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НАН РК сообщает, что научный журнал «Вестник НАН РК» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Вестника НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному мультидисциплинарному контенту для нашего сообщества.

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EXPERIMENTAL METHOD OF STUDYING THE LIMIT STATE OF THE HEAT EXCHANGE SURFACE COVERED BY A CAPILLARY-POROUS MEDIUM

Abstract. Capillary-porous systems have high intensity, high heat transfer ability, reliability, compactness. The results of calculations and experiments showed that the maximum thickness of the particles that break off under the action of compression forces for coatings from granite is $(0,25 \div 0,3) \cdot 10^{-2}$ m. Sections of compression curves that determine the separation of particles with dimensions of more than $0,3 \cdot 10^{-2}$ m for large heat fluxes and short feed times, are screened by the melting curve, and in the case of small heat fluxes and time intervals, the expansion curve. The research is aimed at creating porous coatings in cooling systems from well – and poorly conductive materials.

Keywords: heat transfer crisis; capillary-porous structure; heat and power installations, cooling systems.

Introduction. Successful use of capillary-porous materials in engineering attracted many researchers and inventors to create different devices on their basis. The intensity of heat-eliminating systems and the forcing of processes taking place therein increased [1-3]. In addition to cooling systems, the use of porous materials allowed the creation of units which addressed the problems of explosion safety, labor protection and durability [4, 6]. This was facilitated by the ability to control evaporation processes due to excess fluid in pores and capillary structures, formed by the combined action of capillary and mass forces [7-9].

In thermal power plants (TPPs), capillary-porous materials are used to cool highly-forced detonation burner units [3], to create steam coolers in steam boilers [9], oil coolers that prevent oil from entering cooling water and water from entering the bearing system [10] and labyrinth seals [11], and are used in other devices [10]. The main areas of practical application of capillary-porous systems are presented in [3, 5, 8-11].

Equipment and technological processes in the energy sector should be introduced from the ecological and economic positions primarily. The proposed development of capillary-porous systems will facilitate the implementation of processes, significantly improving and preserving the natural environment.

The main advantages of capillary-porous systems include high intensity, high heat transport ability, reliability, compactness, simplicity in manufacture and operation. These systems improve operational and technological performance and have low capital and operating costs. Based on the study of capillary-porous systems, new technical solutions have been developed to improve the performance characteristics of the thermal power plant in relation to the powerful power units of combined heat and power plants.

The authors of [12] carry out a comparative analysis of methods for calculating the heat transfer, based on the water boiling with underheating in vertical channels, and they consider that the hot spot corrosion of fuel element claddings of nuclear reactor fuel elements is similar to the capillary-porous structure [13, 14]. However, no studies of heat transfer through a regular structured surface have been carried out.

According to the authors' opinion [15,16], surface boiling on porous surfaces can influence the development of corrosion due to the erosive action on the heat exchange surface, when the bubbles of steam fall in an underheated liquid. Therefore, it is required to investigate the evaporation of liquid in

capillary-porous structures in the field of capillary and mass forces, taking into account the velocity and underheating, which are formed by excess fluid.

An estimated intensity of heat transfer for liquid boiling in a large volume and thin films on a smooth surface showed equal possibilities [12-14] at high thermal flow and higher heat transfer parameters than that in systems with a capillary-porous coating [15, 16]. It is required to carry out investigations of the heat transfer capabilities of capillary-porous coatings operating in the field of capillary and mass forces, and to establish ultimate (critical) load values leading to the destruction of the heating surfaces. Figure 1 presents a method for studying capillary-porous systems for various elements of power plants. The systems differ in the fact that they have predominantly a gravitational fluid supply and occupy an intermediate position between thin-film evaporators and porous evaporators with a predominantly capillary fluid supply (heat pipes) in terms of the intensity of heat transfer. Therefore, such systems should be identified in a separate class of heat-eliminating systems. The performed researches make it possible to give recommendations on the selection of the heating-and-cooling medium, take into account the type of its circulation, determine the geometry and material of apparatuses and heat exchange intensifiers, taking into account the conditions and orientations of the system operation under pressure or underpressure, the energy supply and type and the system orientation. Generalization of the experimental results and calculation procedure for heat and mass transfer in capillary-porous systems in accordance with Figure 1, are presented in [17-21].

