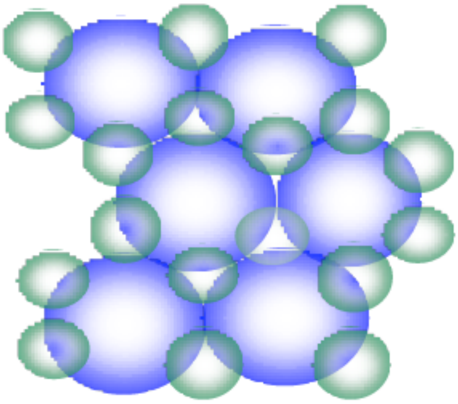
КОРУНД
ULTRA-THIN THERMAL INSULATION

STRUCTURAL FEATURES OF ULTRA-THIN THERMAL INSULATION COATINGS, BURN INJURY PROTECTION AND ENERGY EFFICIENCY

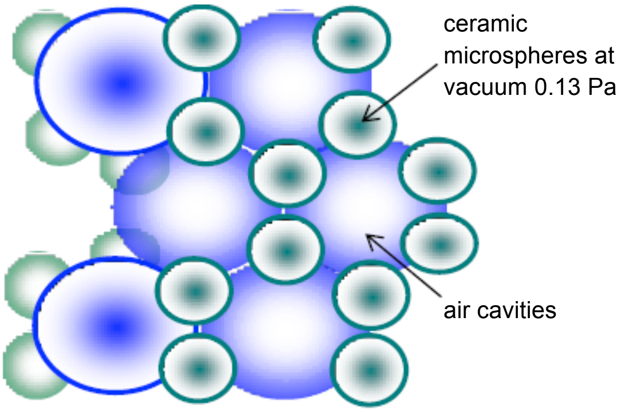
Ultra-Thin Thermal Insulation Coating is a liquid composition of acrylic polymers with latex binding where several types of ceramic (5 to 20 μm) microspheres evacuated to 0.13 Pa exist in suspension.

Applied as a paint – acting as a heat barrier!

When applied to the protected surface, the material starts to evaporate water leaving microscopic air cavities behind inside it surrounded by the envelopes containing evacuated microspheres. After the material is completely cured, the protected surface will have a solid seamless quasi-vacuum coating with absolutely unique thermal and physical properties.



BASIC ARRANGEMENT

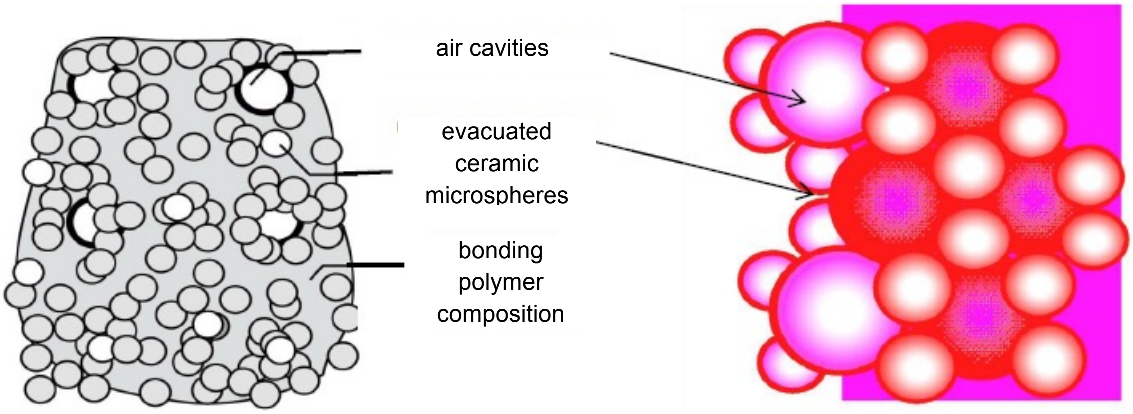


SECTIONAL VIEW

Air cavities and evacuated ceramic microspheres arranged in such pattern make up a flexible load-bearing frame of the coating.

Stationary temperature distribution in such material will be heterogeneous and depend on heat conductivity value of the components.

Heated polymers expand and pressure drops down inside the cavities; this is how additional evacuation takes place causing another decrease in heat conductivity. As a result, a flexible multi-layered **heat-reflecting** coating is made which blocks all means of heat transfer and has a record-breaking low heat transfer coefficient (heat conductivity of ceramic spheres at vacuum 0.13 Pa is 0.00083 W/m°K or less, according to Physical Quantities Handbook, table 15.28, page 361. Published by Energoizdat in Moscow 1991).



