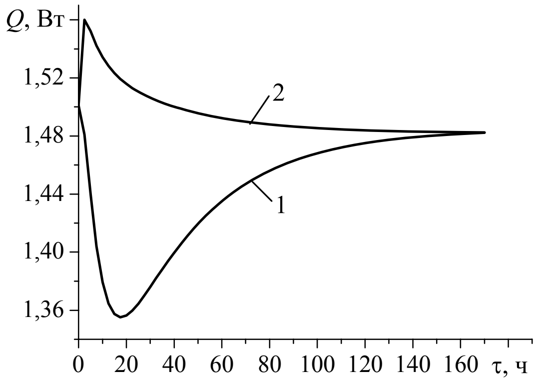

Fig. 5. *Heat flows through: 1) interior and 2) exterior surface of the wall fragment with heating put in it*

For the fragment of wall with connector considered in the work thermal losses in stationary conditions of heat transfer amount 1,48 W (fig. 5), without connector – 1,44 W. The value of heat-engineering homogeneity coefficient is rather high [9], equal to 0,97.

Thus, the performed numerical investigation of thermal conditions of heterogeneous claydite-concrete wall with connector makes possible to reveal the regularities of difference temperature distribution and estimate the influence zone of heat-conductive inclusion. The developed numerical method allows prediction of heat conditions of exterior heterogeneous walls with different thermal physic and geometric characteristics of the materials in cold climatic conditions.

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DEFINITION OF THERMAL RESISTANCE OF PIPE WALLS OF SMALL THICKNESS BY THERMAL FLOWS DENSITY CHANGE

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The provisions basing structural dependence of thermal resistance of materials of pipe walls made of boiler steels in dimensional thickness where effects of bounder jumps of temperatures creating distortions in measurements of heat conductivity factor are shown are presented. The established dependences are explained from positions structural crack formation in undersurface areas.

At research of processes of heat exchange in multilayered cylindrical constructions to which it is possible to attribute multielement systems of heatdump of loop channels of research nuclear reactors, collector packages of electric generating channels of thermoemission nuclear power installations, multielement welded or soldered constructions consisting of thin-wall pipes, thin coatings applied by thermal and galvanic way and other thermally thin layered bodies, thermal resistance of the thin-wall envelopes making heat-transmitting system got the important value. In a modern science of heat exchange « thermal resistance « is defined when the case in point is transport of heat through a complex of constructional materials. Classically transport of heat through constructional materials is usually linked with concept of heat conductivity, factor of heat conductivity λ, thermal diffusivity factor a when the case in point is non-stationary processes, that is applicable and proved for massive, homogeneous, continuous physical bodies. The phenomena of dispersion of energy on a surface are attributed to heat-carriers or thermal radiation. Practice of an experimental research of convective heat exchange, critical thermal flows at boiling, nature of contact heat exchange, thermal dispersion on a surface of solids, thermal accommodation in gases results preferably in registration of temperature differences in boundary area.

There is no unity in understanding of the physical mechanism of formation of temperature differences in boundary areas of media transporting heat among researchers. When the case in point is the order of size, value of thermal resistance on the borders, existing models and hypotheses of diffuse dispersion of thermal radiation, the microlayer theory in convective heat exchange, thermal accommodation in gases, nature of occurrence of boiling crises and importance of contact spots in formation of a heat-conducting surface at contact with solids are estimated by various way. Effect of nonlinearity of temperature profile on metal border (Jacque's effect) [1] and in crystals at low temperatures, unequal heat conductivity inside a body and near its borders are explained by change of free path of fonons, elecrons, gas molecules, owing to dislocation concentration because of mechanical, thermal and other processing of a surface or other reason. From the point of view of the theory of solids physics thermal dispersion on solids border does not differ from processes of thermal energy dispersion in its volume that gives the basis to consider, that thermal resistance and heat conductivity of solids are connected by geometrical characteristics. In the literature nevertheless it is not possible to find the order of temperature jump on solids boundary. In the published results of researches of heat conductivity of thin films one notes area with sharp dependence of heat conductivity on thickness (70...80 nm) and areas (>200 nm) where the value λ monotonously approaches reference value for an array [2]. Solving questions of an experimental research of thermal resistance of thin film elements of heat damp system of a loop channel, technology of thin-film constructions and thermal stability of materials, it is necessary to consider existence of abnormal phenomena of heat conductivity when the case in point is high thermal flows and temperatures.