Model of the capillary-porous structure of the cooling system. Figure 1 shows the model of a capillary-porous coating applied to the coolable surface of a heat-loaded element of power plants. At the onset of the boiling crisis, the critical state of the heating surface arises, and the latter is destroyed along with the coatings. Such a scheme allows to make a model of fissures of brittle coatings and plastic porous structures.

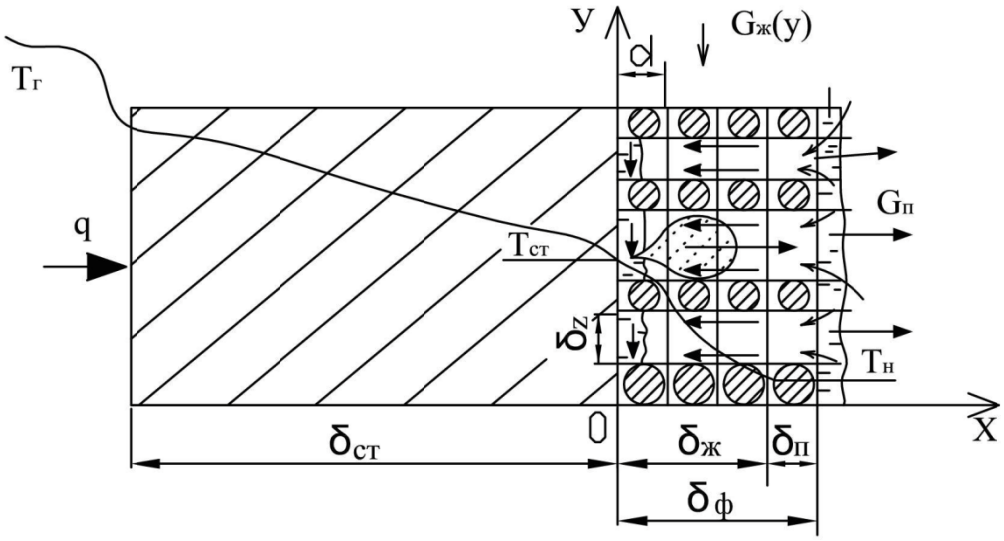

Figure 1 – Physical model of heat and mass transfer in a porous structure covering the coolable surface: Straight lines – fluid movement; wavy lines – steam movement: q – thermal flow, T_g, T_w, T_s – temperatures of gases, walls and saturation; $G_l(y)$, G_s – liquid and steam flow rates; δ_w, $\delta_{p.c.}$, δ_l, δ_s – steam-generating surface, porous coating, liquid and vapor thicknesses, b_z, d – width of porous coating cells and grain diameter

Mechanism and calculation of the critical state of the heat transfer surface. experimental data analysis. The results of the calculations are shown in figure 2-5. The maximum thickness of the particles that break off under the compression forces for granite coatings is $(0{,}25\text{-}0{,}3)\cdot10^{-2}$ m, which is in agreement with the results obtained by high-speed filming. Sections of the compression curves, which determine the breaking-off of particles with a size $\delta>0{,}3\cdot10^{-2}$ m for large thermal flows and small ones τ, are screened with the melting curve, and in the case of small thermal flows and significant time intervals, they are screened with the expansion curve.

