SAFETY OF TECHNOLOGICAL PROCESSES AND PRODUCTION

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ON THE INFLUENCE OF THERMAL AND INERTIAL PROPERTIES OF INSULATING MATERIALS OF LIQUEFIED NATURAL GAS TANK IN THE CALCULATION OF HEAT LOSSES

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Abstract. Negative factors in ensuring the safe operation of liquefied natural gas reservoirs are identified, which manifest themselves during liquefaction, unloading, receiving and regasification of the product. The role of heat losses in ensuring the safe operation of tanks is shown. Methods are analyzed in terms of considering possible variable thermal effects on the outer surface of a tank with liquefied natural gas. A method for thermal calculation of an isothermal tank is presented, which makes it possible to consider the thermal inertia of multilayer insulation when exposed to thermal radiation from a fire of variable intensity.

Keywords: isothermal tank, liquefied natural gas, thermal insulation, thermal inertia

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Introduction

In the current economic conditions, there is an increase in the dynamics of the use of liquefied natural gas (LNG), which leads to the diversification of the global energy market, which expands the possibilities for solving problems of gas supply to remote and hard-to-reach areas of our country. In the Russian Federation, natural gas liquefaction plants are already operating on Sakhalin Island and the Yamal Peninsula, and the design of such complexes for the development of the Shtokman gas condensate field is underway. Mandatory and necessary part of industrial and logistics complexes designed for liquefaction, unloading, receiving and LNG regasification, large above-ground tanks are becoming available [1].

The LNG storage process is the most important element of an LNG plant and the terminal that carries out its reloading. Similar structures are located over large areas and are considered a potential source of production risks. LNG is pumped from liquefaction plants to tanks or tankers through product pipelines using special pumps. LNG is usually stored at a temperature of -160 °C and slight excess pressure. The most common is the isothermal storage method, which is carried out at an excess pressure in the range of 4.9÷6.8 kPa and the LNG boiling point corresponding to the absolute pressure value. An approximate design of an above-ground isothermal LNG storage tank is shown in fig. 1.