SCHEMATIC VIEW **TEMPERATURE FIELD**

Fig. 1 Schematic and heat representation of ultra-thin ceramic coating.

Special Mechanisms of Heat Transfer

Actual use of ultra-thin ceramic thermal insulation fluids based on acrylic bonding agents showed that their features and **burn injury protection** capability is so innovative that they go beyond the safe temperature limits set for conventional insulators and need special explanation.

Out of all methods used to measure temperatures and determine their critical limits, organoleptic method is the most available.

If your hand is in contact with a hot surface but not causing you any pain or irritation, the surface temperature will be +45°C at the most. According to the standards applied in USA, Germany and Russia, exposure of human skin to temperature +60°C during 2 seconds will lead to a first-degree burn and is injury potential. For conventional types of insulation used for decades, generally rock wool or similar, plus a protective cover (sheath made of galvanized metal or aluminium), it is correct. The temperature over +45°C is dangerous.

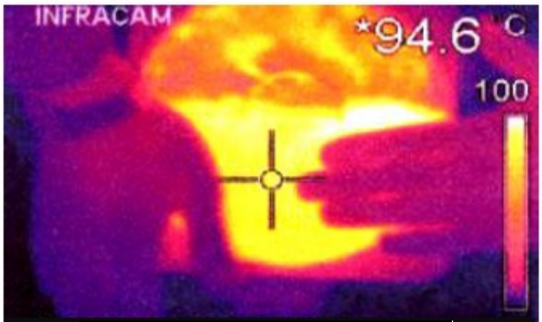


Fig. 2 Thermal imaging

However, when it comes about ultra-thin coatings, it is absolutely wrong!
Instruments show the surface temperature 94.6°C (fig. 2), while hands are touching the surface of insulation without any discomforting feeling! What a paradox?!

All paradoxes are easily explained by application of physical laws.
First, let us define the terms referred to below:

Heat Conductivity is the property of a material to transfer heat when subjected to different temperatures across its surface (heat transferred from more heated parts to less heated ones as induced by the thermal motion of particles) (W/m°C).

Heat Capacity is the amount of energy required for a change in temperature of a one-kilo matter by one degree (kJ/kg°C).

Thermal Diffusivity is the rate of the temperature change in different spots of a body. Found as a fraction of Heat Conductivity / Heat Capacity (m^2/sec).

Heat Loss / Absorption is the heat transfer from a surface to the ambient atmosphere through convective and radiation heat transfer.

Convective Heat Transfer is the heat transfer from (to) a surface by surrounding air or water.

Radiation Heat Transfer is the heat transfer from (to) a surface by electromagnetic radiation.

Conductive Heat Transfer is the heat transfer at the molecular level, where subjected to the thermal gradient, from the heated particle to the less heated one.

Transition Heat Transfer Processes in Ultra-Thin Thermal Insulation Coatings, Burn Injury Protection Mechanisms

This type of coatings is applied in thin layers (400 μm) with drying intervals 12 to 24 hours to let the material cure completely and ensure impressive performance. By slowly overlaying, the coats make up thin films where the top part (60 to 100 μm) consists only of “popped” microspheres, while the middle part (300 to 340 μm) contains microscopic air pores surrounded by ceramic spheres. This is similar to tree growth rings. Each coat efficiently prevents the heat flow from entering the next coat. The heat flows from one coat to another following the path of least effort.

Layered coating structure blocks the energy transfer, thus increasing thermal resistance.

The first coat drops the heat flow rate emitted by the hot surface dramatically; the subsequent coats continue to decrease it at a milder rate (fig. 3).

