BRONYA®

SUPERFINE HEAT INSULATION

METHODS DEFINITIONS OF PERFORMANCE LIQUID CERAMIC THERMAL INSULATING COVERINGS OF ARMOR.

TEMPERATURE MEASUREMENT SURFACES.

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1. THERMAL INSULATING PROPERTIES OF THE COATING

Bronya liquid ceramic thermal insulation coating is a water-based liquid composition. It consists of microscopic ceramic evacuated spheres, pigmenting, inhibiting and anti-penne additives. The main component is a polymer latex composition. Hollow microspheres (ceramic) are dispersed in the composition. The dimensions of the microspheres are 0.01 ... 0.5 mm.

This heat-insulating coating Armor is used for corrosion protection, thermal insulation, protection against ultraviolet radiation, and also has dielectric properties. The thickness of one layer of the Bronya coating is 0.4 ... 0.5 mm. In promotional materials, it is reported that the hollow microspheres are rarefied.

When used in heat supply systems, the most important thermotechnical properties of heat-insulating materials are manufacturability of use, durability, low coefficient of thermal conductivity, environmental safety.

The technology for applying liquid thermal insulation to pipelines and other surfaces is simple and affordable. Its feature is the ability to cover surfaces of complex configurations, while the presence of insulation does not create inconvenience during maintenance and repair. When using conventional heat-insulating materials in heating networks, areas remain uninsulated or partially isolated, the presence of which leads to additional heat losses. Bronya liquid thermal insulation coating can provide a significant reduction in additional heat losses. If it was possible to reduce these heat losses by at least half, then this would give a fuel economy of 8.3% (taking into account the boiler plant efficiency 0.9).

Taking into account the totality of the positive properties of Bronya liquid thermal insulation, it is also advisable to use it for thermal insulation of heat pipes and other elements in closed rooms (boiler rooms, pumping substations, TRS, etc.). At the same time, in addition to thermal insulation, the coating will allow to reduce the dimensions of heat-insulated elements, provide ease of maintenance, and improve the ecology and design of premises.

The durability of Bronya liquid ceramic thermal insulation is at least 10 years. Accelerated climatic tests of the coating on concrete and metal surfaces made it possible to conclude that the safety of the protective and decorative properties of the coating corresponds to at least 10 years in temperate and moderately cold climatic regions.

The durability of mineral wool insulation widely used in heating networks is estimated at 5-6 years. However, this insulation quickly loses its potential thermal insulation properties due to moisture. Under the influence of moisture, the insulation layer loses its original configuration (especially with overhead laying of heat pipelines), the effective thermal conductivity coefficient increases significantly, as a result of which heat losses to the environment increase. In contrast, liquid thermal insulation is not moistened, retains its original shape, dimensions, and thermal insulation properties. For these reasons, the coating must provide an initial heat loss throughout its life. In this regard, it will be advisable to use a coating for thermal insulation of overhead heat pipelines.

The most important indicator of heat-insulating material is the coefficient of thermal conductivity equal to 0.0012 W / m ° C. That is, liquid thermal insulation coatings are far superior to known thermal insulation materials.

2. POSSIBILITIES OF INDICATORS MEASUREMENT COATING EFFICIENCY

In heat supply systems, the use of thermal insulation allows solving two main problems: ensuring a safe temperature on the outer surface of a heat conductor for a person, and also reducing heat loss to an acceptable level. It is impossible to completely eliminate heat losses to the environment, but it is possible to reduce it by using more effective insulation, or by increasing the thickness of the insulation. Both require additional costs. For heat pipelines, an increase in the thickness of the insulation leads to a decrease in heat losses only up to a certain limit, after which heat losses increase with an increase in the thickness of the insulation. Therefore, from the point of view of heat losses, it is necessary to choose the “golden mean”, comparing the costs of insulation with possible heat losses.

With regard to the temperature of the outer surface of heat pipelines and other equipment of heating networks, modern requirements are quite definite. These requirements are that in contact with the surface of the skin, a person should not get burned. It is believed that when a person's skin contacts a surface with a temperature of 60 ° C for 5 seconds, a person will receive a first-degree burn (without damaging internal tissues). When calculating thermal insulation, the maximum surface temperatures in the working areas should be 45 ° C (indoors) and 55 ° C (outdoors).