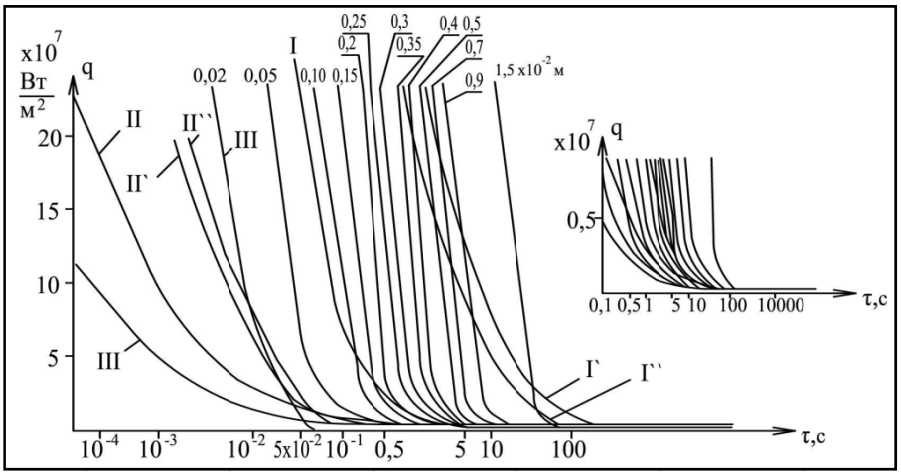

Figure 2 – Dependence of thermal flows causing compression stresses III of a granite coating according to the time of action τ for different thickness δ of the breaking-off particles:
I – tension stresses sufficient for destruction (I', I" – copper and stainless steel, h = $0{,}1 \cdot 10^{-3}$ m);
II – surface fusion (II', II" – copper and stainless steel, h = $0{,}1 \cdot 10^{-3}$ m)

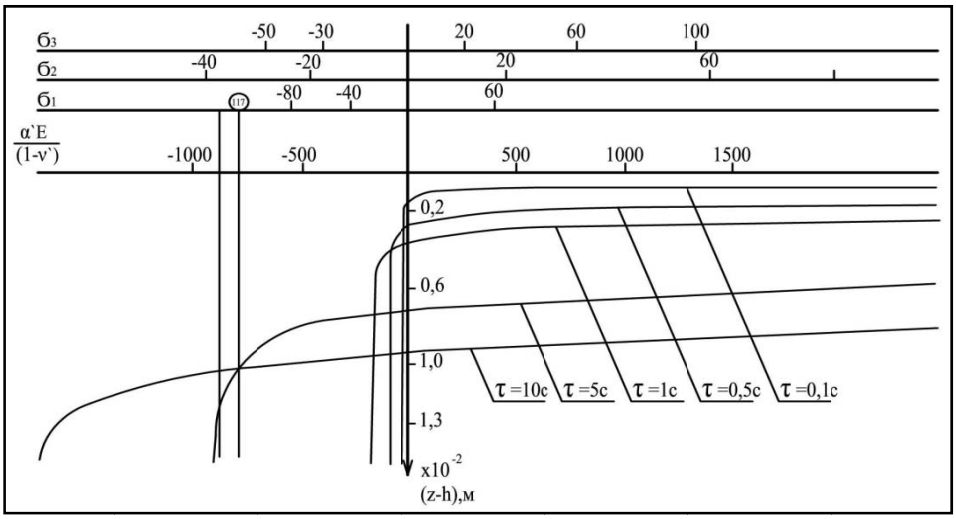

Figure 3 – Stress diagrams for the thickness of the limiting plate for different thermal flows and time of their action:
$q_1 = 0{,}142 \cdot 10^7$ W/m^2; $q^2 = 0{,}042 \cdot 10^7$ W/m^2; $q_3 = 0{,}075 \cdot 10^7$ W/m^2; II7 – ultimate tension strength: σ, $\cdot 10^5$ H/m^2, E, $\cdot 10^5$ H/m^2

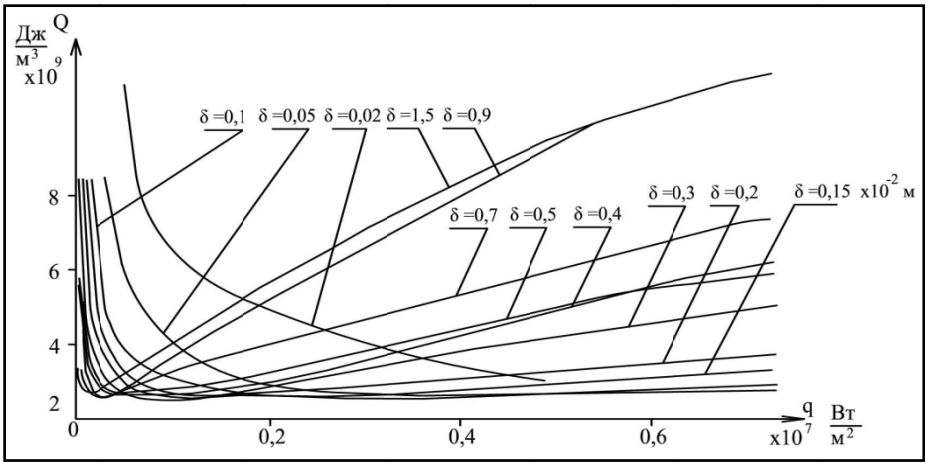

Figure 4 – Change in the ultimate destruction energy Q of the granite coating depending of q for various δ. Q = q τ/ δ