The recognized methods for calculation a heat transfer consider temperature difference in multilayered heat-conducting system as result of summation of thermal resistance of separate sites. Irrespective of heat exchange conditions temperature differences in thin envelopes are defined as function of thermal flow and relation of envelope wall thickness to average value of heat conductivity factor. Mechanism of heat transfer in a solids according to linear Fourier law is equilibrium on the form, i. e. experimental value of heat conductivity factor can be found the more precisely, as temperature function, than less temperature difference. In real conditions of intensive heat exchange in thin-wall envelope tube constructions from a high-temperature heat source to low temperature work body should collide more often with the phenomena of heat transfer in nonequilibrium external thermodynamic modes. Probably, heat transfer constants in conditions of nonequilibrium heat exchange have to be defined by another way. Considering the main laws of the thermal radiation, many authors note, that in the process of during radiate heat exchange only thin surface metal layers, about 1 ?m, and isolators up to 1 mm take part, thereby thermal radiation is defined as only surface phenomenon, and at discussion of technique of measurement of heat conductivity factors, heat transfer in solids is considered as volume phenomenon, and it is suggested to reject all surface factors.

References to works in which the phenomena of abnormal heating (cooling) of a surface of solids subjected to intensive thermal influence are considered are given in [3]. It is noted, that the nature of this phenomenon till now is not investigated and connected with increase of defect density of matter surface structure owing to action of forces of thermomechanical character. Abnormal phenomena in relation to the classical theory of heat conductivity are noted in a layer 40...100 mkm, i. e. in the thickness comparable with structural characteristics of matter. Noting determining value of heat transfer character in boundary areas, authors [3] usually do not give data by quantitative characteristics, there are no even estimated data on value of thermal resistance tin surface structures. In the field of the contact heat transfer theory it was not possible to find the main cause of anomalies in contact conductivity. Not numerous results of measurements of a temperature field profile the metals, executed by Jacque [1], are reflected only qualitatively, without explanation of the reasons causing occurrence of nonlinearity of a boundary temperature profile, are not comparable with known results of thermal resistance measurements in the systems containing thin-wall constructions, for example, fuel elements of nuclear reactors and heat exchange surfaces of steam and gas generators with liquid metal heat-carriers. In experimental measurements of heat conductivity factor of alloys, composite materials the complex and ambiguous character of dependence of heat conductivity on temperature is found. In an explanation of the reason of deviations from traditional representations of functionality of connection of temperature heat conductivity factor many authors consider inner structure changes in materials and compositions. In particular, the role of structural factors in steels is noted.

The summary of state of question of forecasting of thermal resistance in construction materials, especially in their combination, that is characteristic for complex constructions of heat transfer systems, allows to draw the following conclusions at a preliminary stage of planning of experimental work:

1. The actuality of researches of behaviour of thermal resistance of thin-wall pipe in dependence on thickness and time is not removed in connection with the unstated reasons of abnormal behaviour of effective heat conductivity factor in boundary areas.
2. Thermal resistance of thin-wall envelope constructions can differ from value calculated on known constants and techniques used for massive bodies.

3. At carrying out of researches on resource stability of elements of heat damp system and materials it is necessary to specify influence of external inequality on constants of heat transfer and to establish the order of their deviation from known values.

Methodical features of resource researches of thermal resistance of thin-wall pipes

Heat-resistant thin-wall (0,5...5 mm) pipes from alloyed steels by virtue of specificity of their physical mechanical properties at the higher temperatures and resistance to oxidation are the widespread materials in energy stressed constructions. Critical consideration of features of behaviour of heat conductivity factor of pipe materials from steels results in necessity to reveal resource dependence on temperature and thermal flow. At ascertaining of character of changes of heat conductivity factor of thin layers very limited quantity of experimental data is given in the literature [4] and there are almost no calculated dependences of functional connection of heat conductivity factor on temperature and time of thermal loading. Considering, that thermal resistance of thin-wall steel pipes can be exposed to essential resource changes, especially in conditions of external inequality, it was accepted decision to execute a series of resource thermocyclic tests of samples to reveal thermal instability.

