Heat conductivity of aerogel-based rolled materials for high-thermal isolation for equipment and pipelines

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Abstract. In this article, the general information about aerogels as well as application areas of materials based on them are presented. Scientific and technical review on heat conductivity of aerogel-based thermal insulation materials was made. It was determined, that among the Russian studies the results of behaviour of these materials under high temperatures are not presented. Comprehensive studies of thermal characteristics, including heat conductivity values in temperature range of 10–650 °C (where 650 °C is the maximal operating temperature) for the thermal insulation rolled materials based on TiO₂-aerogel DRT06-Z (Alison Aerogel) were carried out. The mathematical relationship between heat conductivity and operating temperature in range of 10–650 °C was determined. Using the obtained results, the calculation of thickness of insulation for the studied aerogel-based rolled materials was realized according to the construction rules SP 61.13330.2010, that can be applied for design of high-heat insulation for equipment and pipelines.

1. Introduction
During the last years, the products based on composite materials using aerogel of different composition as a high-porosity components are more often in available at the market of heat insulating materials. Aerogel is a gel-like material where liquid phase is fully replaced by gaseous phase. Structure of aerogel is characterized by mainly open porosity (at least, 90 % of pores are micro- and nanosized) and a high specific surface area. Structurally, aerogel is rigidly-bound particles of organic or inorganic component, that form a high-porosity framework, filled by air or any gas. Such structure of the material provides with low values of heat conductivity, light refraction coefficient, dielectric permeability and sound velocity [1].

The first mention of aerogel in scientific-technical literature was appeared in the 30s of the XX century. However, practical application of it is limited because of the industrial technology absents. At the end of the XX century, only, synthesis methods for different types of aerogels were refined that...
allowed introduction of materials based on them into different areas. Nowadays, the most popular application area for aerogels are space industry, chemistry, energetics, medicine, protection of the environment etc. [2–7]. Also, aerogels, due to unique thermal characteristic, can be applied as an isolative material from high and cold temperatures.

At present time, aerogel same as a vacuum insulated panel are the one of the most effective thermal insulative materials (with heat conductivity lower than 0.020 W/(m·°C) at room temperature). But, aerogels vs. vacuum insulated panels potentially can be exploited at high temperatures.

Nowadays there are a lot of composite materials bearing aerogels in combination this different functional components [8, 9]. To achieve heat insulative and heat protective characteristics the inorganic refractory components such as ceramics, glass and mineral fibers normally are used. As a matrix the organic and inorganic aerogel is used. But, if a high-temperature heat protection is required, inorganic aerogel is used, only. Among the inorganic aerogels, only TiO$_2$-aerogels are synthesized commercially [10–13].

But a quite high costs of aerogel-based materials vs. ordinary heatinsulative analogues leads to a limited application of them in construction industry as insulators. From the other hands, the complex of improved thermal, physical and mechanical characteristics typical for advanced aerogel-based rolled materials provides many significant advantages when a heat insulation of pipes, reservoirs, equipment. That why such materials more are often used in industry (Figure 1), although a high price. This article is focused on description of study of heat conductivity for the rolled material DRT06-Z (Alison Aerogel), consisting of glass fiber and TiO$_2$-aerogel as well as calculation of a required insulation thickness for equipment and pipeline under a high-temperature maintenance, using the obtained results.

![Figure 1](image1.png)

**Figure 1.** Application of aerogel-based rolled materials for heat insulation of equipment and pipelines.

### 2. Study background

The above review of up-to-date scientific-and-technological literature about heat conductivity of aerogel based materials demonstrates almost complete absence of such studies in Russia. Russian literature sources are focused on review of foreign studies [1, 14] or studies of heat conductivity of aerogel based materials at 25 °C [15, 16], applicable for civil application only, but not applicable for technical insulation. So, to determine thermal characteristics of construction materials the comprehensive study for rolled aerogel-based material DRT06-Z (Alison Aerogel) including the tests on such performance characteristics as steam permeability, sorption humidity, short-term and long-term water absorption, compressive strength at 10 % of deformation, tensile strength parallel to the front surfaces, radius of curvature, heat conductivity in temperature range of 10–650 °C (where 650 °C is the maximal operating temperature for this material) was carried out in the laboratory of construction thermophysics NIISF RAASN and Certification research center «Thermal insulation».
Heat conductivity test at high temperature for the studied samples was carried out with the device GHP 456 Titan (Figure 2). In the test three samples of material DRT06-Z were prepared in form of plates with size of 300x300 mm in nitrogen protective medium according to Russian Standard GOST 7076 in temperature range of 100–650 °C. The heat conductivity test in temperature range of 10–45 °C was carried out with the device ITP-MG4 «250» and the plate-like samples with size of 250x250 mm. As a result was average value of heat conductivity among all tested samples at each temperature point [17].