Operating temperature of Bronya series ultrathin heat-insulating coatings

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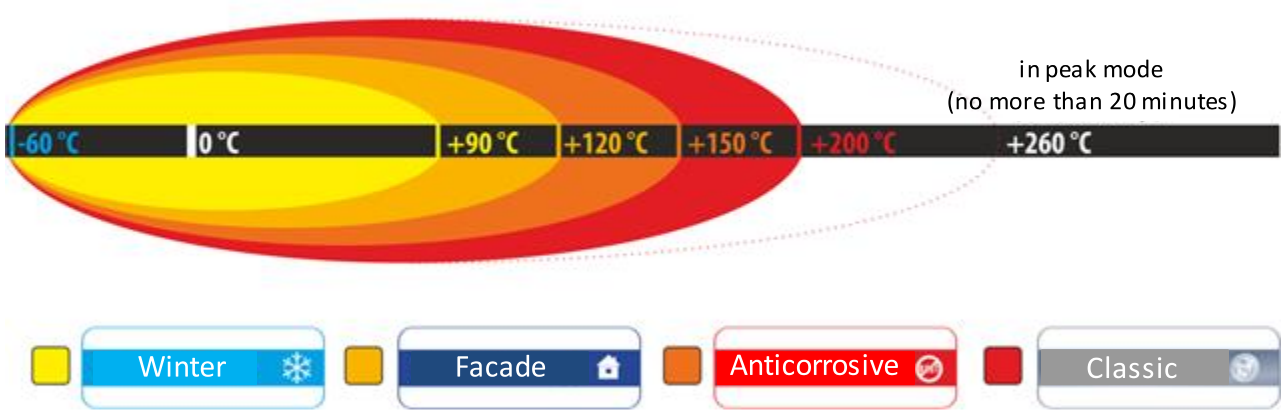

It is also known that the temperature effect on the human skin depends not only on temperature, but also on the properties of the environment or surface with which the skin is in contact. In this regard, one can recall the difference from contact in good frost with metal and wood. Those who like to take a steam bath raise the temperature in the steam room to 60 ° C and higher and do not get burns. It will be even more convincing to grab a pair of coins with you and feel the difference from touching it and the wooden shelf. In the examples provided, measuring instruments are not needed to confirm that the temperatures of different surfaces are the same. The above temperature 55 ° C is set for the metal cover layer, and for other surfaces the temperature is 60 ° C.

Bronya liquid ceramic heat-insulating coating has unique properties. The uniqueness also applies to the effects on human skin. Simple experiments have been done to verify this. Thus, in the course of research it was found that the surface temperature of the coating is 100 ° C safe for humans (at least 5 s of contact), and at a surface temperature of the coating of 175 ° C, the water on it begins to boil.

Application temperature of Bronya series ultra-thin heat-insulating coatings

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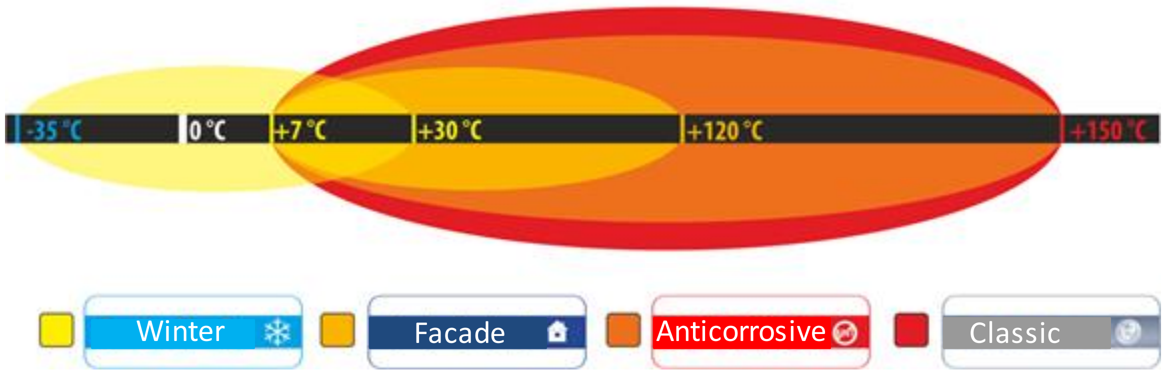


Similar experiments were also performed. An electric furnace was used, on the flat surface of the heating element of which a super-thin heat-insulating coating Bronya was applied. The temperature of the coating surface was measured using a thermocouple complete with DT-838 (the characteristics of the device are given below). At different temperatures, the time of contact of the palm with the surface was determined, during which there were no unpleasant sensations. The average contact time for three people is shown in Table 1.