Double character of a problem of the resource thermocyclic tests, consisting in revealing of a role of thermal resistance, its order and uncertainty of character of its resource change causes necessity to base experimental research technique. At the present there are no fulfilled ways and techniques, allowing to prove presence of temperature jump on boundary of solids in conditions of external inequality. Quite often anomalies in definition of heat conductivity factor are explained by an error of definition of thermal flow density being difficult for withdrawal. It is difficult to base and define a regular error which arises in the process of measuring of material surface temperature. At use of low thermal flows low temperature differences arise at relative high levels of temperature. For example, taking into account, that the error of thermoelectrodes BP-5, BP-20 is about 1 %, that at a level of temperature 800 °C will make a deviation about 16 °C in measurement of temperature difference, authentic temperature difference on a thin-wall envelope should be approximately 60 °C. Practice of measurements at pressure $\sim 6 \cdot 10^{-3}$ Pa shows, that registered temperature differences in thin-wall envelope at work on radiation can be 20...30 °C. At increase of thermal flows it is difficult to base a degree of influence of thermal radiation on junction and thermoelectrodes.

Substantiation of a technique of measurement of thermal resistance of thin-wall envelopes is based on known stationary and non-stationary ways of measurement of heat conductivity. Use of non-stationary methods at measurement of thermal resistance is based on identity of techniques of manufacturing of thermocouple junctions, thermostating of the free ends and technology of closing up of work junctions on the surface of a series of samples with various thickness. The error of used thermocouples should have an identical mark and the close module. Stability of a sign at very low thermal flows serves as the control moment in all series of measurements of differential thermo E.M.F. Identity of techniques of manufacturing of junctions of thermocouples BP-5, BP-20 is provided with welding in an inert gas atmosphere. The thermocouple junction has no technological joints, the work end is welded by spot welding on the surface of the envelope to be researched. Identity of technology of manufacturing of work junctions and their closings up in a sample is established and proved by series of calibrations on thermostating samples and method of checking with the reference thermocouple. The proposed technology allowed in further to get rid of individual calibration and to provide steady metrological characteristics.

In definition of heat conductivity of the pipe wall material the effects connected with dependence of heat conductivity on sample thickness, cyclicity, temperatures and time of thermal influence are observed, Fig. 1.

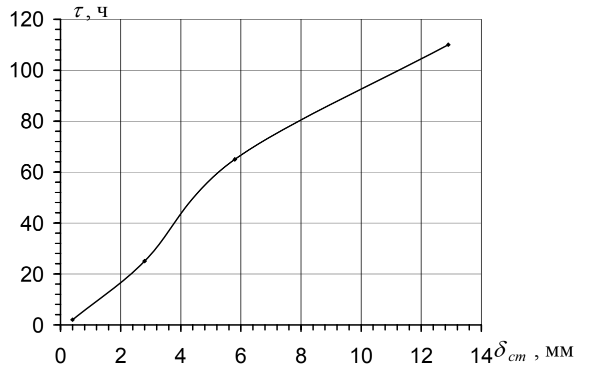

Fig. 1. *Time of registration of steady values of effective heat conductivity from thickness of pipes from steel 0X18H10T. T=600...650 °C*

Non-stationary methods in the process of thermal resistance change registration were used as a way for proof of presence of temperature jump on border of a thin-wall pipe boundary and applied as addition to measurements in stationary thermal mode.

The found hysteresis phenomena of change of thermal resistance during increasing and decreasing of temperature were correlated with changes of integrated intensity of lines of X-ray reflection of iron lattice in an alloy in specially organized resource high-temperature X-ray structure tests as support of thermophysical ones. Researches of temperature changes of structural stresses correspond to complex displays of thermal resistance, Fig. 2.

Measurements of thermal resistance were carried out in two stages. At the first stage the primary goal was detection of deviation of thermal resistance from calculated one. At the second stage of researches resource tests of samples from stainless steel were carried out with the purpose to reveal resource instability of thermal resistance and to build the generalized curve of dependence of effective heat conductivity factor of stainless steel on envelope thickness by stable values of the thermal resistance obtained during resource tests.