![Figure 2. Heat conductivity test applying machine GHP 456 Titan.](image)

Table 1 demonstrates the resulted experimental data of heat conductivity for the rolled material based on aerogel DRT06-Z (Alison Aerogel).

| Average temperature of a sample, °C | Heat conductivity of dry sample, \( \lambda_0 \), W/(m·°C) |
|-----------------------------------|---------------------------------------------------|
| 10                                | 0,019                                             |
| 25                                | 0,020                                             |
| 125                               | 0,025                                             |
| 300                               | 0,039                                             |
| 400                               | 0,056                                             |
| 500                               | 0,072                                             |
| 650                               | 0,112                                             |

Figure 3 graphically presents effect of different temperature on heat conductivity for the tested materials.
Figure 3. Effect of temperature on heat conductivity of aerogel DRT06-Z.

The study result show, that at high temperatures (higher than 600 °C) the agglomeration of SiO₂-nanoparticles takes place, which, normally, leads to structure transformation of aerogel [18–20]. Variation in porosity as well as increasing of radiation effect when testing under high temperatures initiates a nonlinear growth in aerogel heat conductivity that is in agreements with the obtained data (Figure 3).

3. Using the results
The determined relationship between heat conductivity of dry roll material based on aerogel DRT06-Z (λ₀, W/(m·°C)) and average temperature (tₐ, °C) can be described by equation (1) and allow calculation a heat conductivity in all temperature range of the studied material application:

\[ \lambda = 0.0182 \cdot e^{0.0028 \cdot t_{\text{aver}}} \]  \hspace{1cm} (1)

Using these data, the calculation of thermal insulation thickness for roll material based on aerogel DRT06-Z was realized according to standard procedure SP 61.13330.2010 "SNiP 41-03-2003 Thermal insulation of equipment and pipelines". In addition, the thickness of the insulation layer according to the normalized heat flux density for pipelines with positive temperatures located in the open air and indoors, as well as the thickness of the insulation layer at certain temperature at the insulation surface were determined.

In Table 2 the calculating data for the insulation layer at certain temperature at the insulation surface according to standard procedure 2.3 SP 61.13330.2010 are shown taking into account thicknesses for products from rolled material based on aerogel DRT06-Z (Alison Aerogel): 3 mm, 6 mm, 10 mm. Temperatures at surface of thermal insulation were taken for insulated surfaces located in the working or serviced areas of the room according to paragraph 6.7 of SP 61.13330.2010.

Table 2. Required thickness of rolled material DRT06-Z vs. temperature of its external surface.

| Pipeline diameter, mm | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|-----------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                       |    |     |     |     |     |     |     |     |     |     |     |     |
| Temperature of thermal element, °C |     |     |     |     |     |     |     |     |     |     |     |     |
| 50                     | 40 | 45  | 55  |     |     |     |     |     |     |     |     |     |
| 100                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 150                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 200                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 250                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 300                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 350                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 400                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 450                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 500                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 550                    |    |     |     |     |     |     |     |     |     |     |     |     |
| 600                    |    |     |     |     |     |     |     |     |     |     |     |     |

Insulation thickness, mm
4. Conclusions

Complex of studies of rolled material based on aerogel DRT06-Z (Alison Aerogel) allowed obtaining some performance thermal characteristics, including properties, those were studied for heat insulative aerogel based materials for the first time. The obtained values of hat conductivity in temperature range of 10–650 °C are significantly lower vs. ordinary thermal insulators, applied for technical insulation at high temperatures. Such comparative analysis will be carried out in further studies. The determined mathematical relationship between temperature and heat conductivity allowed calculation of thermal insulation thickness for roll material based on aerogel DRT06-Z to standard procedure SP 61.13330.2010 that can be used when design thermal insulation of equipment and pipelines exploited at high temperature.

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