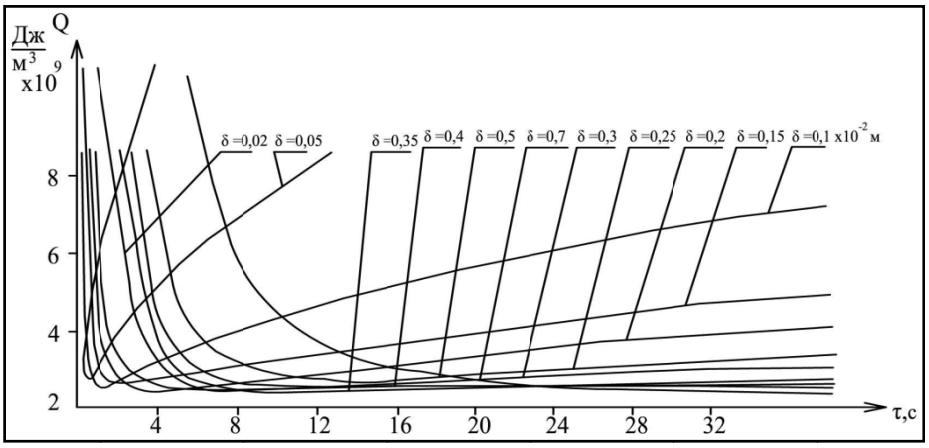

Figure 5 – Change in the ultimate destruction energy Q of the granite coating depending of τ for various δ

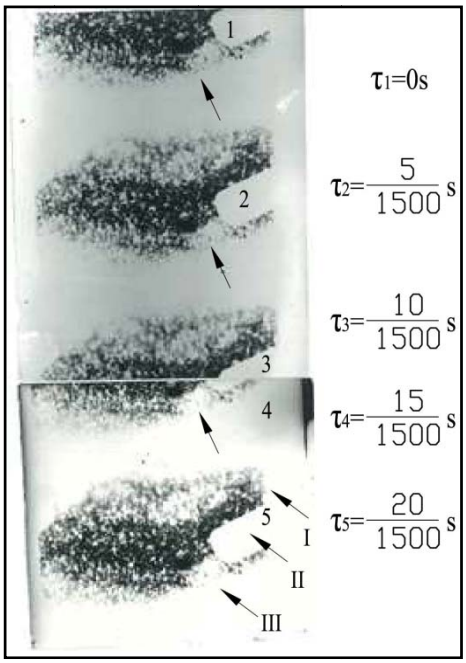

Figure 6 – A record of flight of husks with the size $\delta = 2{,}5 \cdot 10^{-3}$ m when a granite coating particle is destroyed by a rocket-type burner ($q = 1{,}2 \cdot 10^6$ W/m^2):
I – capillary-porous coating; II – burner axe, from which supersonic high-temperature, pulsating detonation gas flow flows out;
III – a particle broken off from the coating

The relationship between tension and compression stresses is stress diagrams within the plate for various time intervals from the beginning of the process under consideration. At small τ, in the region of 10^{-1} s, only compressive stresses arise. Starting from $\tau \approx 1$ s, in some region $\Delta(h\text{-}z_i)$ up to $0{,}3 \cdot 10^{-2}$ m, the compression stresses turn into tension stresses in a very short period of time, and for different time intervals, they are at different depth from the plate surface.

The upper limit of the stable destruction of the quartz coating is 10^7 W/m^2, and that from granite is up to $0{,}5 \cdot 10^7$ W/m^2, and the lower limits, when there is still a detachment of particles under the influence of thermal stresses of compression are $0{,}25 \cdot 10^7$ and $0{,}05 \cdot 10^7$ W/m^2, respectively.

The destruction of an anisotropic medium under the action of directional heating is based on the uneven expansion of its components (crystals). When increasing in volume, the heated layer of the coating rock starts to press adjacent less heated layers. Since the expansion in all other directions is hampered by the reaction of the unheated layers, the rock starts to expand freely from the open side and, due to its overextension, it separates and splits off.