Table 1 - Results of experiments to determine the safe temperature on the surface of the coating

Coating surface temperature, ^{0}C	Palm-to-surface contact time without discomfort, sec.
60	30 and more
70	30 and more
90	14
100	8
115	5

According to the table. 1 safe for human skin is the temperature on the surface of the coating 90 ° C (with a certain margin).

With the help of the same electric furnace, it was found that the water on the surface of the coating begins to boil at a temperature of 170 ... 175 ° C. To establish this temperature more accurately, it is necessary to more clearly define the signs by which it is necessary to determine the beginning of boiling. In this case, such a task was not posed, and the moment of intensive formation of vapor bubbles in water, which were clearly visible through a magnifying glass, was taken as the beginning of boiling.

To assess the safe temperature on the coating surface, specialists used a graph on one axis of which the temperature of the metal surface is plotted, and on the other - the temperature on the coating surface. According to this graph, for example, the temperature on the surface of the coating is 80 ° C (which corresponds to a temperature of 55 ° C on the metal surface).

Regardless of the results of the studies carried out, the performance indicators of thermal insulation coatings in practice should be determined by measurements. Imagine, on a heat pipe there is a conventional thermal insulation with a covering layer of roofing felt or plastic. How to measure the temperature of the outer surface? According to the theory, contact measurement methods are not applicable, since it is impossible to ensure reliable contact of the surface with the temperature sensor. The situation is no better with a metal cover layer with a thickness of the order of 0.5 ... 1 mm. What can be offered in this case for providing contact is hardly suitable for use in a production environment. There remain non-contact methods and measuring instruments.

Experts carried out a series of measurements on a full-scale object using the instruments at their disposal.

The object is a water heat pipe with dУ = 600 mm (outer diameter is 630 mm, inner diameter is 612 mm), located in the pumping station room. The pipeline is insulated with mineral wool wrapped in a steel mesh, outside of which a layer of heat-insulating plaster with a thickness of 2 ... 3 mm is applied to the canvas. The total thickness of the insulation layer is 55 mm. There are air gaps of variable height between the layers. Two sections of the heat conductor with a length of about 0.8 m were freed from insulation, one of them was stripped and left without insulation, the second section was covered with a 1.6 mm thick Bronya heat-insulating coating. The measurements were carried out in the section of the non-insulated pipeline, in the section with the existing insulation and in the section with the Bronya coating.

The water temperature was measured by a standard resistance thermocouple installed in the pipeline, connected to an automatic bridge KSM-2 with a record of readings on a chart tape. Heat-insulated containers with water were installed at each of the sections, the water temperature in each container was recorded on the KSM-2. The data from such measurements can be used for a rough comparative assessment of the effectiveness of different thermal insulation.

Various instruments were used for measurements:

- heat flux density meter IPP-2 complete with heat flux density probe PTP-9.9P (manufacturer - Exis CJSC, Moscow; measurement range 10 ... 9999 W / m2, permissible reduced measurement error ± 5%, conversion factor 73, 3 W / (m2 · mV));

- SUR-25 thermometer (made in the USA, measuring range -20 ... + 120 0C, permissible reduced measurement error ± 2%, sensing element - calibrated bimetallic plate);

- digital multifunctional meter (Elcometr) 319 complete with a thermocouple (measurement range -20 ... 200 0C, temperature measurement error is ± 0.5 0C);

- infrared thermometer "Fluke 561" (manufacturer - "Fluke Corporacion", China; measurement range -40 ... + 550 0C; measurement error is ± 1% of the measured value or ± 1 0C; spectral range - 8 ... 14 microns).

Surface temperatures were also evaluated by touch. Human skin is a good thermal sensor. The temperature of 36 ° C is determined quite accurately by touch. Less accurately, but reliably, the temperature is 55 ° C. The skin tolerates this temperature for a long time without unpleasant sensations, but one feels that this is the limit, above which the contact time will have to be limited. On these two reliable reference points, you can build a temperature scale and, after some training, more or less accurately determine the temperature (no higher than 60 ° C).

