Assessment of the influence of the structural characteristics of granular systems of microsilicon on the properties of thermal insulation materials

1*Sangulova I.B., 2Selyaev V.P., 3Kuldeev E.I., 4Nurlybaev R.E., 4Orynbekov Ye.S.

1"International Educational Corporation", Almaty, Kazakhstan
2Ogarev Mordovia State University, Mordovia, Russia
3Satbayev University, Institute of Metallurgy and Ore Beneficiation, Almaty, Kazakhstan
4"SAVENERGY" Limited Liability Partnership, Almaty, Kazakhstan

* Corresponding author email: e-mail: indiraberkinbaykyzy@gmail.com

ABSTRACT
The article discusses experimental studies of the size and shape of structured particles of microsilica small angle x-ray scattering method and a photophonon theoretical description of the heat transfer process in complex heterogeneous structures to assessment of the structural characteristics of granular systems for the properties of thermal insulating materials. The mechanism of heat transfer in granular, porous systems is quite complex, since heat exchange occurs in a material consisting of two phases (solid and gas) and at the phase boundary. Heat transfer in liquid thermal insulation coatings can be carried out from one solid particle to another. In this case, the thermal conductivity will depend on: the chemical and elemental composition of the material; particle granulometry; surface topology - the presence of inhomogeneities, defects on the surface; the number of touches and the contact area between the particles. The heat transfer of gas in the pores is carried out when gas molecules collide. Thermal conductivity will be determined by the ratio of the free path of molecules and linear pore sizes, temperature and dynamic viscosity of the gas phase, the nature of the interaction of gas molecules with the solid phase. Heat transfer by radiation depends on the nature of the particles, the dielectric, magnetic permeability and the degree of blackness of the particle surface. Based on the analysis of possible mechanisms of heat transfer in granular systems, it can be argued that the effective thermal conductivity of the system depends, all other things being equal, on the structure of the pore space of granular materials, topology and the number of particle touches. Considering idealized models of the structure of granular materials in the form of ordered folds of perfectly smooth balls, we can obtain several variants of structures: with tetrahedral; hexagonal; cubic packing of balls.

Keywords: x-ray diffractionmeter, microsilicon, thermal conductivity, diatomite, structure, filler.

Introduction
To determine the main structural parameters that affect the thermal conductivity of filled polymer binders, let us consider the mechanisms of heat transfer in solid, liquid, gaseous media.

It is customary to distinguish between three main mechanisms of heat transfer: thermal conductivity (conduction); convection; radiation [(1), [2], [3], [4], [5]].

The conduction mechanism of heat transfer occurs due to the exchange of kinetic energy when...
moving molecules collide with each other or with the surfaces of a solid or liquid phase that limits space.

Convection - heat transfer by a moving environment, air or liquid streams.

Radiation - emission of electromagnetic energy emitted by some kind of heat, such as the sun.

In quantum theory, heat transfer in solids by thermal conductivity is considered as a process of nonequilibrium phonon distribution, and thermal conductivity is determined by the deviation of the phonon distribution from the equilibrium state at a given temperature gradient.

Considering the transfer of heat in the gas phase of the composite (in pores, hollow spheres), the molecular kinetic theory assumes the presence of two mechanisms of heat transfer by gas - due to the collision of molecules and radiation.

The efficiency of molecular heat transfer in pores, spheres of liquid heat-insulating coating further (LTC), depends on temperature, pressure, geometry of the pore space, the nature of interaction at the boundary of a solid with gas.

Experimentally established, that the effective thermal conductivity of heterogeneous finely dispersed granular systems, even at atmospheric pressure, may turn out to be lower than the thermal conductivity of the gas filling the pores.

To describe the process of heat transfer in continuous media and determine the coefficient of thermal conductivity, the most often used methods are based on the application of the principle of generalized conductivity, which is based on the analogy (similarity) between the differential equations of stationary heat flux, temperature, mass, current, etc.

