HEAT ENGINEERING

EXPERIMENTAL STUDY OF THE THERMAL CONDUCTIVITY OF HEAT INSULATION MATERIALS BASED ON EXPANDED VERMICULITE

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Results are presented for experimental studies of the thermal conductivity of expanded vermiculite. Tests are performed in an experimental test unit by a steady-state heat flux. Thermal studies are carried out in the range 300 – 1100 K. It is shown that thermal conductivity increases uniformly with an increase in temperature. The most probable reason for an increase in thermal conductivity is the effect of heat radiation. Results are provided for an approximate second power polynomial.

INTRODUCTION

The properties of heat insulation materials have been studied for many decades. The results of studies may be found in publications on power generation [1], and in special monograms [2, 3] devoted to the technique of an appropriate experiment and analysis of features of heat transfer in materials used for heat protection of structures and equipment. However, every time when material scientists change the technology for preparing or modifying a material composition [4], a requirement arises for a new approach to an experiment in order to obtain information about the action of these changes on material properties. This becomes particularly important when we are talking about increased temperature and about operation of materials in corrosive media. An important characteristic of heat insulation is the thermal conductivity coefficient (TCC). Information about its dependence on temperature is used in numerical analysis of the efficiency of heat protection with the action of a flame on a structure. Results are presented in this article for studying the thermal conductivity of insulation based on vermiculite, i.e. a natural composite of refractory oxides.

MEASUREMENT METHOD AND EXPERIMENTAL DEVICE

In order to measure TCC a method of steady-state heat flux in a plate was selected. Under conditions of direct measurement of heat capacity, directed at a specimen, it relates to a class of the so-called absolute methods not requiring use of reference specimens. The basis of the method is solution of a boundary problem for thermal conductivity for a unidimensional steady-state problem without internal sources of heat release.

The differential equation

$$\text{div}(\lambda \text{ grad } T) = 0$$

is resolved here with boundary conditions of the first order:

$$x = 0, \ T = T_0, \quad x = L, \ T = T_L,$$

where $T_0$ and $T_L$ are temperatures of the boundary surfaces of a plate.

In an approximation for constant thermal conductivity solution of the problem leads to a calculation equation of the form

$$\lambda = \frac{WL}{S(T_L - T_0)}, \quad (3)$$

where $W$ is heat capacity transferred through a specimen from a heater to a cooler; $L$ is specimen thickness; $S$ is specimen cross sectional area.

The value for thermal conductivity calculated by Eq. (3) traditionally relates to and average specimen temperature. Under conditions when the “cold” plane of specimen during
According to technical conditions, prescribed during planning the device, measurement of thermal conductivity should be carried out in an air atmosphere. This requirement is quite unacceptable in selecting the heater construction. In this case an optimum solution appeared to be use of a disk 1 made of boron carbonitride, within whose body cylindrical channels were drilled. A cylindrical spiral of nichrome was placed in these channels. The side surface of the carbonitride disk was surrounded by a tape made of stainless steel on which a winding of an additional heater 6 was placed. A set of differential thermocouples was placed between the disk of the main heater and the tape of the additional heater on a mica insulator whose signal is used in order to maintain adiabatic conditions in the side surface of heater 1 during specimen heating. With a zero value of emf for this set the capacity of the heater is distributed between the upper and lower specimens. With an identical nature for them the heat flux in each specimen equals half the electric power of the heater.

Supply to the heater is provided by a stabilized voltage source. Electric parameters of the heater (current and voltage in the working zone) are measured by a digital voltmeter and recorded by a computer program for data collection. The thermal state of specimens is monitored by six thermoelectric converters 7 of the KhA type. The diameter of electrodes is 0.3 mm. Two thermocouples are installed at the boundary surfaces if a specimen, an additional thermocouple is introduced in a radial channel located in the central plane of specimen to a depth of about 40 mm.

"Cold" ends of the thermocouples are joined with copper wires in grooves of a special copper box for cold joints 8, located on a copper supporting pipe 9 of the lower thermostat. Thermocouple beads are also fastened to the body of this box recording the temperature of the box. The cold ends of the control thermocouple are placed in a Dewer vessel 10 filled with melting ice. Signals of all the thermocouples are also recorded by a digital voltmeter V7-65 and collected in the same file of the collection program and data processing.

Thus, the measuring unit described provides bringing the test specimens to the required temperature regime, measurement of the delivered power, and this means the heat flux a specimen, and preparation of data for the distribution of temperature within the system. This information is sufficient in order to determine the thermal conductivity coefficient.

RESULTS OF STUDIES

Results presented below relate to flame protection heat insulation of unfired material, obtained from expanded vermiculite by semidry compaction with a mineral binder. The material has a fire safety certificate No. SSPB.ru. UPOO1.V02318. Specimens for study were cut from plates manufactured in accordance with TU 5767-002-43545684-01 in the form of disks with thickness of about 10 and a diameter of about 60 mm. The main components according to GOST 12865:67 were distributed as follows, wt.%: SiO2 41, Al2O3 12.1, MgO 27.8, Fe2O3 6.3, Na2O 3.4, CaO 1.8. In addition, impurities of other compounds are present in the material (< 1% of each). Specimen density was determined before a test. It was 710 kg/m³.

Tests were carried out in a series of steady-state regimes with a subsequent increase in heater power. Establishment of each regime due to the low thermal conductivity of the material occupied 2.0 – 2.5 h. Typical curves for emergence into a steady-state are shown in Fig. 2. It follows from them in particular that during heating there is no phase rebuilding in the material. The heating rate is changed uniformly over the