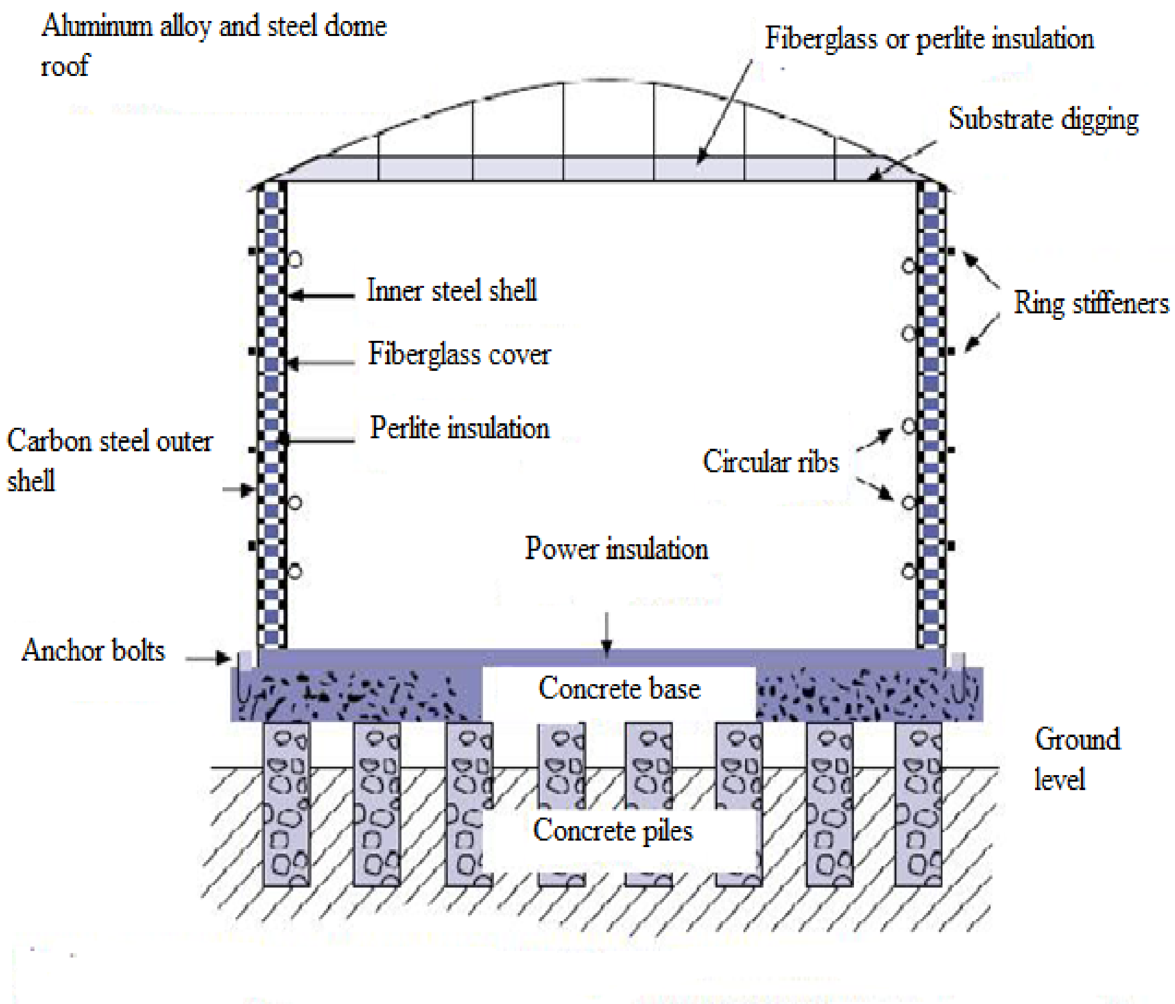

Fig. 1. **Approximate design of an above ground tank isothermal storage of LNG**

Main part

Existing domestic and world experience shows that at fuel and energy complex facilities related to LNG transportation, several hundred people die annually as a result of accidents associated with violation of the thermal conditions of tank operation [2].

There is also the problem of LNG losses during storage in tanks, which is closely related to ensuring their safe operation. Thus, according to information from the KOGAS-Tech company (36 operating tanks), when operating a typical tank with a useful volume of 200 000 m^3, the permissible standard loss of methane per day is 0,05 %, which is 100 m^3 of LNG leakage due to external thermal effects [3].

The value of the specific mass average daily evaporation rate of liquefied methane is determined by the equation:

$$m = \frac{M_н}{F \cdot \tau},$$

there Mn is the rate of mass losses per day; F – free surface area of LNG in the tank; τ – LNG evaporation time.

After simple calculations, the value of the specific mass average daily evaporation rate of liquefied methane m=0,1 g/(m^2·s) is determined. This assumes that, subject to isothermal conditions, when the temperatures of the liquid phase of methane and its saturated vapors are equal and amount to approximately 164 °C, and the excess pressure of such vapors does not exceed 10 kPa, about 0,1 g of methane evaporates per unit of free surface per second. However, violation of the isothermal condition, including due to external thermal influence, sharply changes the entire thermodynamics of the gasification process of the liquid fraction of LNG, which can lead to an emergency outflow of the gas fraction of LNG into the surrounding space with the subsequent formation of a fire and explosive mixture [4]. Thus, one of the necessary conditions for complying with the conditions for the safe operation of LNG tanks under external variable thermal influence is maintaining its isothermally, which includes, among other things, creating effective thermal insulation of the outer surface.

By design, isothermal tanks are usually thin-walled cylindrical vessels of significant capacity, insulated on the outside with a variety of materials with a thermal conductivity coefficient $\lambda<0,1$ W/(m °C), such as mineral felt, fiberglass, and foamed polymer materials.