It is possible to use topological models, when solving more complex problems to determine the thermal conductivity coefficient. However, they do not take into account the features of the quantum mechanisms of heat transfer through the main matrix of the material [[5], [6], [7]].

Analysis of modern research in this area

To assess the effect of the structural characteristics of granular microslica systems on the properties of heat-insulating materials, a comprehensive analysis showed that the only mechanism for heat transfer for granular systems would be:

- heat transfer through a flat, two-layer and multi-layer plate.

In the works of Krainov A.Yu. To calculate the heat transfer through a flat plate, the value of the heat flux through a plate of thickness \( L \), having a thermal conductivity coefficient \( \lambda \), the walls of which have a constant temperature \( T_0 \) and \( T_1 \), is determined. The mathematical formulation of the problem consists of a stationary one-dimensional heat equation with boundary conditions of the first kind [8].

- heat transfer of coatings with a coefficient of thermal conductivity that depends on the temperature of the environment.

In the works of V.A. Maksimov, S.R. Vitaly. the values of the thermal conductivity coefficient of some ultrathin liquid composite heat-insulating coatings have been experimentally determined. The calculation of the measurement error has been performed. As a result of the work done, the thermal conductivity coefficient of ultra-thin liquid composite heat-insulating coatings was experimentally determined for sample No. 1 \( \lambda = 0.086 \text{ W/(m·°C)} \), for sample No. 2 \( \lambda = 0.091 \text{ W/(m·°C)} \). But, the real thermal conductivity coefficient of the samples under study in practice turned out to be higher than the declared one.

According to the authors, this discrepancy is possible due to the fact that manufacturers of liquid coatings in laboratory determination of thermal conductivity either used some "ideal" conditions, or the coefficient was obtained by theoretically solving the problem of thermal conductivity in liquid composite heat-insulating environment.

Despite this, the authors consider such liquid thermal insulation coatings to be of great interest for builders, since they allow insulating objects of complex geometric shapes (valve bodies, complex units, etc.), which in some cases makes them practically irreplaceable. Correct consideration of the thermal properties of paints will allow avoiding excessive increases in heat losses of insulated pipelines with a coolant or building enclosing structures, and will also protect them from possible defrosting during periods of negative temperatures [9].

- heat transfer of a plate with a coefficient of thermal conductivity depending on the coordinate.

The work of Kolmychkov V.V., Mazhorova O.S. is devoted to the numerical study of convective structures arising near the stability threshold in a non-Bussinesq fluid, the thermal diffusivity of which depends on the vertical coordinate. The main attention is paid to the study of the existence and
stability of a flow in the form of square cells for various values of the Prandtl number [10].

- phonon-photon model for the theoretical description of the process of heat transfer in complex heterogeneous structures.

In the works of Gladkov S.O. for an arbitrary type of porous structures, a theoretical approach is proposed for calculating their thermal conductivity coefficient $\kappa$ as a function of porosity $\xi$, temperature $T$, density $\rho$, and a number of other parameters. The general calculation algorithm is based on the theory of nonequilibrium processes. Its modification in the language of the gas-kinetic approximation allows one to obtain compact formulas for $\kappa$ and easily estimate the corresponding dependences. On a specific example of such a very important in practical terms refractory substance, like concrete, the theoretical formulas are compared with experimental results and their good agreement is shown [11].

**Methods for determining the structural characteristics of granular systems**

1. To study the properties of microdispersed materials, a Hecus S3 - MICRO small-angle X-ray diffractometer was used.

   The most important feature of this method is the ability to analyze the internal structure of disordered systems - particles, pore space, interfaces between heterogeneities of heterogeneous substances.

   As the scattering coordinate, we used the magnitude of the scattering vector modulus $s = 4\pi \sin\theta / \lambda$, where 29 is the scattering angle, $\lambda = 1.5418$ Å is the wavelength of the radiation used. Scattering intensities were recorded in the range of $s$ values from 0.0094 to 0.40 Å$^{-1}$, which made it possible to study inhomogeneities with linear dimensions $L \sim (2\pi) / S$, in the range of 2 ... 60 nm.