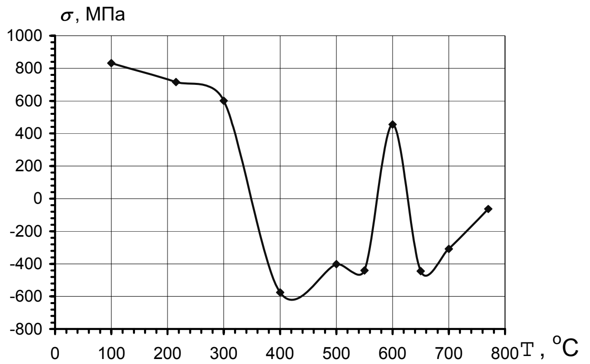

Fig. 2. *Change of inner structure stresses of a pipe material from CT10 in dependence on temperature*

Non-stationary methods of definition of thermal resistance of thin-wall pipes have not obtained wide distribution and substantiation. Aspiring to fill this blank, attempt of substantiation of application of non-stationary method to detect temperature jump on a thin-wall envelope surface is done in this work. The following theses are laid in the basis of consideration

1. At action of a thermal flow on a material a nonlinear temperature profile appears in near-boundary area.
2. Thermal resistance of a material at action of a thermal flow on a surface does not coincide with its value calculated using through heat conductivity factor and geometrical characteristics of a sample.
3. The phenomena of thermal dispersion similar with known thermal accommodation in gases appear on the material surface irradiated with a radiant thermal stream.
4. Temperature and resource structural changes in pipe wall materials are capable to cause corresponding changes of thermal resistance

Existing ways of definition of heat conductivity factor are based on measurement of stationary temperature differences on boundaries of area of various geometry, in the assumption, that the temperature profile inside considered geometrical area has linear character, for example, in case of a unlimited plate, heat conductivity factor λ is defined according to Fourier law by expression:

$$\lambda=q\cdot\delta/\Delta T,$$

where λ – is heat conductivity factor; δ – is plate thickness ; ΔT – is temperature difference.

Techniques of processing of measurements results take into account nonlinearity of a temperature profile by approximation and building of dependence $\lambda=f(T)$, the average temperature depends on a way of averaging, thus it is supposed, that in a narrow range of values ΔT distribution of a temperature field on area δ has linear character. Processing of measurements results and their generalization as $\lambda\sim f(T)$ gives the basis to consider, that the heat conductivity factor is proportional to tangent of an angle of temperature field inclination along coordinate «x» in the centre of an unlimited plate at temperature $T=0,5(T_a-T_d)$, where T_a and T_d are temperature on the side of thermal influence and on the side of thermal dispersion accordingly.

Changes of an energy flow in a small interval of values from Q_1 up to Q_2 causes corresponding changes of an angle of temperature profile inclination, thus in a plate with thickness Δx energy concentrates:

$$\Delta Q=Q_2-Q_1=c(T)\cdot\rho(T)V\cdot\Delta T, \qquad (1)$$

where: $\Delta T=0,5[(T_в^{(2)}-T_в^{(1)})+(T_н^{(2)}-T_н^{(1)})]=\delta T_в+\delta T_н$, c, ρ, V – are thermal capacity, density and volume.

In a small temperatures interval where dependence $\lambda(T)$ can be neglected, using Fourier law, we shall write:

$$\Delta Q=\lambda(T)\cdot(\Delta T_2-\Delta T_1)F\tau/\Delta x, \qquad (2)$$

where $\Delta T_2=T_в^{(2)}-T_н^{(2)}$; $\Delta T_1=T_в^{(1)}-T_н^{(1)}$, F, τ – are surface area and time accordingly.

Uniting expressions (1) and (2), after transformations, we have:

$$\rho(T)c(T)=2\lambda(T)F\tau/\Delta x;$$

let`s express from this equality:

$$\lambda(T)=c(T)\rho(T)\Delta x/(2F\tau);$$

taking into account, that for plate $V=F\cdot\Delta x$, let`s write:

$$\lambda(T)=c(T)\rho(T)(\Delta x)^2/(2\tau). \qquad (3)$$

Thus, to define $\lambda(T)$ it is necessary to find time of onset of quasistationary thermal mode τ:

$$\tau=c(T)\rho(T)(\Delta x)^2/2\lambda(T).$$

As this mode one understands time during which steady value of a thermal flow is established in a heated up sample.