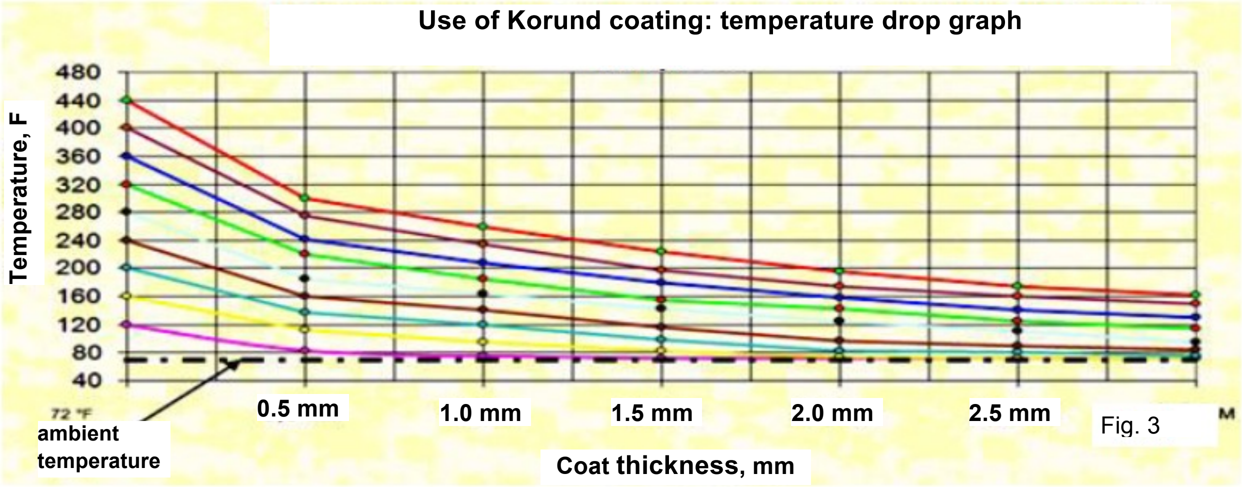


Fig. 3

For ultra-thin thermal insulation coatings, the heat transfer is a complex combination of conductive, convective and radiation heat transfer.

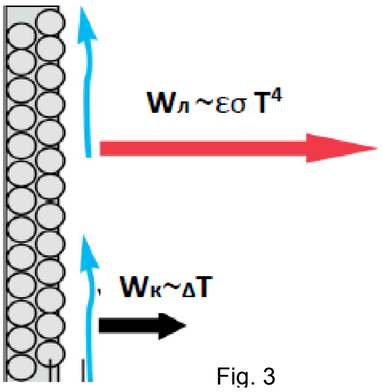


Fig. 3

Thermal radiation is the key contributor to the heat transfer. The value of the radiation heat flow is proportionate to the coating surface temperature raised to the 4th power (power-law dependence $W_r \sim \varepsilon\sigma T^4$, **where: T** is the insulation surface temperature) and material emissivity.

Convective component is fully dependent on the location of the surface to be insulated, surrounding conditions and proportionate to the temperature differential $W_{conv} \sim \Delta T$, where $\Delta T = t_{ins.surf.} - t_{amb}$ (fig. 4).

The heat loss of the convective component is negligibly low and proportionate

$\Delta T = t_{heat\ transfer\ fluid} - t_{surface}$

Transition heat exchange processes occur in ultra-thin thermal insulation coatings following common physical principles that block all heat transfer processes:

- ***Unprecedentedly low heat conductivity of the mixture of evacuated ceramic spheres* (huge volume of immobile vacuum creates a reliable solid thermal barrier)*; the less the diameter of the spheres, the lower the heat conductivity;***
- ***High reflectivity of spherical surfaces;***
- ***Low emissivity of spherical surfaces;***
- ***Extremely low thermal diffusivity of the coating.***

Millions of thin-walled ceramic spheres taking up to 85% of the total volume of the material, when evaporated and cured, form a solid rough-profile coating. The entire surface of the coating is literally powdered with thin-walled evacuated microspheres projecting above the layered polymer base. Specific gravity of the evacuated microspheres is approximately 0.1 g/cm^3.

Microscopic spheres have very thin shell walls measured in nanometers. Heat capacity of such shells is 1.1. kJ/kg°C.

Thermal effect on human skin depends not only on the temperature, but also on the properties of the surface which is in contact with the skin.

Well known are the feelings obtained when touching a wooden bench and a coin in the spa steam room, or even more so, when coming in contact with a wooden and metal surface in a very freezing area.

When touching the coating surface, the hand comes in contact with the protruding microspheres and cools them down immediately (heat capacity of a human body is 3.4 kJ/kg°C which is 3.15 times more than the one of the coating). (Fig. 5)