2. One of the most important parameters that determine the thermal insulation properties of materials based on microstructured mineral powders (silica, diatomite) is thermal conductivity. Knowing a number of characteristics of dispersed systems, such as the size, thermal conductivity of the material of primary particles, the method of filling and some other characteristics, it is possible to theoretically calculate the thermal conductivity of granular systems based on the polystructural theory and, as a result, it is possible to assess the structural characteristics of granular systems for the properties of heat-insulating materials ([12], [13], [14], [15], [16], [17]).

**Assessment of the structural characteristics of granular systems to the properties of heat-insulating materials**

For the theoretical description of the process of heat transfer in complex heterogeneous structures, a photophonon model was used, according to which the general expression for the thermal conductivity of a porous system is written in the form of an additive function ([12], [13], [14], [15], [16], [17]).

$$\lambda = \left(1 - \frac{m}{m_p}\right)^2 \lambda_{00} + \frac{m}{m_p} \left(1 - \frac{m}{m_p}\right) \lambda_{10} + \frac{m}{m_p} \left(1 - \frac{m}{m_p}\right) \lambda_{11}$$  \hspace{1cm} \hspace{1cm} (1)

where $m$ – porosity of the structure;
$\lambda_{00}$ - thermal conductivity of the main matrix;
$\lambda_{11}$ - thermal conductivity of pores;
$\lambda_{10}$ - phonon-phonon thermal conductivity at the interface between pores and the main matrix;
$m_p$ - percolation threshold for the basic matrix model.

Using the gas-kinetic approximation, we represent the thermal conductivity of the main matrix in the form:

$$\lambda_{00} = \frac{1}{3} c_{fon} v^2 \tau_{fon}$$  \hspace{1cm} \hspace{1cm} (2)

where $c_{fon}$ - phonon heat capacity per unit volume of the main matrix;
$v$ - average speed of sound in the material;
$\tau_{fon}$ - phonon relaxation time, which is associated with phonon scattering by structural inhomogeneities and at the boundaries of contact of pores with the main matrix.

The phonon heat capacity is determined by the formula (at $T >> \theta_0$)

$$c_{fon} = \frac{3k}{a^3}$$  \hspace{1cm} \hspace{1cm} (3)

where $k$ - Boltzmann constant;
$a$ - average interatomic distance of the main matrix material.

The phonon relaxation time satisfies the expression [10]:
\[
\tau_{fon} \approx \frac{m_p \rho a^4 v (1 - \frac{m}{m_p})}{k \frac{T}{m}} \tag{4}
\]

where \( \rho \) – base matrix material density; \( T \) – absolute temperature (K).

Substituting (3) and (4) into (2), we obtain the expression

\[
\lambda_{00} = \left(1 - \frac{m}{m_p}\right) \frac{\rho v^3 a m_p}{T} \tag{5}
\]

Similarly, representing the photon flux as a photon gas, we can write

\[
\lambda_{11} = \frac{1}{3} c_{fot} c^2 \tau_{fot} \tag{6}
\]

where \( c_{fot} \) - photonic heat capacity per unit pore volume;

\( c \) - speed of light in pores;

\( \tau_{fot} \) - photon relaxation time within pores.

The work presents an expression for determining the photon heat capacity:

\[
c_{fot} \approx k \left(\frac{k T}{\hbar c}\right)^3 \tag{7}
\]

\((h – Planck’s constant), and the photon relaxation time for the case of vacuum or a low concentration of gas molecules in the pores:

\[
\tau_{fot} = \frac{L}{c} \tag{8}
\]

\( L \) – linear pore sizes. Substituting (7) and (8) into (6), we obtain

\[
\lambda_{11} = \frac{1}{3} \frac{k L}{c^2} \left(\frac{k T}{\hbar}\right)^3 \left(\frac{k T}{h}\right)^3 \tag{9}
\]