As an example being necessary for estimations, it is possible to take the data for the sample from steel 0X18H10T with wall thickness 4,9 mm and for comparison with wall thickness 2,8 mm. Using the reference data [5], let`s accept constants: $c(T)$=586 J/kg·K; $\rho(T)$=7500 kg/m^3; $\lambda(T)$=20 W/m·K.

The calculated time of approach of quasistationary mode for the 4,9 mm wall is:

$$\tau_{4,9}=586\cdot7500\cdot(2,8\cdot10^{-3})^2/2\cdot20=2,64 \text{ c}.$$

Accordingly, for a wall 2,8: $\tau_{2,8}$=0,66 s.

That in this steel sample temperature difference for 1 min were established, the following wall thickness is necessary:

$$\Delta x=\sqrt{\frac{2\cdot\lambda(T)}{c(T)\cdot\rho(T)}\cdot\tau}=23,36 \text{ мм}.$$

Thus, to detect time of approach of quasistationary mode for thin-wall pipes without application of special devices is difficult. The existing devices of the thermal monitoring used in experimental researches, allow to register this time during ten minutes that will demand application of samples from stainless steel with thickness of tens mm. The values of effective heat conductivity obtained in stationary thermal modes are given on Figs. 3, and 4. Time of transition from a point to a point is 1,5...2,0 h. It is visible from diagrams, that in sequence of measurements cycles hysteresis phenomena are noted. In the assumption of existence of a nonlinear temperature structure the problem of definition of heat conductivity factor is complicated by implicit character of dependence $T=f(x)$, that does impossible averaging of thermophysical constants. Observably hysteresis phenomena in change of thermal resistance, hence effective heat conductivity, are accompanied by change of internal stresses. Internal stresses at influence of temperature are subjected to banite structural transformations, change size and sign, result to crack formation and to development of internal porosity. In these conditions obtaining of steady values of thermal resistance is complicated by development of relaxation processes.

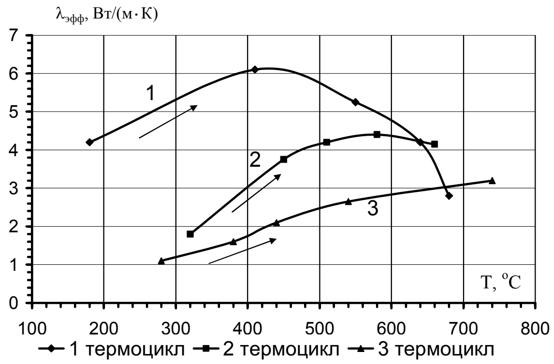

Fig. 3. *Character of change of effective heat conductivity of a pipe wall material from steel 0X18H10T in the first three thermocycles for δ_{st}=3,8 mm*

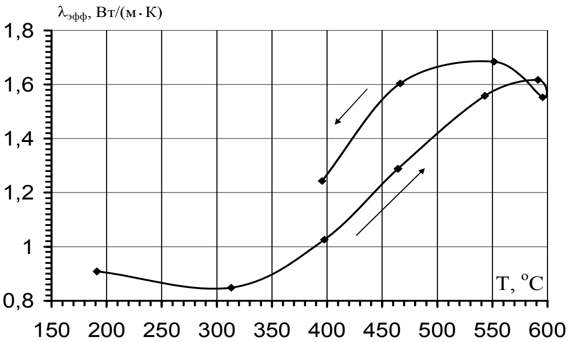

Fig. 4. *A temperature hysteresis of effective heat conductivity of a pipe material with thickness 5 mm from steel 12Х1МФ*

