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INVESTIGATION OF THE THERMOPHYSICAL CHARACTERISTICS OF MINERALS AT VARIOUS HEATING PARAMETERS

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The study of natural minerals in the production of heat and electrical insulating materials is of particular practical interest for the study of their thermophysical characteristics. The regularities of changes in the heat capacity of minerals when heated in production and operating conditions are of particular interest. Natural minerals of wollastonite and quartz were considered as the object of research. The heat capacity of these minerals was measured in an apparatus with a three-dimensional sensor and a panel for automatic control of gas flows, when heated to the temperature of 1600ºC by the calorimetric method. Based on the experimental results, graphs of the dependence of the heat capacity of mineral samples on temperature were constructed.

Keywords: wollastonite, quartz, differential scanning calorimetry, heat capacity, thermal condition.

Introduction

The problem of theoretical and experimental study of the properties of natural minerals remains relevant. To know the thermo-physical properties of substances under different variable temperature conditions is important for several reasons. Here it is important to define the thermo-hysical characteristics of natural minerals, those of building, heat-insulating, facing materials and products and their recyclability. The thermo-physical characteristics of closed structures affect the thermal and air conditions of buildings for various purposes, as well as ventilation and air quality, which currently consume a significant amount of thermal energy, as well as the operation of heating systems.

One of the most promising areas of science and practice for improving the grinding process is target-specific changing the properties and state of natural minerals [1]. Stationary, non-stationary and complex methods based on the theory of thermal conductivity are used to determine the thermo-physical characteristics of minerals and materials in stationary or non-stationary thermal conditions. In addition, these methods can be absolute and relative [2]. Natural minerals are widely used as heat insulators in metal smelting, heating, various wall-mounted boilers, and electric heaters. In foundry and metallurgy, heat-resistant molding materials, especially in powder form, diatomaceous earth and other refractory materials are used. The extraction of high-melting and heat-resistant minerals in the Republic of Kazakhstan is of particular interest. Currently, the minerals of the Republic of Kazakhstan are used for the manufacture of raw bricks, houseware, souvenirs, various parts of electric stoves, ovens, etc. [3, 4].

1. Experimental part

The heat capacity of the whole body is taken into account when studying the structure of substances and their properties, studying phase transitions and critical phenomena, calculating the total amount of impurities in a substance, determining the thermal effects of chemical reactions. In addition, heat capacity as a thermo-physical parameter is an effective tool for scientific research. The determination of the heat capacity of natural minerals was carried out in the LABSYS™ EVO apparatus with synchronous thermo-gravimetric, differential thermal analysis, a 3D sensor at a temperature of up to 1600 ºC and an automatic gas flow control panel (LABSYS™ EVO TG, DTA, DSC 1600 ºC) in the “Methods of physical and chemical research” engineering laboratory of Karaganda E.A. Buketov University (Fig. 1) [5].

Fig.1. LABSYS™ EVO thermal analyzer (main view)

The work is carried out as follows: using a laboratory balance, the mass of the studied minerals is determined: wollastonite, quartz samples from two deposits (Aktas) and (Nadyrbai). The sample weights are, respectively, equal: wollastonite – 8 mg, quartz (Aktas) – 9.36 mg, and quartz (Nadyrbai) – 9.6 mg.

Differential Scanning Calorimetry (DSC) is a method in which the difference in heat flows applied to the crucible with the test sample and the reference crucible is measured as a function of temperature and/or time during the exposure of the test and reference samples to a controlled temperature program under a specified atmosphere and using symmetrical measuring system. The use of DSC makes it possible to significantly reduce the time for conducting experiments and to obtain experimental data on the specific heat capacity of the investigated products with an error of no more than 3%.

Two valved crucibles are placed in the DSC measuring chamber, the test sample is placed in the first one, and the second is used as a reference (free) crucible. The material of the crucible is set depending on the maximum heating temperature of the sample and the tested substance, which should not react with the crucible. In the experiment, platinum was used (up to 1000° C) as the crucible material. The experimenters run the apparatus program and set the parameters to perform the required thermal scanning. During the experiment the program of continuous heating was used. After starting the device, measurements were taken.

The temperature was determined using the thermocouples in the measuring chamber of the calorimeter. When the sample begins to heat up, heat is released. Then the system can measure and analyze the change in specific heat. The melting points of the tested natural minerals were obtained from the reference data**.** Accordingly, the melting points of minerals are: wollastonite – 1400-1500° C, quartz (Aktas) – 1710-1720 ° C, quartz (Nadyrbai) – 1710-1720 ° C. These values are necessary so that when minerals are heated, their temperature values exceed the specified range.