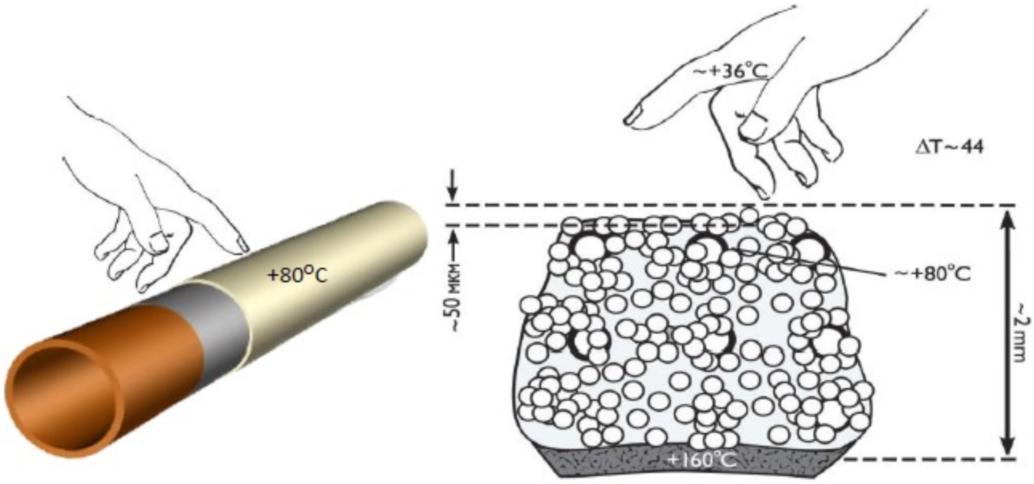


Fig. **5**

Since the coating features very low effective heat conductivity (λ = 0.001 W/m°C) and heat capacity (C= 1.1 kJ/kg°C) when compared to the heat conductivity (λ ≈ 0.5 W/m°C) and heat capacity (C= 3.4 kJ/kg°C) attributed to the human skin, the temperature in the contact point immediately becomes close to the one of the human body.

Thermal diffusivity of the material is also negligibly low (0.0000016 m^2/sec) and completely blocks any heat supply to the contact point.

No temperature increase in the contact point, hence no heat injury.

This is how SELF-CONTAINED BURN INJURY PROTECTION works!

For heating lines (any type) operated in **summer period** and for indoor use, the ambient heat loss of the coating surface is negligible.

$\alpha_{amb} = \alpha_k + \alpha_l = 2 - 3.5$ W/m^2°C – **heat loss is within normal limits.**

Legend:

δ_{ins} – insulation thickness; λ_{ins} – insulation heat conductivity coefficient; t_w – heat fluid temperature;
t_e – ambient temperature; t_i – insulation surface temperature; **q** – heat losses;
α_n; α_v – heat loss and heat absorption coefficients; T_{ins} – outer insulation surface temperature;
R_{tot} – heat transfer resistance of pipe+heat insulation structure; $t_{in.ins}$ – inner insulation surface temp.

Insulating coat thickness at the set surface temperature			**Insulation thickness selection based on standardized density of the heat flow (heat loss) and insulation surface temperature**											
			Outer insulation surface temperature			Heat loss			Inner insulation surface temperature			Heat transfer resistance of pipe + heat insulation		
$\delta_{ins} = \lambda_{ins}(t_w - t_i)/\alpha_n(t_i - t_e)$			$T_{ins} = t_{in.ins} - (\delta_{ins} q/\lambda_{ins})$			$q = t_w - t_e/R_{tot}$			$t_{in.ins} = t_w - q/a_v$			$R_{tot} = 1/\alpha_v + \delta_1/\lambda_1 + \delta_2/\lambda_2 + 1/\alpha_n$		
δ_{ins}*	**0.0017**	m	T_{ins}*	**43.5**	°C	q*	**59**	W/m^2	$t_{in.ins}$	**143**	°C	R_{tot}	**2.22**	m2 °C/W
λ_{ins}	0.001	W/m°C	δ_{ins}	0.0017	m	t_w	150	°C	t_w	150	°C	α_v	8.7	W/m^2 °C
t_w	150	°C	λ_{ins}	0.001	W/m°C	t_e	20	°C	q	59	W/m^2	δ_1	0.008	m
t_e	**20**	°C	$t_{in.ins}$	143	°C	R_{tot}	2.22	m2 °C/W	α_v	8.70	W/m^2 °C	λ_1	58	W/m^2 °C
t_i	**45**	°C	q	59	W/m^2	Tab. 1						δ_2	0.0017	m
α_n	2.50	W/m^2 °C										λ_2	0.001	W/m^2 °C
												α_n	2.50	W/m^2 °C

Somewhat different processes are observed in winter. Negative ambient temperatures cause a decrease in insulation surface temperature and promote heat loss (please see Tab. 1; 2).

δ_{ins}*	**0.0017**	m	T_{ins}*	**10.7**	°C	q*	**77**	W/m^2	$t_{in.ins}$	**141**	°C	R_{tot}	**2.22**	m2 °C/W
λ_{ins}	0.001	W/m°C	δ_{ins}	0.0017	m	t_w	150	°C	t_w	150	°C	α_v	8.7	W/m^2 °C
t_w	150	°C	λ_{ins}	0.001	W/m°C	t_e	-20	°C	q	77	W/m^2	δ_1	0.008	m
t_e	**-20**	°C	$t_{in.ins}$	141	°C	R_{tot}	2.22	m2 °C/W	α_v	8.70	W/m^2 °C	λ_1	58	W/m^2 °C
t_i	**45**	°C	q	77	W/m^2	Tab. 2						δ_2	0.0017	m
α_n	2.50	W/m^2 °C										λ_2	0.001	W/m^2 °C
												α_n	2.50	W/m^2 °C