Let's make attempt to obtain expressions for estimation of approach time of quasistationary thermal mode in the assumption of existence of temperature jump near boundary of an unlimited plate. For this purpose let`s use a technique of obtaining of xpression, considered for the case of a linear temperature profile. Neglecting accumulation of energy in surface layers of a material, let`s write expression for calculation of change of energy, $\Delta Q=c(T)\rho(T)V\Delta T$, concentrated inside the plate at increase of an external heat flow ΔQ from value Q_2 up to Q_1, or through thermal flow density:

$$\Delta Q=\Delta q_F F. \quad (4)$$

Taking Fourier law as a basis for temperature distributions we have: $q_F=\lambda\dfrac{dT}{dx}$, in the integral form expression (4) will be written as:

$$\Delta Q=\lambda\frac{\Delta T_1-\Delta T_2}{\Delta x}F\tau, \quad (5)$$

where $\Delta T_1=T_в^{(1)}-T_н^{(1)}$, $\Delta T_2=T_в^{(2)}-T_н^{(2)}$, τ is the time of establishment of a stationary temperature field.

Let's assume, that with an error, being equal to experiment error, the difference of average temperatures *?T* differs from temperature drops a little on the internal and external walls of the plate, i. e. let`s accept equality:

$$\Delta T=T_в^{(1)}-T_в^{(2)}=T_н^{(1)}-T_н^{(2)}. \quad (6)$$

According to the assumption, let`s write:

$$\Delta Q=c(T)\rho(T)V(T_в^{(1)}-T_в^{(2)})=c(T)\rho(T)V(T_н^{(1)}-T_н^{(2)}). \quad (7)$$

Comparing (5) with (7), we have equality:

$$\lambda(T)F\tau(T_в^{(1)}-T_н^{(2)})/\Delta x=c(T)\rho(T)V(T_в^{(1)}-T_в^{(2)}),$$

which transformation looks:

$$\lambda(T)\frac{1-\dfrac{T^{(1)}{}_н-T^{(2)}{}_н}{T^{(1)}{}_в-T_в^{(2)}}}{\Delta x}F\tau=C(T)\rho(T)V, \quad (8)$$

then the formula for definition of heat conductivity factor gets the following form:

$$\lambda(T)=\frac{c(T)\cdot\rho(T)\cdot V\cdot\Delta x}{F\cdot\tau(1-\dfrac{T_н^{(1)}-T_н^{(2)}}{T_в^{(1)}-T_в^{(2)}})};$$

applying thermal diffusivity factor as: $a=\lambda(T)/[c(T)\rho(T)]$ and taking into account, that $V=F\Delta x$, we have inequality:

$$a=\frac{\Delta x^2}{\tau\cdot(1-\dfrac{T_н^{(1)}-T_н^{(2)}}{T_в^{(1)}-T_в^{(2)}})}.$$

Designating dimensionless relative temperature difference as $\Theta=\dfrac{T_н^{(1)}-T_н^{(2)}}{T_в^{(1)}-T_в^{(2)}}$, let`s present equality (8) in criterial form: $\text{Fo}_в=\dfrac{1}{1-\Theta}$, here Fo=$a.\tau/(\Delta x)^2$ is Fourier criteria.

Presenting equality (8) in form:

$$\lambda(T)\frac{T_в^{(1)}-T_в^{(2)}}{T_н^{(1)}-T_н^{(2)}}F\tau=c(T)\rho(T)V(T_н^{(1)}-T_н^{(2)}),$$

or:

$$\lambda(T)\frac{\dfrac{T_в^{(1)}-T^{(2)}{}_в}{T^{(1)}{}_н-T_н^{(2)}}-1}{\Delta x}F\tau=c(T)\rho(T)V,$$

after transformations we shall obtain: $a(T)\cdot\dfrac{\frac{1}{\Theta}-1}{\Delta x}F\tau=V$, in criterial form: $\text{Fo}_н=\dfrac{\Theta}{1-\Theta}$.

In the case if temperature differences on an internal wall of the plate are higher, than on external, Θ<1 and $\tau(T)$ has finite value, if equality of temperature differences is observed thermal resistance of the plate is defined by surface temperature jumps.