It is shown in the work that in formula (1) the terms containing \( \lambda_{01} \) and \( \lambda_{10} \) are small compared to other terms and can be discarded. Then expression (1) will look like this:

\[
\lambda = \left(1 - \frac{m}{m_p}\right)^2 \lambda_{00} + \left(\frac{m}{m_p}\right)^2 \lambda_{11} \, \text{and given (5) and (6)}:
\]

\[
\lambda = \left(1 - \frac{m}{m_p}\right)^2 \left(\frac{\rho v^3 a m_p}{T}\right) \frac{m_p}{m} + \frac{1}{3} \left(\frac{m}{m_p}\right)^2 \frac{k L}{c^2} \left(\frac{k T}{h}\right)^3 \tag{10}
\]

The resulting formula makes it possible to estimate the dependence of the thermal conductivity of the LTP on the porosity of the material structure (\( m \)), linear pore size (\( L \)), density (\( p \)) on temperature and calculate the effective thermal conductivity of a dispersed porous substance, based only on the knowledge of some macro- and microscopic material parameters; to solve the inverse problem - by measuring the effective thermal conductivity of a dispersed powder by the method of stationary heat flux or by the method of laser flash, knowing the density, speed of sound and average interatomic distances, calculate the characteristic linear dimensions of its pores. At low temperatures, the thermal conductivity of a granular system is determined mainly by its phonon component. With an increase in temperature (\( T >> \theta_p \)), this component decreases \( \propto T^{-1} \), but radiant heat transfer (by photons of electromagnetic radiation) \( \propto T^3 \) increases. If the dependence of thermal conductivity on temperature (10) is represented in the form

\[
\lambda(T) = \frac{A}{T} + B T^3 \tag{11}
\]

then the minimum value of the effective thermal conductivity \( \lambda(T) \) will be observed at a temperature.

\[
T_{min} = \sqrt[3]{\frac{A}{3B}} \tag{12}
\]

In this case, the photon thermal conductivity (10) will be the smaller, the smaller the linear dimensions \( L \) of the pores of a given material. Consequently, formulas (10) and (12) make it possible, on the basis of the data obtained as a result of studying the structural characteristics of the pore space of dispersed powders, to reasonably recommend granular systems for use as a filler for LTM. It is proposed to determine and evaluate the structural characteristics of filler powders by the method of small-angle X-ray scattering (SAXS) [1]. The features of structural inhomogeneities of microsilica [[1], [18], [19]] and natural diatomite of the Utesai deposit, as well as a filler powder of the FRONT-VIP vacuum insulating panel from VACU - ISOTEC KG were investigated.

**Experimental part**

Small-angle X-ray scattering is a diffraction method widely used to study nanoobjects of
various physical nature and state of aggregation, including highly dispersed powders.

The experimental material was obtained in the form of small-angle X-ray scattering indicatrices for all investigated dispersed powders. As the scattering coordinate, we used the magnitude of the scattering vector modulus \( s = \frac{4\pi \sin \theta}{\lambda} \), where \( \theta \) is the scattering angle, \( \lambda = 1.5418 \) Å is the wavelength of the radiation used. Scattering intensities were recorded in the range of \( s \) values from 0.0094 to 0.40 Å\(^{-1}\), which made it possible to study inhomogeneities with linear dimensions \( L \sim \left( \frac{2 \pi}{s} \right) \), within 2 ... 60 nm. The character of the \( I(s) \) curves indicates that the studied materials contain scattering inhomogeneities (pores) of different linear sizes, and high values of the scattering intensity are due to the sharp contrast caused by the large difference between the density of silica particles and pores. Fig. 1 shows the experimental SAXS curves of the natural diatomite of the Utesayskoye deposit and the filler powder of the FRONT-VIP insulation panel. The scattering indices of the other three microsilica have a similar form to the FRONT-VIP SAXS curve.