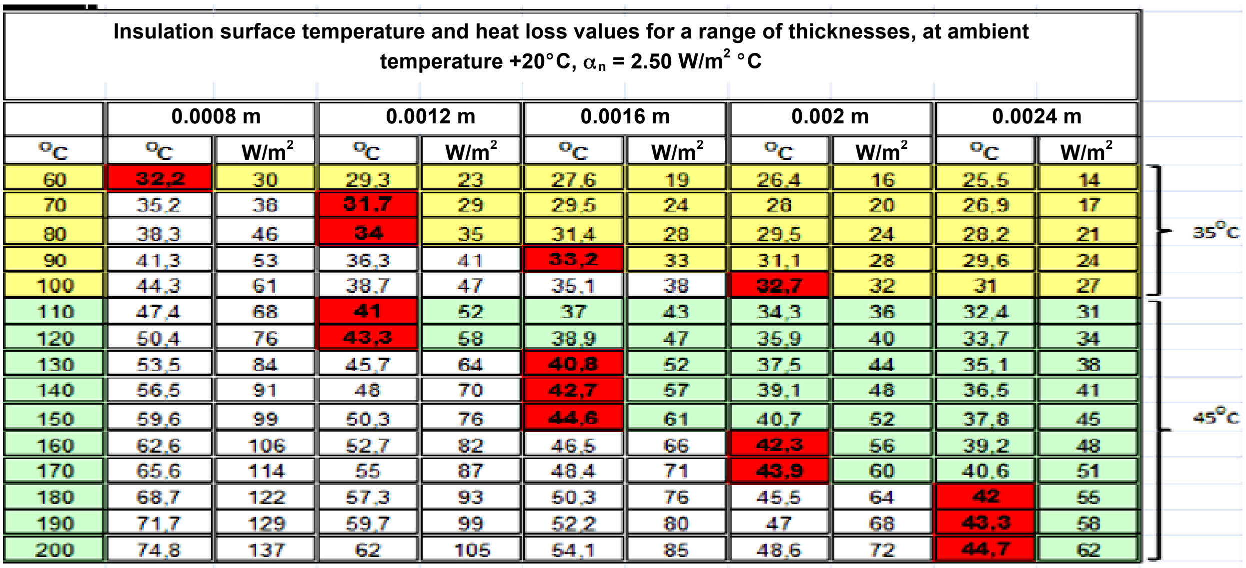
Winter. Insulation surface is covered with snow. (tab. 2)
Insulation surface temperature is 4 times lower:

- ✓ radiation heat exchange drops significantly $W_r \sim \varepsilon \sigma T^4$
- ✓ conductive component of the bonding polymer is negligibly low (as the coating is ceramic by 85%)
- ✓ convective component ≈ 0 (surface is covered with snow)
- ✓ heat loss coefficient is low α_{amb} = 2 – 3.5 W/m^2 °C

Conclusion: ***Overall capacity of heat losses is insufficient to thaw the snow, especially since extremely low thermal diffusivity of the coating practically blocks any heat supply to the contact area and heat loss coefficient is ultimately low.***
Heat loss is minimum, snow does not thaw.

Thermal insulation fluid thickness is generally calculated using the specified values of surface temperature, then checked against standardized heat flow density. If the heat loss exceeds its standard value, insulation thickness will be increased to meet SNiP requirements to heat losses. (Tab. 1)

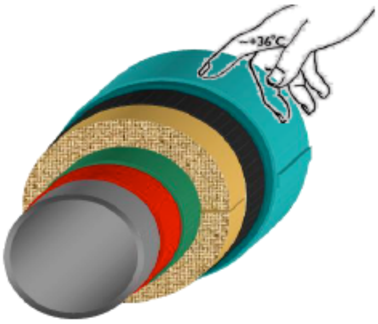
According to SNiP requirements to heat losses, insulation thickness can be selected using the table below.