Modern classification involves dividing LNG tanks into the following main types:

– single tank consisting of an internal low-temperature tank and an outer casing, the so-called single containment tank;

– a double tank having a design similar to a single one, and made of a material that retains structural properties at low temperatures, the so-called double containment tank;

– a fully sealed tank, which is a further development of the double tank design with the ability to ventilate the intershell space and control the concentration of LNG vapors, the so-called full containment tank;

– a membrane-type tank, in which the low-temperature container is made of corrugated plates of relatively small thickness [3].

Analysis of design solutions used in large volume tanks and the course of thermal processes occurring during their operation, made it possible to identify certain negative factors that appear during liquefaction, unloading, receiving and LNG regasification:

– possible time dependence of the thermophysical properties of materials used in the layers of backfill insulation;

– unacceptable deformations of the structural elements of the tank during the process of stratification or turning over layers of the liquid fraction of LNG;

– loss of tightness of the outer casing of the tank with subsequent ignition of the resulting fire-explosive mixture of product and air [5].

Perlite is often used as a thermal insulation material filling the interwall space of double tanks, which has an undesirable compaction feature with a subsequent increase in the value of the thermal conductivity coefficient λ. This phenomenon contributes to an increase in heat flow from the environment surrounding the tank, which and leads to an increase in the intensity of LNG evaporation [6].

Since almost all thermal insulation materials have finite vapor permeability, during the operation of isothermal LNG tanks, the problem of increasing the humidity of such materials due to the condensation process was identified, which intensifies corrosion processes and worsens the thermal insulating properties of the material. As moisture condenses, the relatively insignificant value of the thermal conductivity coefficient of the heat-insulating material ($\lambda<0,1$ W/(m °C) approaches the value of the thermal conductivity coefficient of ice ($\lambda\approx$ 2,22÷3,48 W/(m °C), which significantly worsens the operational parameters of isothermal LNG tanks.

The solution to such problems lies in the use of new materials. One such materials may include foam glass, which is a cellular material made from glass by foaming carbon dioxide generated during the combustion of fine coal powder. Foam glass is a non-flammable material with moisture-repellent ability and an extended temperature range of its use (-260 °C ÷ +430°C), however, the density values ($\rho\approx$120÷140 kg/m^3) and specific heat capacity (cp≈0,84 kJ/(kg °C) of this material predetermine the need to take into account its thermal inertial properties [7].

Overcoming all of these factors in one way or another involves the use of an effective method for calculating the thermal insulation of an LNG tank, which would take into account possible variable thermal effects on the outer surface of the LNG tank, among which several of the most common ones can be identified.

Methodology A.M. Arkharova is based on the representation of the heat-insulating layer as a multilayer flat thin wall, which makes it possible to neglect end thermal effects when determining the value of heat losses Q [4]:

$$Q = F_m \cdot \frac{\lambda}{\delta} \cdot \left(t_c - t_x\right),$$

there λ – is the thermal conductivity coefficient of the thermal insulation layer of the tank; δ – thickness of the heat-conducting layer of the reservoir; tc and tx are the ambient temperatures and the LNG temperature in the cold cavity of the tank, respectively; $F_m=(F_c \cdot F_x)^{0,5}$ – average effective area of the heat-releasing surface of the tank; F_c and F_x are the areas of the outer and cold surface of the tank's thermal insulation, respectively.

Using the method of M.G. Kaganer assumes that the magnitude of the heat flow through the insulation of the tank is determined by the same equations of heat transfer by thermal conductivity. If a vacuum-powder or vacuum-multilayer thermal insulation structure is used, then equations based on the law are used to determine heat losses J.B-J. Fourier for one-dimensional structures, and if the cross-sectional area of the heat-insulating layer is not constant, then the average effective area of the heat-transferring surface of the reservoir Fm is used [8]:

$$\frac{Q}{\Delta t} - \frac{\lambda \cdot F_m}{\delta_m} = \sum_{i=1}^{n} \frac{F_{m,i}}{\delta_i},$$

there n – is the number of layers of thermal insulation of the tank; $\Delta t = t_c - t_x$ – temperature difference between the heating and cold environment.