Figure 1 - Curves of small-angle X-ray scattering of dispersed powders: 1 - natural diatomite; 2 - filler powder FRONT-VIP

Figure 2 - Size distribution of scattering inhomogeneities: 1 - natural diatomite; 2 - microdispersed silica obtained from diatomite; 3 - condensed silica; 4 - white soot; 5 - FRONT-VIP filler powder.

To find the approximate size distribution functions of scattering inhomogeneities (for spherical particles), the SAXS curves were rearranged into coordinates \( \ln I(s) - s^2 \). Using the Kitaygorodsky method, we obtained the dependencies shown in Fig. 2. Pore size distribution curves of dispersed microsilica have pronounced maxima; a similar function of natural diatomite is bimodal. Table 1 shows the results of the analysis of distribution curves - the maxima of the distribution functions \( \Delta d \); average values of the linear dimensions of the scattering inhomogeneities \( <d> \); variances of distribution functions \( \Delta d \).

Table 1 - Pore size distribution of dispersed microsilica

| Powder type                        | \( d_v, \) nm | \( <d>, \) nm | \( \Delta d, \) nm |
|------------------------------------|---------------|--------------|-------------------|
| Natural diatomite                  | 2             | 10           | 2 - 7             |
| Dispersed microsilica obtained from diatomite | 8             | 12           | 3 – 18            |
| Condensed silica fume              | 22            | 26           | 10 – 34           |
| White soot                         | 2             | 13           | 2 – 21            |
| FRONT-VIP                          | 20            | 20           | 8 – 37            |

In general, the average linear dimensions of the scattering inhomogeneities of the investigated dispersed powders are \( \sim 10 - 30 \) nm, which, according to the classification of M.M. Dubinin, officially adopted by the International Union of Pure and Applied Chemistry (IUPAC), corresponds to mesopores. Capillary condensation of water molecules occurs in them, which are partially removed during heating (calcination) of dispersed powders [11].

The SAXS indicatrices were rearranged into double logarithmic coordinates \( \lg I(s) - \lg s \). An analysis of these dependences showed that, in all investigated dispersed materials, a fractal character of scattering by structural inhomogeneities of the nanoscale level is observed. To determine the fractal dimensions of these inhomogeneities, a method was used, which consists in determining the slope of the corresponding linear section of the scattering curve plotted in the indicated coordinates. If the investigated structural elements of the nanoscale, such as pores, pore clusters, and interfaces of inhomogeneities are of a fractal nature, then in certain intervals of values of the modulus of the scattering vector, a power-law
decay of the scattering indicatrix \( I(s) \sim s^{-\alpha} \) with a non-integer value of the exponent should be observed, and \( \alpha < 4 \). At \( 1 \leq \alpha < 3 \), the power-law decay of \( I(s) \) is characteristic of scattering from fractal clusters or aggregates of nanoparticles (mass fractals) with the dimension \( D = \alpha \). In the case when \( 3 < \alpha < 4 \), scattering from nanoparticles with a nonsmooth fractal surface is observed, the fractal dimension of which is determined as \( D_s = 6 - \alpha \). The exponent \( \alpha \) in this case is defined as \( \alpha = \Delta \lg I(s) / \Delta \lg s \).

On the SAXS curve of diatomite from the Utesai deposit, three rectilinear sections are distinguished, corresponding to the values of the scattering vector \( 0.013 - 0.026 \ \text{Å}^{-1}, 0.031 - 0.061 \ \text{Å}^{-1} \), and \( 0.067 - 0.095 \ \text{Å}^{-1} \). The parameter \( \alpha \) for these sections is \( 2.59, 1.56 \), and \( 3.73 \), respectively. The most large-scale scattering objects behave like mass fractals with a fractal dimension \( D = \alpha = 2.59 \), which is typical for branched self-organized porous structures. The second rectilinear segment of the indicatrix \( \Delta \lg I(s) - \Delta \lg s \) corresponds to inhomogeneities with fractal dimension \( D = 1.56 \), which can be clusters in the form of curved chains of spherical pores of nano- and micrometer scale, possibly pore channels. In addition to mass fractals, the natural diatomite of the Utesayskoye field exhibits inhomogeneities with a fractal interface. The dimensions of such inhomogeneities are \( 7 - 9 \) nm, and the fractal dimension is \( D_s = 6 - \alpha = 2.27 \). This value of the fractal dimension corresponds to a slightly indented surface, if we take into account that a perfectly smooth surface has \( D_s = 2.0 \), and a highly indented porous surface - \( 3.0 \). Fractal characteristics of all studied materials are shown in Table 2.