If vacancy cavities can be transformed into dislocations, the investigated coating obtain plastic properties and is not destroyed by the action of the torch. All metals are the same. Some rocks also have such property. The testing was conducted with steam generating metal heating surfaces at the time of the boiling crisis [2]. For metals, crystals are destroyed in directions up to 10^{-5} V. The process of destruction

consists of steps of initiation of fissures and their development. As a result of the thermal action, microcracks are initiated in the region of stress concentrators (inclusions, inhomogeneities, fissures). High internal stresses can also arise due to the inhomogeneous flow of plastic deformation, after which brittle failure occurs. In this regard, plastic deformation is considered as the primary cause of destruction, although it can delay the growth of fissures. on the one hand, bond discontinuities due to thermal fluctuations are at the heart of the destruction, and on the other hand, destruction is a kinetic thermoactivation process, which is based on the displacement of vacancies to fissures, the growth of which determines the kinetics of destruction.

Conclusion. Based on the conducted studies in case of exposure with a torch of a kerosene-oxygen burner of the porous coating within working area, we have up to $4 \cdot 10^7$ W/m^2 corresponded to q of coatings of $\approx 0{,}4 \cdot 10^7$ W/m^2. The metals destruction mechanism is fundamentally different from the rocks coatings destruction mechanism. Despite this, thermal flow dependences on time of their action and depth of penetration of temperature perturbations were identified on the basis of analogy, which help to avoid the boiling crisis in the cooling system and ensure an optimal selection of porous coatings of low porosity and thermal conductivity. In the future, the studies of other porous natural materials are required.

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ҚЫЛТҮТІКТІ-КЕУЕКТІ ОРТАМЕН ЖАБЫЛҒАН ЖЫЛУАЛМАСУ БЕТІНІҢ ШЕКТІК КҮЙІН ЗЕРТТЕУДІҢ ТӘЖРИБЕЛІК ӘДІСІ

Аннотация. Қылтүтікті-кеуекті жүйелер жоғары қарқындылыққа, жоғары жылуберу қабілеті мен сенімділік және ықшамдылық қасиеттеріне ие. Тәжрибе мен есептеулер нәтижелері көрсеткендей, граниттен жасалған жабындылар үшін сығу күштері әсерінен жұлынып алынатын бөлшектердің максималды қалыңдығы $(0,25\div0,3)\cdot10^{-2}$ м. Үлкен жылу ағындары мен берістің аз уақыты үшін өлшемдері $0,3\cdot10^{-2}$ м артық бөлшектердің жұлынып алынуын анықтайтын сығу қисықтарының аумағы балқу қисығымен, ал кіші жылу ағындары мен уақыт интервалдары үшін – созылу қисықтарымен экрандалады. Зерттеулер өткізгіштігі нашар және өткізгіштігі жақсы материалдардан суыту жүйелерінде кеуекті жабындыларды жасауға бағытталған.

Түйін сөздер: жылуберу кризисі; капиллярлы-кеуекті құрылым, жылулық энергоқондырғылар, суыту жүйелері.

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ЭКСПЕРИМЕНТАЛЬНЫЙ МЕТОД ИССЛЕДОВАНИЯ ПРЕДЕЛЬНОГО СОСТОЯНИЯ ТЕПЛООБМЕННОЙ ПОВЕРХНОСТИ, ПОКРЫТОЙ КАПИЛЛЯРНО-ПОРИСТОЙ СРЕДОЙ

Аннотация. Капиллярно-пористые системы обладают высокой интенсивностью, большой теплопередающей способностью, надежностью, компактностью. Результаты расчетов и эксперимента показали, что максимальная толщина частиц, отрывающихся под действием сил сжатия для покрытий из гранита составляет $(0,25\div0,3)\cdot10^{-2}$ м. Участки кривых сжатия, определяющие отрыв частиц с размерами более $0,3\cdot10^{-2}$ м для больших тепловых потоков и малого времени подачи, экранируются кривой плавления, а в случае малых тепловых потоков и интервалов времени – кривой растяжения. Исследования направлены на создание пористых покрытий в системах охлаждения из хорошо – и плохо проводных материалов.

Ключевые слова: кризис теплопередачи; капиллярно-пористая структура; тепловые энергоустановки, системы охлаждения.

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