Insulation surface temperature and heat loss values for a range of thicknesses, at ambient temperature +20°C, α_n = 2.50 W/m^2 °C

	0.0008 m		0.0012 m		0.0016 m		0.002 m		0.0024 m	
°C	°C	W/m^2	°C	W/m^2	°C	W/m^2	°C	W/m^2	°C	W/m^2
60	32,2	30	29,3	23	27,6	19	26,4	16	25,5	14
70	35,2	38	31,7	29	29,5	24	28	20	26,9	17
80	38,3	46	34	35	31,4	28	29,5	24	28,2	21
90	41,3	53	36,3	41	33,2	33	31,1	28	29,6	24
100	44,3	61	38,7	47	35,1	38	32,7	32	31	27
110	47,4	68	41	52	37	43	34,3	36	32,4	31
120	50,4	76	43,3	58	38,9	47	35,9	40	33,7	34
130	53,5	84	45,7	64	40,8	52	37,5	44	35,1	38
140	56,5	91	48	70	42,7	57	39,1	48	36,5	41
150	59,6	99	50,3	76	44,6	61	40,7	52	37,8	45
160	62,6	106	52,7	82	46,5	66	42,3	56	39,2	48
170	65,6	114	55	87	48,4	71	43,9	60	40,6	51
180	68,7	122	57,3	93	50,3	76	45,5	64	42	55
190	71,7	129	59,7	99	52,2	80	47	68	43,3	58
200	74,8	137	62	105	54,1	85	48,6	72	44,7	62

Transition Heat Transfer Processes in Conventional Insulators with Aluminium Sheathing



The heat flow is transferred through the layer of conventional insulators by conductivity; in this case, the only blocker will be the heat conductivity of thermal insulation.

Due to its high heat conductivity **(209 W/m°C)** and thermal diffusivity **(0.000086 m^2/sec)**, aluminium quickly absorbs the heat flow and distributes the temperature evenly across its surface.

Then, a **very intensive ambient heat loss** will occur through convection and radiation; **the surface of sheathing** will become **cold**.

The heat loss of the entire structure will be $\alpha_n = \alpha_k + \alpha_l$ **= 23** and more W/m^2 °C, with the fair share attributed to the radiative heat transfer component.

If a human body is in contact with sheathing, the temperature in the contact point will drop to the skin temperature in few seconds due to high heat capacity of the human body (3.4 kJ/kg°C).

However, high thermal diffusivity of sheathing causes the heat flow to concentrate at the heat misbalance spot (contact point) and level out the surface temperature. In addition, intensive heat supply to the contact point tries to maintain same level of radiation component.

If the sheathing temperature is high, burn injury is unavoidable.

In winter period, the **snow is intensively thawing** on the sheathing surface for the same reasons. The lower the ambient temperature, the more intensive the heat loss, as the conductive heat transfer grows (growth Δt) and the capacity of radiation component is maintained by the thermal diffusivity of aluminium.

Conclusion: **Overall heat flow capacity is sufficient for the snow to thaw and icicles to build up on cold sheathing.**

Conventional Insulators Vs. Ultra-Thin Thermal Insulation Coatings

	Conventional Insulators	**Ultra-Thin Thermal Insulation Coatings**
Energy efficiency	heat conductivity 0.045 W/m^2 °C	heat conductivity 0.001 W/m^2 °C, i.e. 45 times less conductive, 45 times more efficient
Cost efficiency	high heat loss and high price	price for 1 sq.m is less by 25 to 30%, heat loss is less by 35%
Durability	3 to 5 years	indoor 20 years, outdoor 15 years
Corrosion and condensate protection	no protection, absorbs moisture	impervious, 100% metal adhesion, 100% corrosion, condensate and UV protection
Equipment protection	impossible, or too complicated	protects any geometries, flanges, valves, bends
Burn injury protection	no protection	self-contained burn injury protection secured by physical properties of the coatings
Visual inspection of equipment	any visual or ultrasound inspection is only possible when disassembled	100% visual and ultrasound inspection of any equipment: water, fuel, oil storage tanks, bends, flanges, valves
Installation time	6 to 8 hours per sq.m	output for airless spray application 100m^2/hour, by brush 0.1 hour/m^2
Sound proofing	none	damping effect on any surfaces in the entire frequency range (turbine enclosures, air ducts)
Weight	5 to 7 kg/m^2	flexible, light-weight 0.18 kg/m^2 (single coat), no excess load
Maintenance and disposal	maintenance and disposal is expensive and complicated, investments needed	no maintenance needed during the service life; all repairs and post-repair restoration is very simple; no allowance for maintenance required; no special waste treatment
Eco-friendliness	health hazard	eco-friendly, safe for application and use
Appearance	deteriorates quickly	remains as good as new during the entire service life, makes the room lighter
Fire safety	flammable when soaked with a lubricant or fuel	flammability class Г1, flame propagation index=0, thermally decomposable at 850°C, releases carbon dioxide and nitrogen to put out the flame and fume; approved for use with the equipment and piping located in any fire-rated areas; applies no fire load; classified as an ultra-thin coating up to 2 mm; defined as fire safe.
Crime prompting	can be stolen	cannot be stolen and reused

Surface Temperature Measurement of Ultra-Thin Thermal Insulation Coatings

Methods and instruments currently used in heat engineering to measure the temperature of conventional insulation are in no way suitable for temperature control of ultra-thin thermal insulation coatings.