Example: for the pipe sample from steel 0X18H10T with wall thickness Δx=4,9·10^{-3} m, in a stationary heat mode with measured values: ΔT_a=66,67 °C, ΔT_d=64,88 °C, ΔQ=184,9 W, $T_d^{(2)}$=623,81 °C,

$T_a^{(1)}$=690,48 °C, $T_d^{(2)}$=616,67 °C, $T_d^{(1)}$=681,55 °C, τ=1800 c, calculations by the above-stated formulas result in the following values of heat conductivity factors:

$$\Theta = \frac{T_н^{(1)} - T_н^{(2)}}{T^{(1)}_в - T^{(2)}_в} = 0,973;\ \mathrm{Fo}_в = \frac{1}{1-\Theta} = 37,244;$$

$$\mathrm{Fo}_н = \frac{\Theta}{1-\Theta} == 36,244;$$

$$\lambda_в = \frac{\mathrm{Fo}_в c\rho\Delta x^2}{\tau} = 2{,}184\ \mathrm{W/m\cdot K};$$

$$\lambda_н = 2{,}125\ \mathrm{W/m\cdot K}.$$

So low values of effective heat conductivity factor are explained by specific nonlinear temperature profile on thickness of the pipe sample with characteristic microdamageability by microcracks in subsurface layers, Fig. 5.

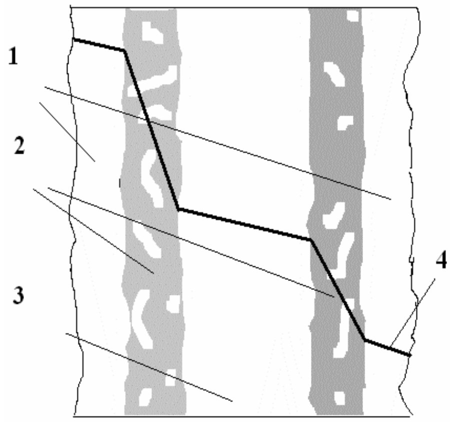

Fig. 5. *Physical model of a flat heat-transferred wall: 1) a rough surface; 2) a subsurface layer; 3) a deep layer; 4) a temperature profile*

Measurements of a microhardness profile testify existence of structural damages under pipe wall surface, Fig. 6.

Conclusions

1. Effective heat conductivity factor of thin-wall steel pipes can be defined on the moment of registration of quasistationary thermal mode at shock thermal loading.
2. Reason of thermal jumps on the pipe surface can be presented by numerous series of structural microcracks under surface owing to mechanical damages at rolling which cannot be eliminated by annealing and normalization and which presence finds indirect confirmation in measurement of a microhardness profile and temperature changes if inner structural stresses of the second kind.

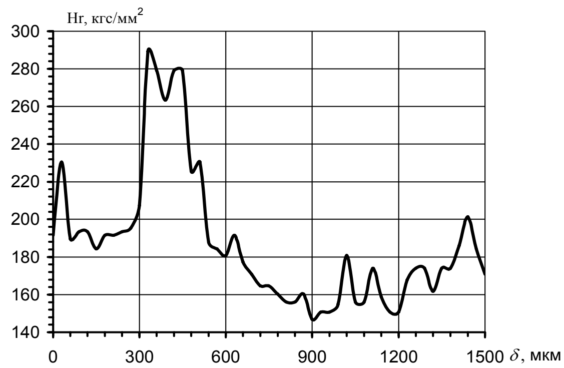

Fig. 6. *Changes of microhardness on the wall thickness of the pipe material of a (beginning from external side) made from steel Ст10*

3. It is established, that the effective heat conductivity factor on an internal pipe wall has higher values, than on external one.
4. Practice shows, that the setting time of stationary thermal temperature drop on boundary of thin-wall pipes is tens in minutes. It gives basis to consider, that a nonlinear temperature profile is at thin-wall pipes, i. e. surface temperature jumps take place.
5. Experimentally – measured values of effective heat conductivity factor of a material of pipe wall samples made of boiler steel of marks Ст10, Ст20, 15ХМ, 12Х18Н10Т, at repeated thermal loading have shown initial deviations from reference values of heat conductivity on the order smaller.
6. For confirmation of reference value of heat conductivity factor λ=20 W/m·K for stainless steel 0Х18Н10Т, the calculated time of approach of quasistationary mode in linear dependence should be of the order τ =2...3 s, and in the assumption of existence of nonlinear dependence of a temperature profile, experimental value reaches 180 s, that corresponds to heat conductivity 2,1...2,2 W/m·K. Steady values of thermal resistance are reached for tens hours annealing, depending on sample thickness.

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