The most indicative results (averaged data) of the measurements, when the largest number of devices were used, and the water temperature was the highest during the heating period, are shown in Table 2.

To analyze and evaluate the measurement results, calculations were also carried out using the known dependencies for heat transfer through a cylindrical wall.

The heat flux density was determined by the formula

$$q_F = \frac{t_{вн} - t_{н}}{d\left(R_{из} + R_{н}\right)} \qquad (1)$$

Where $t_{вн}$ - $t_{н}$ temperatures, respectively, of water in the pipeline and outside air; d is the diameter for which the value is determined q_F ; $R_{из}$, $R_{н}$ - thermal resistances, respectively, of thermal insulation and heat transfer to the ambient air.

Table 2 - Averaged measurement results at different sections of the heat pipeline (water temperature in the pipeline 92 ° C, air temperature in the room 18 ° C)

Measured value	**Measurement tool**	**Measured value for heat pipe sections**		
		non-insulated heat pipe	existing thermal insulation	Liquid insulation
Outer surface temperature, ^{0}C	Fluke 561	87,9	39,7	60,7
	SUR-25	74	39 *	39 *
	Elcometer 319	85	40	38
	To the touch	>60	≈36	≈40
Heat flux density, W/m^2	IPP-2	1389	306	409
Linear heat flux density, W / m (recalculated by heat flux density)	-	2748	711	813

The measurements marked with an asterisk were during the period when the water temperature rose to 96 ^{0}C.

Formula (1) does not take into account the thermal resistance of heat transfer from water to the inner surface of the pipeline and the pipeline wall. These values are small compared to and $R_{из}$, $R_н$ therefore, when calculating heat conductors, they are in most cases neglected.

Thermal resistance values were calculated using the formulas

$$R_{из} = \frac{1}{2\lambda_{из}} \cdot ln\left(\frac{d_{изн}}{d_{трн}}\right) \qquad (2) \qquad\qquad R_н = \frac{1}{\alpha_н \cdot d_{изн}} \qquad (3)$$

where $\lambda_{из}$ - thermal conductivity coefficient of thermal insulation; $d_{трн}$, $d_{изн}$ - outer diameters of pipeline and insulation, respectively; $\alpha_н$ - coefficient of heat transfer from the outer surface of the insulation to the ambient air.

The linear heat flux density was determined by the formula

$$q_l = \pi \frac{t_{вн} - t_н}{(R_{из} + R_н)} = \pi \cdot d \cdot q_F \qquad (4)$$

The temperatures of the outer surface of the insulation were determined by the formula

$$t_{изн} = t_{вн} - \frac{1}{\pi} \cdot q_l \cdot R_{из} \qquad (5)$$

For calculations, the following values of quantities were taken:

- $d_{трн}$ = 630 mm;

- for the existing insulation described above, the thermal conductivity coefficient is difficult to determine. For mineral wool, λ values are 0.04... 0.05 W / (m · K), for asbestos-cement and lime plasters λ = 0.4... 0.7 W / (m · K). The metal mesh in the insulation layer increases the resulting λ, and the existing air gaps decrease. It is very difficult to estimate the degree of contact between the layers. For such insulation, the value of λ can be estimated at the level of 0.15 ... 0.25 W / (m · K). For calculations, it was taken $\lambda_{из}$ = 0.2; $\delta_{из}$ = 55 mm; $d_{изн}$ = 740 mm. It is clear that an approximate estimate of λfrom will also give approximate calculation results;
- Bronya is accepted for liquid thermal insulation: $\delta_{из}$ = 1,6 mm; $d_{из}$= 633,2 mm; $\lambda_{из}$= 0,001 W/(m ·K);
- for surfaces with a low emissivity should be taken $\alpha_н$ = 6, with a high emissivity - $\alpha_н$ = 11 W / (m2 · K) (for rooms). For the surfaces under consideration, it is difficult to estimate the values of the emissivity, but nevertheless the coating should be attributed to surfaces with a low emissivity, and the surfaces of an uninsulated pipeline and existing insulation are explicitly gray. In addition, for an uninsulated pipeline, the convective component should be significantly higher than for the other two surfaces due to the higher surface temperature. That is, the value for an uninsulated pipeline should be more than 11 W / (m2 · K), but not as large as in the open air (29 W / (m2 · K). Taking into account the above, it is accepted: for coating $\alpha_н$ = 6 W / (m2 · K); for existing insulation $\alpha_н$= 8 W / (m2 · K); for non-insulated pipeline $\alpha_н$ = 20 W / (m2 · K).