The methodology outlined in the works of R.F. Barron (for example, in [9]), largely repeats the main provisions of A.M. Arkaroola's methodology, but the thermal conductivity efficiency indicator λm is used. However, most of the proposed methods are based on the stability of the parameters of external thermal influence, which is not possible to ensure in the case of sufficiently noticeable thermal radiation resulting from a fire at a neighboring facility.

A possible promising direction in increasing the heat-reflecting properties of the surfaces of LNG tanks is the installation of a special layer that is capable of reflecting part of the radiated heat flux incident on it. When solving problems of this kind, additional screens made of aluminum foil and coatings are usually used from various paint and varnish compositions, as well as coatings based on polymers, glass or ceramic microspheres.

It is necessary to develop a methodology for describing the thermal insulating properties of the surfaces of LNG tanks, considering the impact of thermal radiation from a fire, characterized by variable intensity.

Let us assume that changes in the intensity of the thermal radiation of a fire incident on the surface of the tank are periodic in nature, especially since the transformation apparatus of Zh.B-Zh. Fourier allows you to select a harmonic series. In this case, the law of thermal conductivity takes the form:

$$q = -\lambda \cdot \left(\frac{\partial \vartheta}{\partial x} \right)_n = \lambda \cdot k \cdot \sqrt{2} \cdot \vartheta_n^{\max} \cdot \cos\left(\omega \cdot \tau + \pi/4\right), \quad (1)$$

there ϑ_n^{max} – is the largest deviation of the temperature of the outer surface of the tank from its average value, that is, the amplitude of temperature fluctuations; τ – duration of thermal impact of fire on the outer surface of the tank; ω – circular frequency of temperature fluctuations on the outer surface of the tank; a is the thermal diffusivity coefficient of the heat-insulating material; $k=(\omega/2a)^{0,5}$ – coefficient that takes into account the accumulating properties of the thermal insulation material of the tank.

Considering that the thermal insulation materials used in the design of LNG tanks are selected based on the presence of a relatively low thermal conductivity coefficient, in [10] it was proposed to simplify equation (1) somewhat:

$$q_{n,\tau} = B \cdot \sqrt{2} \cdot \vartheta_n^{\max} \cdot \cos\left(\omega \cdot \tau + \pi/4\right), \quad (2)$$

there B – is the heat absorption coefficient, characterizing the accumulating properties of the heat-insulating material, the value of which is determined by these propertiesin accordance with equation (3):

$$B = \sqrt{\lambda \cdot c_p \cdot \rho \cdot \omega} = c_p \cdot \rho \cdot \omega \cdot \sqrt{a \cdot \omega}, \quad (3)$$

there c_p – isobaric heat capacity of the insulating material of the tank wall; ρ – density of the insulating material of the tank wall.

Based on equations (2) and (3), the largest value of the heat flux density $q^{max}n$ and the amplitude of temperature deviation oscillations on the surface of the heat-reflective layer of the tank wall $\vartheta_n(\tau)$ are related by the equation:

$$q_n^{\max} = c_p \cdot \rho \cdot \vartheta_n(\tau) \cdot \sqrt{a \cdot \omega}.$$

A fragment of the algorithm for thermal calculation of an isothermal LNG tank, considering the effect of heat absorption of the heat-insulating layer under conditions of periodic external thermal influence, is shown in Fig. 2.

