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Thermal insulation systems for the Arctic

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Abstract. Approximately 20 percent of the territory of Russian Federation is located in the Arctic, there resides about 1.5 million people and about 30 large and medium sized cities are located. Another significant factor is the concentration in the territories north of the 67th parallel of a large number of developed and promising mineral deposits: oil and gas among them. In connection with the extraction and processing of natural resources, it is necessary to develop construction technologies in conditions of extremely low natural temperatures and permafrost. Construction in such regions is becoming one of the priorities of modern technological development, which provides for the creation of special construction systems oriented to the construction of high-risk facilities in the Arctic Circle. Such facilities include sea oil ships, oil and gas platforms, equipment for transportation of petroleum products, gas reduction units, and oil refining plants. In each of the above listed objects, it is necessary to correctly choose the insulation, which will ensure a high thermal insulation ability, and also be fireproof and durable. The research methodology outlined in the article is based on the method of mathematical planning of the experiment and statistical processing of its results with subsequent analytical optimization. Engineering interpretation of the results allowed to form a nomogram for the selection of technological parameters. The decisions, which became the subject of discussion in the article, are relevant for any region in which oil and gas production on the sea shelf and, especially, in severe climatic conditions develops.

1. Introduction

The development of mining operations takes place in all countries that have territories beyond the Arctic Circle. Significant experience has been accumulated by British, Canadian and Scandinavian companies. Especially in terms of offshore oil production zones, autonomous drilling platforms and also in terms of transportation of these products in subzero temperatures and extreme weather conditions. It should be noted that the main territory for which design solutions were developed and where their implementation was realized is the North Sea water area.

For example, the Norwegian oil platform Troll is the tallest building in the history of mankind, which was moved relative to its starting position. It was towed over a distance of more than 200 kilometers in 1996 to the North Sea in 80 kilometers to the North-West from the city of Bergen in the South-West of Norway. The platform stands on the seabed 303 meters below the sea surface, platforms height is 472 meters. At the location of the Troll platform, the Gulf Stream flows, which softens the climatic conditions.
In Russia, experience in the construction and operation of oil and gas platforms is inferior to foreign ones. The only platform that produces oil products on the Russian Arctic shelf is the offshore ice-resistant fixed platform (OIRFP) Prirazlomnaya. Production on this platform began in 2014, and the first million barrel of oil was produced in September of the same year.

The use of thermal insulation is necessary in terms of technological effectiveness of the installation, fire safety, comfort of operation and minimization of costs for all maintenance operations of the technological process.

2. Problem statement
The use of heat-insulating materials is an effective way of forming an insulation shell, as well as reducing energy costs and improving the durability of building structures. The properties of stone wool based products and their operational stability are largely determined by the conditions for the formation of a mineral wool carpet, the uniformity of distribution in the carpet and the curing of the binder and the conditions of heat treatment.

From the standpoint of energy efficiency, the criterion for the functionality of the building system is the thermal resistance of the structure, and the parameter determining the choice of the thermal insulation material (TIM) is its thermal conductivity. From the point of view of operational stability, the strength characteristics are the main ones. This is confirmed, among other things, by theoretical research. The logic here is as follows: a decrease in strength characteristics leads to the draft (compaction) of the material, that is, to an increase in the average density, a. consequently, to an increase in thermal conductivity and a drop in the thermal resistance of the system.

Special requirements are imposed on the constructions and systems of their isolation, operating in extreme (cold or hot) climate. In a hot climate, overheating of raw materials or petroleum products can lead to the release of volatile fractions, which causes an increase in their content in the premises of the facility, with insufficient level of sealing, and also a blast from any spark. In conditions of low temperatures, the thickening of liquid hydrocarbons is highly undesirable, since it interferes with the transfer technology. In this case, heating systems with thermal insulation are used.

The thermal insulation of specialized structures (associated with the technology of hydrocarbon production, processing and transportation) must meet a number of requirements. First, it must be thermo-technical effective, (to provide the normal thermal resistivity of the inolactic cell for the region). Secondly, to be non-combustible and to withstand not only calculated fire temperatures (600°C), but also to protect their properties at temperatures of 1000-1200°C (such temperatures are created when the oil is heated in the insulated or partially insulated rooms).

