (vol XVIII) 3 46-54
[3] Gavriliev R I 1998 Thermal properties of rocks and soil covers of the cryolithozone ed R I Gavriliev (Novosibirsk, Publishing house of SB RAS) 280
[4] Etzler F M and Conners J J 1990 Temperature dependence of the heat capacity of water in small pores IPST tecHn.pap.ser. 2 (Atlanta) 28
[5] GOST 24816-81 1982 Construction materials The method of sorption humidity determination (Moscow)
[6] GOST 5180 – 2015 2016 Soils Methods of laboratory determination of physical characteristics (Moscow)
[7] Emelina A L 2009 Differential scanning calorimetry (Study guide Laboratory of the Faculty of Chemistry) MSU 42
[8] Starostin E G, Timofeev A M, Kravtsova O N and Tappyrova N I 2016 Specific heat capacity of bound water in clay soils within sorption humidity (International research journal) 11-4 53 112-116