Quantity designation	Unit of measure ment	Calculated values for heat pipe sections			
		bare pipeline	existing isolation	Ultra-thin thermal insulation Bronya	
				λиз=0,001	λиз=0,004
Rиз	(m · K) / W.	-	0,4023	2,533	0,6333
Rн		0,07936	0,1689	0,3632	0,2632
Qf	W / m^2	1480	175,1	41,2	130,4
qi	W / m	2922	406,8	81,9	259,2
tизн	°C	-	39,9	25,9	39,1

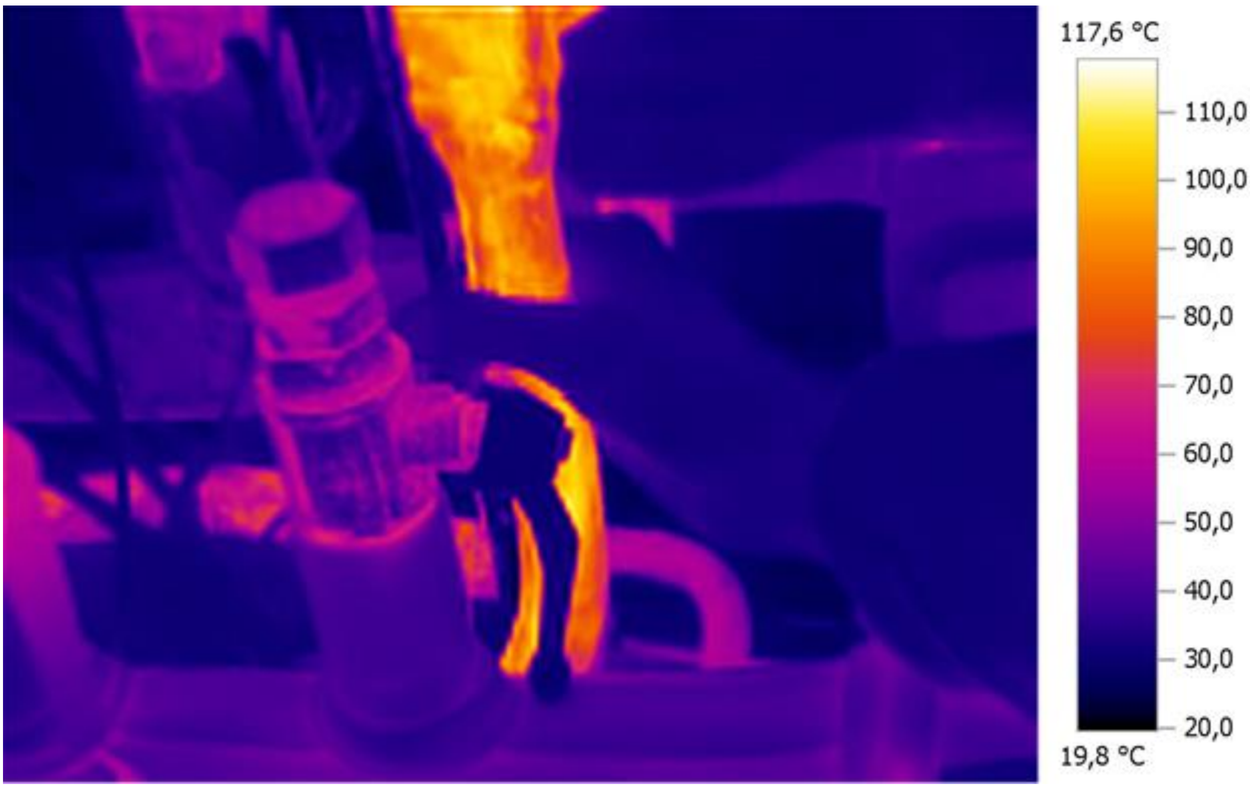
The calculation results are shown in Table 3.

Analysis of the results of measurements and calculations shows the following.

There is no reason to doubt the results of measuring temperatures $t_{вн}$ and $t_н$ (92 ° C and 18 ° C, respectively). Temperature measurements made with the Elcometer 319 are also rated as the most reliable. On the surface, the differences between the readings of the Elcometer 319 and the “Fluke 561” are so significant that one of them must be considered incorrect.