Dispersed microsilica obtained from natural diatomite also contains three types of scattering inhomogeneities, two of which are mass fractals with dimensions \( 2.32 \) and \( 2.13 \). The scale of such objects is \( 8 - 40 \) nm. Small-scale pores \( 4 - 8 \) nm have rather heavily indented interfaces (\( D_s = 2.64 \)). Condensed silica fume, in contrast to other investigated dispersed powders, does not have X-ray scattering inhomogeneities that could be attributed to mass fractals. The interfaces of the SiO\(_2\) particles - the pores have a fractal dimension \( D_s = 2.40 \). White microsilica contains fractal clusters of pore space with linear dimensions of \( 4 - 25 \) nm. The interfaces of larger scattering formations (\( 25 - 40 \) nm) are strongly indented - their fractal dimension is \( D_s = 2.83 \). The scattering curve \( \Delta \lg I(s) - \Delta \lg s \) of the FRONT - VIP filler powder has two crossover points: branched porous aggregates \( 20 - 40 \) nm in size have a fractal dimension \( D = 2.59 \), and inhomogeneities on a scale of \( 12 - 20 \) nm have highly irregular surface with \( D_s = 2.70 \). In addition, the data of small-angle X-ray scattering allow us to suggest that on the surface of the smallest elements of the structure of the filler powder \( 4 - 12 \) nm, there may be layers of scattering inhomogeneities with a lower electron density than that of silicon dioxide (parameter \( \alpha = 4.10 \)).

Table 2 - Fractal characteristics of the investigated materials

| № | Material                          | \( \Delta s, \text{Å}^{-1} \) | \( \alpha \) | \( D \) | \( D_s \) | \( d, \text{nm} \) |
|---|-----------------------------------|------------------|---------|-------|-------|----------|
| 1 | Natural diatomite                 | 0.013 – 0.026    | 2.59    | 2.59  | 2.27  | 24 – 48  |
|   |                                   | 0.031 – 0.061    | 1.56    | 1.56  |       | 10 – 20  |
|   |                                   | 0.067 – 0.095    | 3.73    |       |       | 7 – 9    |
| 2 | Dispersed microsilica obtained    | 0.016 – 0.025    | 2.32    | 2.32  |       | 25 – 40  |
|   | from diatomite                    | 0.025 – 0.080    | 2.13    | 2.13  |       | 8 – 25   |
|   |                                   | 0.080 – 0.160    | 3.36    |       | 2.64  | 4 – 8    |
| 3 | Condensed microsilica             | 0.016 – 0.160    | 3.60    |       | 2.40  | 4 – 40   |
| 4 | White soot                        | 0.016 – 0.025    | 3.17    |       | 2.83  | 25 – 40  |
|   |                                   | 0.025 – 0.160    | 2.66    |       | 4.40  | 4 – 25   |
| 5 | FRONT - VIP                       | 0.016 – 0.032    | 2.59    | 2.59  | 2.70  | 20 – 40  |
|   |                                   | 0.032 – 0.056    | 3.30    |       |       | 12 – 20  |
|   |                                   | 0.056 – 0.160    | 4.10    |       |       | 4 – 12   |

Analysis of the data obtained gives grounds to believe that the studied granular systems are suitable: for the creation of new generation heat-insulating materials; as fillers for LTC, VIP. At the same time, condensed microsilica and white soot do not require preliminary heat treatment, since
their low moisture content is determined by the production conditions (subject to the rules of storage and transportation of bulk material). Dispersed microsilica obtained from diatomite and natural diatomite must be calcined at temperatures not lower than 400 - 500 °C for 3 - 5 hours. This modification of dispersed powders leads to their deep dehydration and helps to remove residues of organic material of sedimentary origin present in natural diatomites.