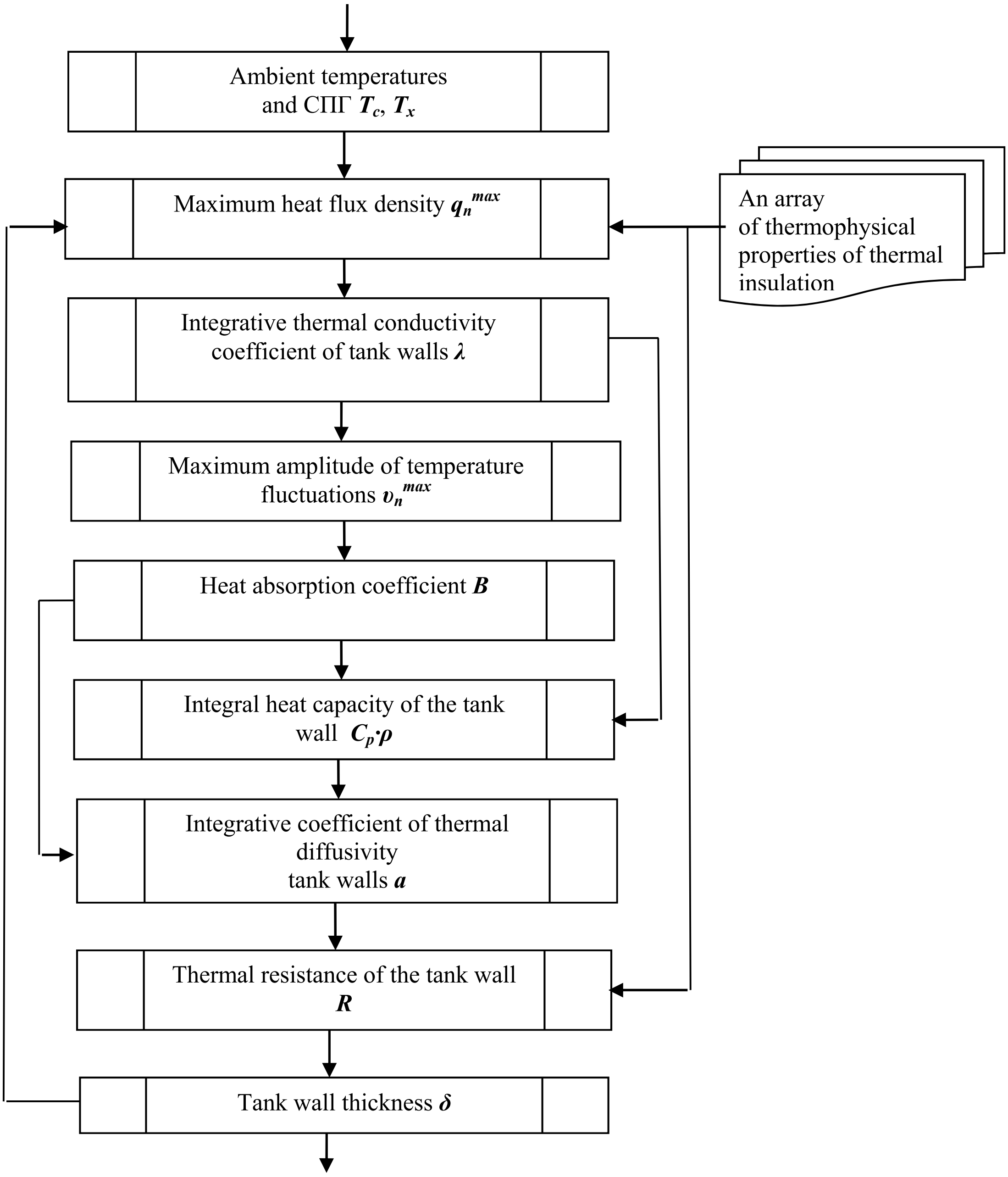

Fig. 2. **Fragment of the algorithm for thermal calculation of an isothermal LNG tank**

Thus, the proposed method for thermal calculation of an isothermal LNG tank allows us to consider the thermal inertia of multilayer insulation when exposed to thermal radiation from a fire of variable intensity.

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