Temperature measurement is one of the most difficult issues in thermal physics, especially when it comes about ultra-thin thermal insulation coatings.

Low heat conductivity and thermal diffusivity of Korund products lead to material errors when using the contact measurement methods to determine the surface temperature of insulated items.

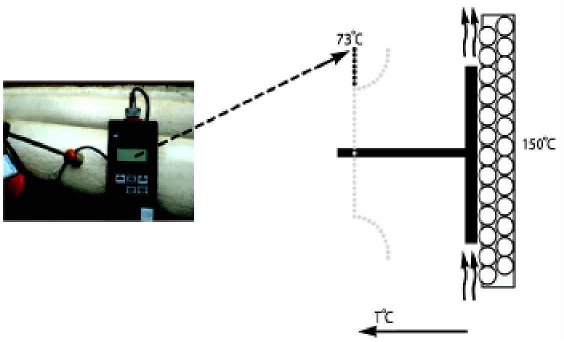
To increase measurement accuracy, special methods have to be selected.

For 'standard' methods, temperature measurement error may be as high as dozens of degrees subject to the temperature of the test item, ambient temperature and thermal and physical properties of the test item.

The lower the heat conductivity of the material, the bigger the measurement error.

When **contact thermometers** with closed metering plate are used, the surface is partially shielded from convective streams by the probe, while the probe is in contact with the surface layer of overheated shells of ceramic spheres. As a result, the meter shows overstated temperature.

This method is unsuitable for trustworthy measurement.

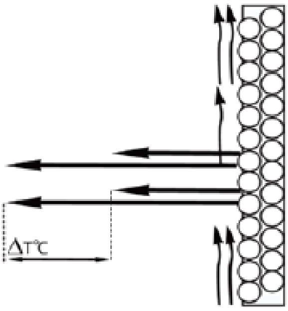


<u>High reflectivity</u> of the Korund products **leads to material errors when using pyrometers and thermal imaging device** calibrated with reference black-body radiators designed for emissivity values around **$\varepsilon \approx 0.99$** and suitable for wave spectrum 7 to 18 μm.

Korund emissivity is **$\varepsilon_{pr} \approx 0.24$** in wave length spectrum 1 to 4 μm. This is the reason why the real (actual) temperature of the item may be twice or thrice higher or lower than the measurement unless the thermal emissivity is accounted for correctly.

Non-contact methods and instruments are suitable only for preliminary pipeline status check and rough temperature measurement as their accuracy is affected by a number of factors (air pollutants, distance to the test item, omitted thermal emissivity, etc.); **thus this measurement cannot be deemed trustworthy.**

Pyrometers can only catch the maximum temperature among the heated shells of ceramic spheres out of the big picture of temperature field. It means that a light-strike is caused by the radiation emitted from the surface of microspheres. Lightest breath of wind will change the temperature of surface microspheres.



Cumulative error of such measurements may reach dozens of degrees. Hence, **pyrometers may not be used for temperature measurement of ultra-thin coatings.**

Thermal imaging devices used in heat engineering **are also unsuitable for these purposes as explained above.**

To determine the surface temperature of ultra-thin thermal insulation coating, the most reliable and trustworthy method is by the touch and using an open-junction thermocouple.

The most accurate and trustworthy method to measure the surface temperature of ultra-thin thermal insulation coatings was proposed in 2009 by Academician N.K. Myshkin, Director of V.A. Belyi Metal Polymer Research Institute.

The method is based on **the fact that water boils at the surface temperature of ultra-thin heat insulators +175°C** and describes the temperature measurement with an open-junction K-type contact thermocouple submerged into water covering the coating surface, without touching the surface.