Taking into account the determination of the temperature by touch, as well as the data on IPP-2 (the linear heat flux density does not differ so much as to lead to such a difference in surface temperatures), the readings of the Fluke 561 (60.7 ° C) should be recognized as incorrect. This can be explained as follows.

The Fluke 561 device is a partial radiation pyrometer operating in the wavelength range of 8 ... 14 µm. In terms of their metrological properties, such pyrometers are close to the properties of quasi-monochromatic pyrometers, for which the methodical measurement error has been determined and can be (at temperatures up to 500 ° C) from 5 to 55 ° C, depending on the emissivity of the measurement object. Therefore, a temperature close to the actual one can be measured by the device only in cases where the emissivity is known in advance and is high (the coefficient is greater than 0.9). The device provides for changing the setting for emissivity (0.3; 0.7; 0.9), but the documentation for the device emphasizes that this does not guarantee an increase in the measurement accuracy. Therefore, it is recommended to measure the surface temperature for each object using a thermocouple (a type K thermocouple can be connected to the device), and then by selecting the setting to achieve the best match of the results. That is, the “Fluke 561” pyrometer, according to its principle of operation, can give a significant error in temperature measurement. Therefore, its main purpose is not for measuring temperature, but for convenient and quick detection of local places of inflows or outflows of heat by scanning the surface. For this, the actual surface temperature is, in principle, not needed, it is enough that its emissivity is the same. This is confirmed by shooting with a thermal imager, where the hand freely holds the section of the pipe covered with liquid thermal insulation Bronya, and the device shows the temperature on the surface of 110 ° C.



SUR-25 readings differ significantly from actual surface temperature. This is easily explained, since the temperature sensor has no contact with the surface and records the temperature of the boundary layer at a distance of 1.5 mm from the surface. The bimetallic plate is directed with its end to the surface and has a width of about 3 mm; therefore, the total thickness of the boundary layer increases to 4.5 mm. In addition, the bimetallic plate is an unreliable temperature sensor for measurement.

The IPP-2 data for a non-insulated pipeline are quite possible, calculations (Table 3) confirm this. The same cannot be said about the IPP-2 readings on surfaces with thermal insulation. Calculations show that the values of heat fluxes 306 and 409 W / m2 do not correlate with temperatures of 38 and 40 ° C (Table 2). For example, for existing insulation with qF = 306 W / m2 and the corresponding value qi = 711 W / m, the surface temperature should be significantly higher than 38 ° C. And if we take as a basis both qi = 711 W / m2, and thir = 38 ° C, then at real values of Rn this can be if λfrom is 2 ... 3 W / (m · K), which is an order of magnitude more than the real values λfrom. At a surface temperature of 39.7 ° C (Table 2), which is estimated above as close to reliable, and real values of Rн and λfrom (the values of the values are estimated above), the heat flux qF should be about 175 W / m2 (Table 3) (or qi = 406.8 W / m). That is, for the existing isolation, the IPP-2 readings are overestimated by about 1.7 times.
For coverage, initially, the calculation was based on the value λfrom = 0.001 W / (m · K). As calculations have shown (Table 3), the indicators obtained in this case clearly do not correspond to the measurements, which may be due to the discrepancy between the accepted and actual values of λfrom. The solution of the inverse problem under the condition tlv = 40 ° C, which was assessed above as reliable, showed that at real tn, the value of λfr should be about 0.004 W / (m · K). Calculations for this value of λfrom are given in table. 3. According to calculations, the qF value should be about 130 W / m2, while the IPP-2 showed 409 W / m2, that is, in this case, we have an overestimation of the IPP-2 readings by 3.1 times.
The overestimated IPP-2 readings on the surfaces of the Bronya thermal insulation can be explained as follows.

where λ is the coefficient of thermal conductivity of the plate material (λ = 0.5 W / (m · K) is indicated in the probe passport); Δt is the measured temperature difference; Δl is the distance between the points of temperature measurement (plate thickness).
Let us determine Δt, which was fixed by the device when measuring, for example, qF = 306 W / m2 (Table 2).

$$q_F = \lambda \frac{\Delta t}{\Delta l}$$

The principle of operation of the IPP-2 complete with the PTP-9.9P probe is based on measuring the temperature difference on the plate surfaces (according to the passport data, the plate diameter is 40 mm, the thickness is 2 mm). The temperature difference is measured with a thermocouple strip built into the probe plate. According to the measured temperature difference, the heat flux density can be determined by the formula.