Thirdly, heat-insulating products should not contain components supporting combustion, or emitting toxic substances during combustion. And last but not least, thermal insulation materials must be energy efficient, that is, the costs for the installation of insulation systems (the production of thermal insulation, its installation and operation of structures) should be repaid as a result of their use during the regulatory period: from 5 to 10 years.

3. Results and discussion
Most of the domestic technologies are oriented to the release of mineral wool products of a dimensional-oriented structure, which is formed with the help of special aggregates: a spreader and a corrugator placed in the production line. The properties of mineral-fiber TIM are determined by a competent establishment of all stages of the technological process. The properties of fiber (its strength parameters, elasticity, resistance to aggressive enviroment, etc.) are formed during the stages of preparation of the charge, its melting and processing into fiber. The uniformity of distribution of the binder in the fibrous carpet is due to its type and the condition of introduction into the fibrous medium. The properties of the mineral wool carpet are determined by the conditions for the formation of its structure, which, on the one hand, must ensure the maximum interlacing of the fibers, and on the other hand, ensure the continuity of the carpet. The final stage, whose goal is stabilization of the structure of...
the carpet and the formation of properties of the products is heat treatment. At the same time, the uniformity of the binder is uniformly cured.

The objective of the research was to optimize the process of thermal processing of mineral wool carpet, aimed at increasing the operational resistance of products and reducing energy costs for heat treatment.

It was found that the greatest influence on the experimental results (response functions) is provided by the following factors: average carpet density \((x_1)\); content of binder \((x_3)\); fiber diameter \((x_6)\); length of fiber \((x_7)\); the degree of compaction of the two-layer carpet \((x_{10})\), the temperature of the coolant, \(^{9}\text{C} \) \((x_{11})\). The plan for the second stage of the experiment was constructed taking into account the areas of variation of these factors and in accordance with the conditions defined above.

The subject of the study was precisely those factors whose influence on the result was manifested to the greatest extent. As a result, after evaluating the significance of the coefficients and checking the adequacy of the models, the following regression equations are obtained:

\[
y_1 = 38 + 18x_1 + 5x_3 + 5x_6 + 5x_7 + 5x_{11} + 4x_1x_{10} - 2x_1x_7 + 3x_1x_{11} - 2x_6x_{10}
\]

If the confidence interval \(\Delta b = 1.6\)

\[
y_2 = 6.5 + 2.2x_1 + 0.9x_3 + 1.2x_7 + 0.9x_{10} + 0.8x_{11} - 0.3x_1x_7 + 0.3x_1x_{11} + 0.4x_3x_7 - 0.5x_{10}
\]

If the confidence interval \(\Delta b = 0.2\)

\[
y_3 = 96 + 36x_1 + 9x_7 + 8x_{10} + 4x_1x_{10} - 5x_7^2
\]

If the confidence interval \(\Delta b = 3.2\)

\[
y_4 = 37.5 + 0.8x_1 + 0.3x_6 + 0.4x_{10} + 0.2x_1x_{10} - 0.2x_6^2
\]

If the confidence interval \(\Delta b=0.12\)

The principle nature of the influence of factors on the results of the second stage did not change in comparison with the results of the first stage. At the same time, some paired and quadratic interactions that were significant in predicting product properties (solving interpolation problems), parameters of their manufacture and choosing an optimization strategy were manifested.

The method of analytical optimization of technological parameters is developed in MSUCE and passed approbation at research of technologies of building materials of various functional purpose. A special program for the GJ-STAT-06 computer was created, which allows both processing the results of the experiment and performing analytical optimization of the polynomials obtained.
Figure 1. The nomogram for selecting manufacturing parameters of mineral wool panels. The dependence of the compressive strength at 10% deformation, the peel strength of the layers, the average density and thermal conductivity of the mat from the average density after corrugator, mat compaction level (CL), the binder consumption (Cb), the diameter (D) and a length (L) of fibers.

Based on the optimization results, a clear correlation is established between the average density of panels and their thermal conductivity. Both of these dependences on the average density of the carpet are linear (Figure 1). This feature was taken into account in the formation of the II sector of the nomogram, where the dependence of the thermal conductivity of the panels on their average density and diameter of the mineral fibers was determined.