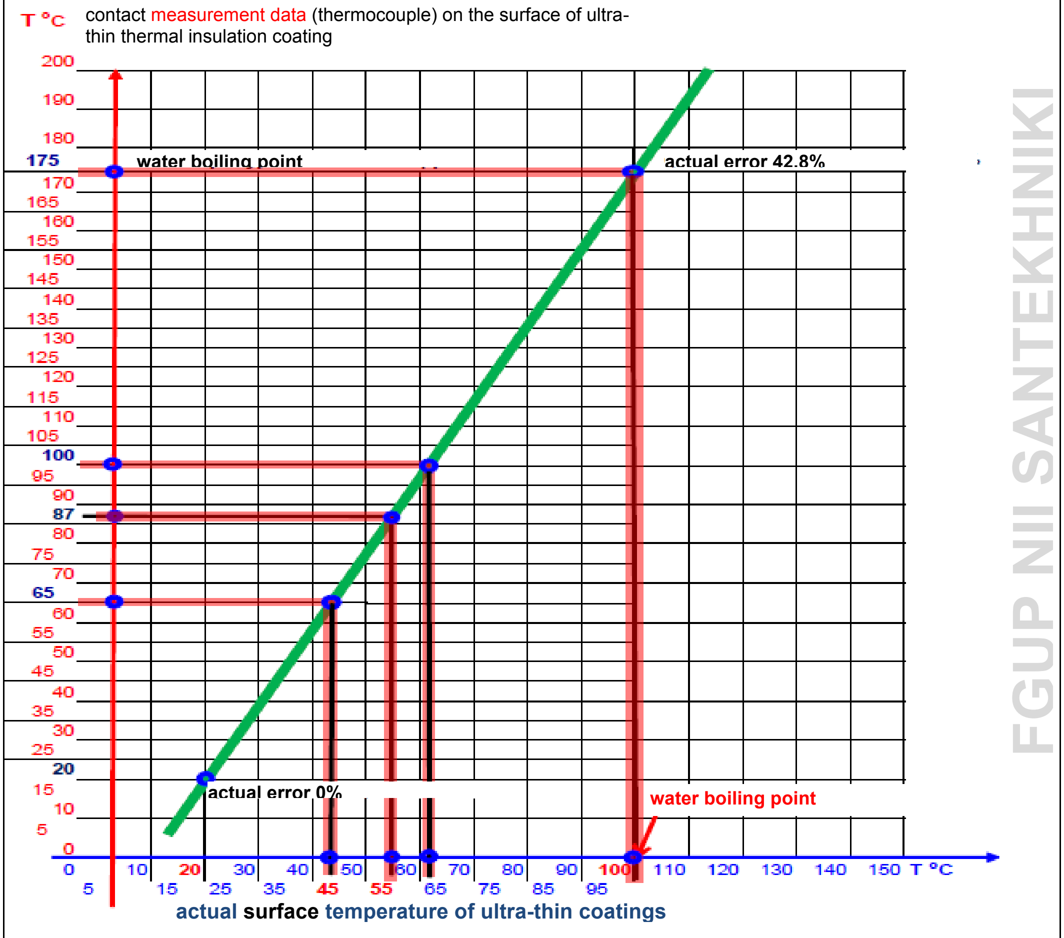
The method proved to be consistent and accurate in laboratory conditions.

Today, the most time-tested and trustworthy temperature measurement is done using the method by Sanitary Equipment Scientific & Research Institute (FGUP NII Santekhniki).

It is based on measuring the temperature with an open-junction K-type contact thermocouple and subsequent error correction using the diagram developed and approved by FGUP NII Santekhniki.

Y-axis is for the temperature determined by contact measurement on the coating surface; X-axis is for the real surface temperature. According to this diagram, the human-safe temperature, for example, will be 87°C on the coating surface (which corresponds to 55°C on the metal surface).

DIAGRAM
Determination of Actual Surface Temperature
for Ultra-Thin Thermal Insulation Coatings



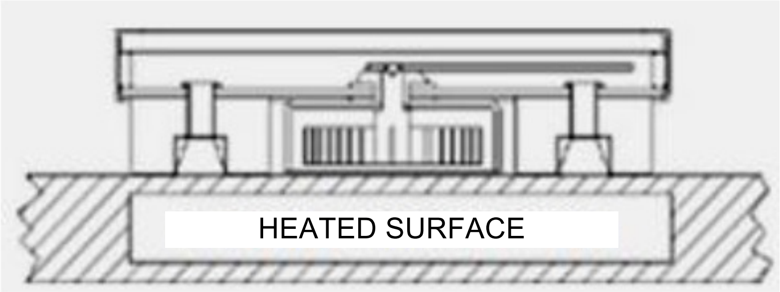
Temp-Coat manufacturer suggested a simpler, yet reliable measurement method based on a set of special thermometers and dedicated procedure. The method has been applied and recommended by the manufacturer.

These unique portable thermometers are designed to measure the temperature of practically any surfaces. Bimetal sensor element quickly measures the surface temperature; it is duly protected from any damage by means of magnets and casing. For most accurate measurement, use the device in windless conditions. Place the thermometer on a surface to be checked with the scale facing up to locate the sensor element above the surface.

Use magnets to move the device to any part of magnetic surface. The device can also be used with non-magnetic horizontal surfaces.

Readings to be taken one minute after the thermometer is in place.

Ambient temperature or air draft near the surface may cause slight impact on measurement.



Saint Petersburg, 2012, Y.V. Bashuyev, Candidate of Engineering