**Conclusions**

1. It was found that dispersed microsilica obtained from natural diatomite also contains three types of scattering inhomogeneities, two of which are mass fractals with dimensions 2.32 and 2.13. The scale of such objects is 8 - 40 nm. Small-scale pores 4 - 8 nm have rather heavily indented interfaces ($D_s = 2.64$). Condensed silica fume, in contrast to other investigated dispersed powders, does not have X-ray scattering inhomogeneities that could be attributed to mass fractals. The interfaces of the $\text{SiO}_2$ particles - the pores have a fractal dimension $D_s = 2.40$. White microsilica scoot contains fractal clusters of pore space with linear dimensions of 4 - 25 nm. The surface of the larger scattering formations (25 - 40 nm) are strongly indented - their fractal dimension is $D_s = 2.83$. The scattering curve $\log I(s) - \log s$ of the FRONT - VIP filler powder has two crossover points: branched porous aggregates 20 - 40 nm in size have a fractal dimension $D = 2.59$, and inhomogeneities on a scale of 12 - 20 nm have highly irregular surface with $D_s = 2.70$. In addition, the data of small-angle X-ray scattering allow us to suggest that on the surface of the smallest elements of the structure of the filler powder (4 - 12 nm), there may be layers of scattering inhomogeneities with a lower electron density than that of silicon dioxide (parameter $\alpha = 4.10$).

The results obtained confirm the presence of a developed pore space of particles and agglomerates of dispersed silicon dioxide of nanometer sizes, can be used to calculate the effective thermal conductivity of heterogeneous systems, for example, mineral silica powders of various origins. The investigated dispersed materials have similar parameters of the pore system at the nanometer level.

2. As a result of the analysis of the influence of the structural parameters of a granular system formed from synthesized silicon dioxide particles, it was found that during the production of LTC, their heat-shielding properties can be adjusted by changing: pressure, viscosity of the molecular weight of the gas; porosity of the macrostructure and clusters; thermal conductivity of the solid and gas phase of the system; accommodation coefficient; coordination number; size of primary particles; fractal dimension that characterizes the topological features of the structure of particles, aggregates, globules, clusters and their tendency to dissipate the energy of gas molecules.

**Conflict of interests**

On behalf of all authors, the correspondent author declares that there is no conflict of interests.

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**Cite this article as:** Sangulova IB, Selyaev VP, Kuldeev EI, Nurlybaev RE, Orynbekov YS. Assessment of the influence of the structural characteristics of granular systems of microsilicon on the properties of thermal insulation materials. Kompleksnoe Ispol’zovanie Mineral’nogo Syr’ya = Complex Use of Mineral Resources. 2022;320(1):5-14. https://doi.org/10.31643/2022/6445.01

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Тыйрышкітелген микрокремний жүйелерінің құрылымдық сипаттамаларының жылу оқшаулағыш материалыдардың қасиеттеріне әсерін бағалау

1 Сангулова И.Б., 2Селяев В.П., 3Кулдеев Е.И., 4Нурлыбаев Р.Е., 4Орынбеков Е.С.

1"Халықаралық білім беру корпорациясы" Жауапкершілігі шекеулі серкімдестік, Алматы, Қазақстан
2 Н.П. Огарев ат. Мордовия мемлекеттік университеті, Мордовия, Ресей
3Сәтбаев Университеті, Металлургия және кен байыту институты, Алматы, Қазақстан
4 "SAVENERGY" Жауапкершілігі шекеулі серкімдестік, Алматы, Қазақстан
Оценка влияния структурных характеристик зернистых систем микрокремнезема на свойства теплоизоляционных материалов

1 Сангудова И.Б., 2Селяев В.П., 3Кульдеев Е.Е., 4Нурлыбаев Р.Е., 5Орынбеков Е.С.