Specific heat c_p, J/g·K is calculated by the formula

$$c_p = m^{-1} C_p = m^{-1} \left(dQ / dT \right)_p , \quad (1)$$

where m is the mass of the sample, g; C_p is the heat capacity, J/K; dQ is the amount of heat, J, required to increase the temperature of the material by dT, K.

The subscript indicates an isobaric process. According to experiment, the specific heat capacities of natural minerals are determined by the proposed formula (1), which represents the amount of heat absorbed by a unit mass of material when heated by 1K at constant pressure. By calculating the dependence of the specific heat capacity of mineral samples on temperature are obtained.

2. Discussion of results

Using the results obtained, a graph of the dependence of the specific heat capacity on temperature *c=f(T)* is plotted. The experimental values of the heat capacity of minerals are given in Table 1. The plot of the obtained heat capacity versus temperature for wollastonite under the thermal condition is shown in Fig. 2.

Table 1. Experimental values of the heat capacity of minerals

Wollastonite		Quartz (Aktas)		Quartz (Nadyrbay)	
T, K	c, J/g·K	T, K	c, J/g·K	T, K	c, J/g·K
304.7	-0.108	305	-0.083	305	-0.146
361	0.31	361	0.038	361	0.072
449	0.414	449	0.093	450	0.128
539	0.376	539	0.095	539	0.143
627	0.405	627	0.148	627	0.208
713	0.333	713	0.121	713	0.237
798	0.293	798	0.125	797	0.166
881.7	0.317	882	0.204	882	0.238
964	0.332	964	0.259	964	0.288
1045.7	0.406	1046	0.328	1045.5	0.348
1126	0.471	1126	0.427	1125.8	0.412
1205	0.508	1205	0.44	1205	0.455
1284	0.542	1284	0.445	1284	0.504
1293	0.552	1293	0.449	1293	0.508

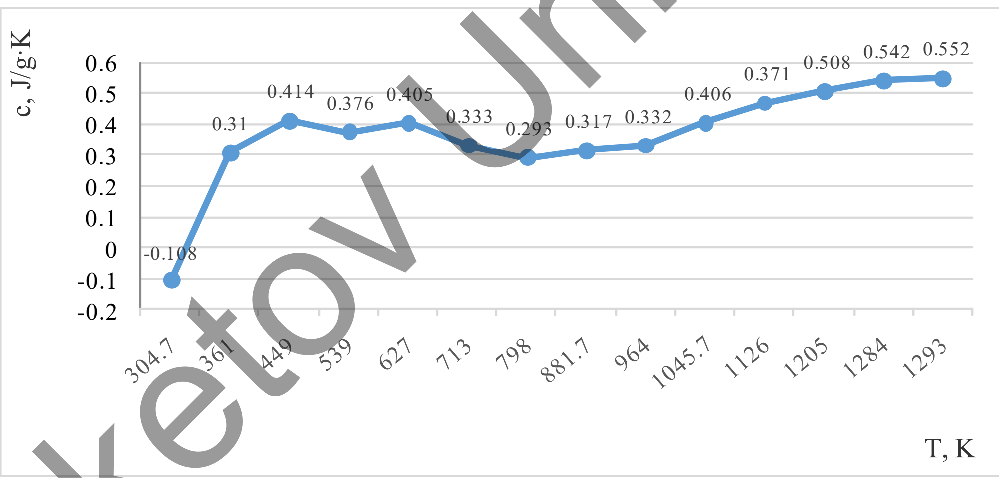

Fig.2. Dependence of the heat capacity of wollastonite $c = f(T)$ under heating process.

As can be seen from this graph, the heat capacity values with in the temperature range from 304 K to 1293 K vary from 0.108 to 0.552 J/g·K. The specific heat capacity for the temperature condition of wollastonite within the temperature range of 1193-1293 K is calculated by the equation (1):

$$c = \frac{(dQ/dT)_p}{m} = \left(\frac{(6.14 - 5.216)}{(1293.82 - 1193.43)} \right) \Big/ 0.008 = 1156.3 J/kg \cdot K.$$

The graph of the temperature dependence of the heat capacity obtained for quartz (Aktas) under thermal condition is shown in Figure 3. As can be seen from the graph, the heat capacity values with in the temperature range from 305 K to 1293 K were -0.083-0.449 J/g·K.