With these temperature differences, small changes in the measuring conditions when the probe comes in contact with the surface can lead to a significant change in the measured value.

Suppose the thermocouple gives an error of 0.2 ° C, then the temperature difference will be measured with an error of Δ = 0.2 / 1.224 * 100 = 16.3% and with the same error we get the value of qF.

In fact, for the best thermoelectrode material (platinum-rhodium platinum), the permissible deviations of readings in the temperature range 0 ... 300 ° C are 0.01 mV, which corresponds to 1.09 ° C. That is, only a thermocouple can give an error that is about 89% of the measured value.

In addition, on pipelines it is impossible to provide contact over the entire surface of the probe plate. On a rigid outer surface, the contact will be linear; on a less rigid surface, it will be partially planar. This can lead to additional measurement errors. According to the passport of the PTP-9.9P probe, the reduced measurement error is ± 5%, which corresponds to approximately 500 W / m2. That is, the permissible measurement error exceeds the measured values (Table 2).

$$\Delta t = 306 \cdot 2 \cdot 10^{-3} \cdot \frac{1}{0{,}5} = 1{,}224$$

If we ignore the absolute values of indicators and compare different thermal insulation by heat flux, then this should be done by the values of qi. It is impossible to compare the heat fluxes qF, since the qF value depends on the diameter for which it is determined. Comparison based on the measurement results (Table 2) shows that the existing insulation and coating provide approximately the same heat loss from the heat pipe. Taking into account possible deviations of the actual initial data from those adopted in the calculations and according to the data in Table. The 3 coatings are practically equivalent in efficiency (with some coverage advantage).

The high efficiency of the coating with a small thickness of insulation consists of three components: a low λ value, a decrease in the diameter of the outer surface, and a decrease in the radiant component of heat transfer.

For any thermal insulation of pipelines, the temperature along the thickness of the insulation decreases according to the logarithmic dependence, that is, the greatest temperature drop occurs in the layer adjacent to the insulated surface, and then the intensity of the temperature change decreases. For Armor coverage, this is more pronounced due to the low λ. Therefore, for heat pipelines, an increase in the thickness of thermal insulation by more than 1.5 ... 2 mm may not be justified. If we compare different thermal insulation only by the values of λ, then due to the nonlinear dependence of the temperature change, linear comparisons of the form cannot be made: if λ of thermal insulation is reduced by 10 times, then at the same temperature of the outer surface, the thickness of the insulation layer should be 10 times smaller. For example, if the thickness of the coating is theoretically increased to 5.5 mm, then according to calculations similar to those carried out above (Table 3), at λiz = 0.004 W / (m · K), we obtain t life = 26 ° C.

The foregoing allows us to draw the following main conclusions:

1) Superfine thermal insulation coating is a highly efficient thermal insulation material. The numerical value of the thermal conductivity coefficient is 0.0012 W / (m · C). This is an order of magnitude less than that of the best heat-insulating materials, which in most cases are used in heat supply systems;

2) This material can be recommended for thermal insulation:

sections of heat pipelines that are currently not insulated at all or partially insulated. This will reduce fuel consumption at heat supply sources by at least 8%;

heat pipelines and other surfaces in enclosed spaces (boiler rooms, pumping stations, TRS) and overhead heat pipelines (durability, ease of maintenance, reduction in size, improvement of ecology and design, etc.);

any heat pipes. In contrast to the widely used glass wool, the coating retains its original heat-insulating properties for a long time, which is confirmed by the operation of full-scale objects with coatings for 3-4 years and the results of accelerated climatic tests, which estimate the durability of the coating at least 15 years.

3) Determination of the temperature of the outer surface of thermal insulation is the most reliable and reliable is the determination of temperature by touch, with a thermocouple, Elcometr 319, PosiTector DPM or other similar devices.

4) High efficiency of the coating with a small thickness of insulation is achieved due to a low coefficient of thermal conductivity, a decrease in the outer diameter of the insulation, and a decrease in the radiant component of heat transfer.

From an environmental point of view, ultra-thin thermal insulation is safe. It does not emit substances harmful to humans and cannot harm human health.

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