1Товарищество с ограниченной ответственностью "Международная образовательная корпорация", Алматы, Казахстан
2 Мордовский государственный университет им. Н.П. Огарева, Мордовия, Россия
3 Сабаевский университет, Институт металлургии и обогащения, Алматы, Казахстан
4 Товарищество с ограниченной ответственностью "SAVENERGY", Алматы, Казахстан

АННОТАЦИЯ

В статье рассматриваются экспериментальные исследования размера и формы структурированных частиц микрокремнезема методом малоуглового рентгеновского рассеяния и теоретическое описание фотофонового процесса теплопередачи в сложных гетерогенных структурах с целью оценки структурных характеристик гранулированных систем для свойств теплоизоляционных материалов. Механизм теплопередачи в гранулированных, пористых системах довольно сложен, поскольку теплообмен происходит в материале, состоящем из двух фаз (твердой и газовой) и на


Информация об авторах:

Сангунова Индира Беркинаевна

Заведующий лабораторией, факультет строительных технологий, инфраструктуры и менеджмента, Товарищество с ограниченной ответственностью "Международная образовательная корпорация", Алматы, Казахстан. Email: indiraberkinboykocy@gmail.com, https://orcid.org/0000-0002-4066-8238

Селев Владимир Павлович

Кандидат геолого-минералогических наук, проректор по корпоративному развитию и стратегическому планированию, Sattaybe University, Институт металлургии и обогащения, Алматы, Казахстан. Email: kuldeev_erhan@mail.ru, https://orcid.org/0000-0003-3343-094X

Кулдеев Ержан Итепенович

Доктор геолого-минералогических наук, профессор, заведующий кафедрой строительных конструкций, Алматы, Казахстан. Email: rusya_nre@mail.ru, https://orcid.org/0000-0003-0161-6256

Нурлыбаев Руслан Ержалиевич

РНД директор, директор товарищества с ограниченной ответственностью "SAVENERGY", Алматы, Казахстан. Email: eljan_79@mail.ru, https://orcid.org/0000-0003-2131-6293

Орнбеков Елжан Серикович

Кандидат технических наук, научный консультант товарищества с ограниченной ответственностью «SAVENERGY», Алматы, Казахстан. Email: ev_kudinov, ev_sevostyanov@abs-net.ru, https://orcid.org/0000-0003-2131-6293

Ключевые слова: рентгеновский дифрактометр, микрокрежмейн, теплопроводность, диаграма, структура, наполнитель.

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Передача тепла в жидкостных теплоизоляционных покрытиях может осуществляться от одной твердой частицы к другой. В этом случае теплопроводность будет зависит от: химического и элементного состава материала; гранулометрии частиц; топологии поверхности - наличие неоднородностей, дефектов на поверхности; количества капиляров и площади контакта между частицами. Теплопередача газа в порах осуществляется при столкновении молекул газа. Теплопроводность будет определяться соотношением свободного пробега молекул и линейных размеров пор, температурой и динамической вязкостью газовой фазы, характером взаимодействия молекул газа с твердой фазой. Передача тепла излучением зависит от природы частиц, диэлектрической, магнитной проницаемости и степени черноты поверхности частиц. Основываясь на анализе возможных механизмов теплопередачи в гранулированных системах, можно утверждать, что эффективная теплопроводность системы зависит, при прочих равных условиях, от структуры порового пространства гранулированных материалов, топологии и количества соприкосновений частиц. Рассматривая идеализированные модели структуры зернистых материалов в виде упорядоченных складок идеально гладких шариков, мы можем получить несколько вариантов структур: с четырехгранной; шестиугольной; кубической упаковкой шариков.

Комплексное Использование Минерального Сырья. №1 (320), 2022 ISSN-L 2616-6445, ISSN 2224-5243

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