According to the III sector of the nomogram, the strength of the panels is determined at 10% of the deformation from the carpet density and the binder consumption, and in the sector IV - the strengths for the separation of the layers, depending on the density of the carpet and the length of the fiber.

Thus, using four sectors of the nomogram, a relationship is established between the characteristics of the carpet, the properties of the fiber, the binder flow, the molding parameters, and the properties of the product. This nomogram allows us to solve both the direct problem: to predict the properties of the products depending on the set values of the variable factors, and the inverse problem: to choose the ratio of the parameters characterizing the technological process, which meet the requirements for strength, density, thermal conductivity.

Studies conducted at the MSUCE show that thermal insulation products - plates based on a modified mineral fiber - meet completely. There is the possibility of manufacturing both construction and technical insulation, as well as systems with the use of such insulation. For insulation of technological and household premises, panels of 80-100 kg / m³ density and thermal conductivity of up to 0.040 W / (m·K) are used. The surface density of the shell material is 100 kg / m².
The activity in this direction of the Rockwool company deserves special attention. This company created a new type of mineral fiber called ROXUL with a high content of alumina and low content of silicon. Mineral wool based on such fibers has increased strength and temperature resistance. The bio-solubility of this fiber complies with regulatory requirements.

System optimization of thermal insulation of pipelines presupposes the solution of several tasks: an assessment of the design parameters of the heat insulation of the pipeline and, in particular, the thickness of the thermal insulation and the method of its installation; choice of the method of thermal insulation of the pipeline: the type of heat-insulating material, taking into account the technological features of its production; optimization of the cost of manufacturing this material.

Depending on the application conditions, the requirements for thermal insulation materials and system solutions also change. In cryotechnologies, preference is given to materials that have closed porosity, a very low thermal conductivity and those that do not collapse at negative temperatures close to absolute zero; the best products of foamed glass or expanded volcanic glasses have proved to be the best. For most types of technical insulation, it is preferable to use products based on stone wool, glass or basalt fiber. Heat-insulating canvases, panels and mats can be made from basalt fiber. Mineral wool (stone or glass) is used to produce plates, mats and shaped products.

A feature of these materials is a high open porosity, which implies their mandatory protection against atmospheric influences. Their favorable features are low density and heat conductivity, incombustibility, high flexibility and the ability to fit tightly to the insulated surface. Fastening of such materials is carried out with the help of special bandages or wire with subsequent application of protective plasters, fixing of special metal casings, packing (winding) of roll materials: glass fibers impregnated with modified bitumen.

Cable heating of pipelines in combination with its external heat insulation is the most promising from the technological point of view of maintaining the working cycle of various production processes. The use of heating cables in the industry makes it possible to provide the required temperature and viscosity of the liquids transferred through the pipes. Maintaining the optimum temperature regime prevents precipitation, increased viscosity and lumps, and reduces the rate of fluid transfer through the pipe. This ensures the necessary technological regime and reduces the risk of possible material losses.

4. Conclusion
The results of the calculations, summarized in the nomogram (Figure 1), allow us to conclude that at temperatures of the coolant of 180-200° C (usually used in production), the duration of isothermal aging is not significant (25-40 sec) and the total duration of heat treatment is regulated mainly by the drying and heating time of the mineral wool carpet. Consequently, by ensuring the appropriate rates of blowing the heat carrier through the material, it is possible to reduce the time of its heat treatment by more than 2 times..

Basic and variable parameters of heat treatment are determined using nomograms. This allows us to make decisions when adjusting technological parameters, in particular, when switching to new types of products, changes in raw material recipes and characteristics of mineral fibers.

The developed technique for optimizing the heat treatment of mineral wool carpet is based on the results of mathematical planning and statistical techniques. In addition to classical methods, the method of analytical optimization developed at the departments of ICA NRU MSUCE is applied. The resulting analytical dependencies (and their graphical interpretation) allows to develop algorithms for controlling production with the help of a computer. A further area of research is the extension of this method to the technology of other heat-insulating materials.

In oil pipeline isolation systems, combined solutions are used: for the metal of the oil pipeline, place a heating cable (with a calculated step), then heat insulation (as rule, technical mats) is laid and everything is protected by an external weatherproof layer.
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