The specific heat capacity of the quartz (Aktas) under thermal condition within the temperature range 1123-1293 K is calculated:

$$c = \frac{(dQ/dT)_p}{m} = \left(\frac{(6.16-5.45)}{(1293.91-1193.11)}\right)\Big/ 0.00936 = 752.88 J/kg \cdot K.$$

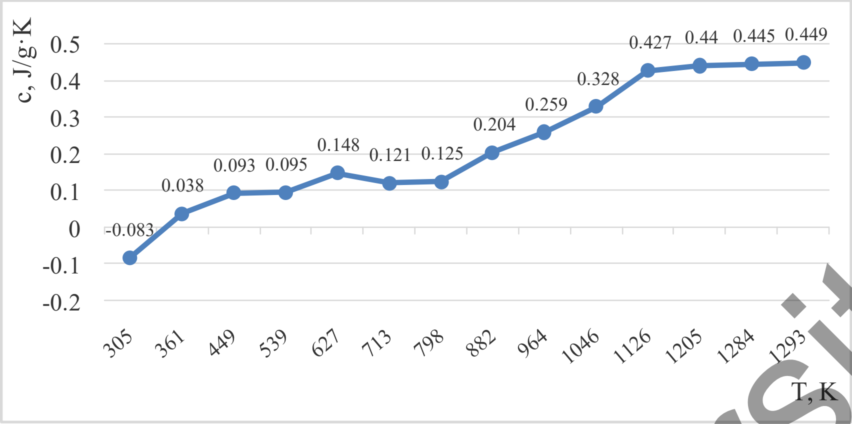

Fig.3. Graph of dependence *c = f(T)*, obtained for quartz (Aktas) under thermal condition

The graph of the temperature dependence of the heat capacity, obtained for quartz (Nadyrbay) under thermal condition, is shown in Figure 4.

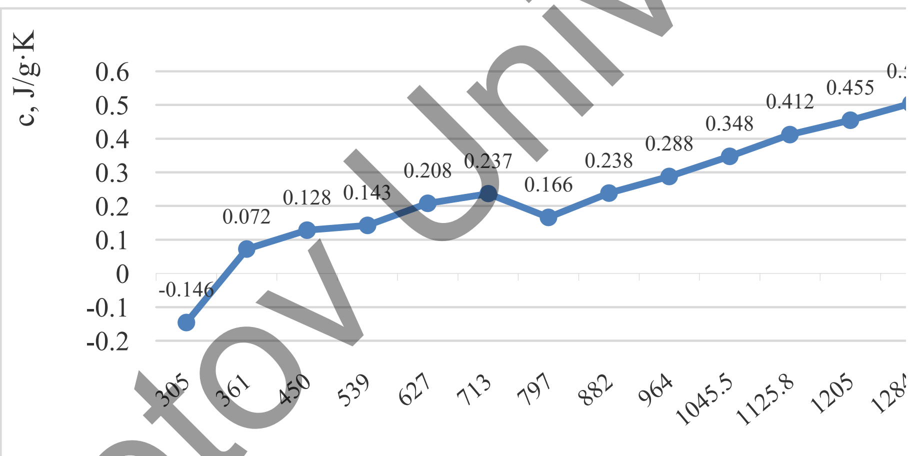

Fig.4. Graph of dependence *c = f(T)*, obtained for quartz (Nadyrbay) under thermal condition

Figure 4 shows that the heat capacity values with in the temperature range from 305 K to 1293 K are 0.146 - 0.508 J/g·K, respectively. The heat capacity of quartz (Nadyrbay) under the thermal condition within the temperature range of 305 -1293 K is calculated by the equation (1):

$$c = \frac{(dQ/dT)_p}{m} = \left(\frac{(6.87-0.44)}{(1293.59-305.35)}\right)\Big/ 0.0096 = 770.7 J/kg \cdot K.$$

After the experiments, the average values of the specific heat capacity with an error of 0.08% were determined and compared with theoretical values [7, 8], which are given in table 2.

Table 2. Comparison table

Mineral	Wollastonite, c, J/kg·K	Quartz (Aktas), c, J/kg·K	Quartz (Nadyrbay), c, J/kg·K
Experimental values	1156.3	752.88	770.7
Theoretical values	1100	692	692

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It can be concluded from the table that the experimental values correspond to the theoretical ones. As can be seen from the temperature-dependent graph $c = f(T)$ of the heat capacity for wollastonite, quartz and dolomite under thermal condition, as the temperature rises, the heat capacity increases accordingly. The observation showed that the specific heat capacity of natural minerals depends on the temperature and concentration of the main components.

Conclusions

The specificity of the theory of thermal condition is that its basic conditions are generalized to the conditions for the existence of bodies of complex composition (systematic) and of any shape, while the usual theory is limited to the study of simple temperature fields or sometimes two-component bodies of a simple shape. Using DSC, the specific heat capacity of natural minerals with an error of 0.08% was determined. Specific heat capacity values are important material characteristics for their research and development as well as for quality control. The developed methods can be applied in information-measuring systems of thermophysical characteristics, in practice for thermophysical measurements, and in construction heat engineering.

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