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STUDY OF HEAT AND MASS TRANSFER IN CAPILLARY-POROUS COOLING SYSTEMS OF A NEW CLASS OF ENERGY THERMAL INSTALLATIONS

Abstract. In this paper a capillary-porous cooling system of the new class for heat removing has been developed and investigated. It allows to control the heat transfer by separating energy processes, and also due to excess of fluid, creating the underheating and flow rate by changing the internal (thermal-hydraulic) characteristics of the boiling process. An algorithm is presented for the study of the influence of various factors on the process of heat and mass transfer (type and circulation of heat (cold) carrier; system design; housing material; the type of system; supply and type of energy; system orientation). A list of applying porous systems to various power installations is presented in order to increase their reliability, efficiency and the maneuverability in view of ecology and, the scheme of location to capillary porous structure and performance of the clamping perforated plates was designed. A critical heat flux, depending on the thermophysical properties of the fluid, the distance between the steam conglomerates, the type of porous structure and its orientation was obtained on the basis of hydrodynamic crisis.

Key words: capillary-porous systems; heat and mass transfer processes; critical heat flux; energy thermal installations.

1. Introduction. In the offered and investigated capillary-porous systems, the management of a heat transfer is organized that allows allocating them a new class of heat-removing systems.

For management of power processes it is offered to divide the general energy into two components: the energy of the heat wave of steam germ emerging explosively and the energy of the compressed steam flow that it is also important to modernize and analogy of the boiling processes in the structure pores (coating) [1]. Increase in a forcing of the cooling system and intensification of processes promotes use of joint action of the mass and capillary forces creating excess of liquid in structure with underheating by the compelled speed of a stream [2-4]. At the same time there is a management of integrated and internal characteristics of the boiling process [3, 4]. For the boiling crisis the limit and ultraboundary condition of a heating surface and a coating it the porous structure is investigated [3, 5-7].

Studies of heat transfer processes are used in thermal power installations: in the combustion chambers and supersonic nozzles [3], in elliptical dust-gas traps [5], in porous geoscreens [8], in the steam coolers of boilers [9], oil coolers of turbines [10], in steam and gas turbines [11-14].

2. Methodology. In the developed capillary-porous systems deserves attention is the study of the dynamics of non-homogeneous (heterogeneous) multi-phase media. They contain macroscopic inhomogeneities (inclusions) whereas in homogeneous environments components are mixed on a molecular scale. Among heterogeneous systems the disperse mixtures consisting of two phases one of which – bubbles, drops, firm particles [2, 3, 5] are of interest. For heterogeneous mixtures do two main assumptions: the extent of not uniformity (inclusions) in mixtures, for example, the size of a bubble or wavelength, is many times more molecular – kinetic sizes, and at the same time the extent of no uniformity there are many times less than distances at which average (macroscopic) parameters of mixture or phases change significantly. These assumptions allow to use the equations of mechanics of continuous single-phase environments for the description of processes in or about separate inclusions (microprocesses) and to describe macroprocesses in the environment, such as a current of the environment in porous structure, distribution in them of waves, characterizing processes by integrated (average or macroscopic) parameters. However there is no analytical decision for the boiling streams. Therefore the carried-out studying of processes by optical methods about wick space and in capillary-porous structure, and also in the field of steam bubbles is necessary for closure of the average equations of the movement of disperse environments. Therefore we defined values of thermal streams, coefficients of a heat-exchange and permeability of porous structures, emission of liquid from structure [3, 6, 10, 14].

A number of the effects proceeding with small concentration of a disperse phase can be quantitatively described by formulas for two-phase streams. Processes of a steam generation, dust trapping, destruction of materials the twirled streams of gas-suspensions refers to such effects [5].

In environments with phase transitions it is possible to count porous elliptic systems when passing strong waves with pressure (1-100) hPa in the metals, minerals, polymers concentrated in the second focus of an elliptic toroid (in a target). Thus new substances, their modifications and phases are formed, metals are strengthened, and synthesis processes are realized. In one device at the same time it is possible to receive pressure sharply different from each other: in gas mixture – to 10 MPa, and in liquid or solid substance – 10^5 MPa and more than [1].

The multiphase character of streams, especially in the presence of capillary - porous coatings, fully reflected in the fields of mass and vibration forces and manifested most fully in the propagation of waves of tension and compression that can be managed in the developed porous elliptic systems. The analytical solution of distribution of waves in two-phase vapor-liquid mixtures where features of the movement of waves in gas mixes with drops or particles are considered, this is important for elliptic porous multiphase gas and dust traps and heat exchangers offered by us [1,5].

The main areas of practical application capillary –porous systems are protected by us patents and copyright certificates for the invention [3, 5, 8, 9, 11, 13].

Introduction of the equipment and technological processes in engineering has to be made, first of all, from ecological-and-economic positions. The offered development of capillary and porous systems will promote carrying out processes, significantly improving and keeping environment.

Capillary – porous systems allow to reach economy of fuel, raw materials, air, water, is warm, to increase reliability of cooling and explosion fire safety of work of the equipment, and to promote highly effective destruction of rocks, concrete, metals, to reduce low-temperature corrosion of surfaces, to reduce pollution of the biosphere poisonous gases, dust, heat, to accelerate the solution of problems of a food program, to gain big economic and social effects in the field of ecology and labor protection [13].

The main advantages of capillary – porous systems are high intensity, big heat-transmitting ability, reliability, compactness, simplicity in production and operation; they improve regime and technological indicators and have low capital and operational costs. For introduction of development the influence of various factors on process of a heat-mass exchange in various capillary – porous systems of thermal energy installations was investigated (Table).

3. Analysis. To improve the reliability, efficiency and maneuverability of power plants taking into account the ecology the following processes are effective [3, 5, 8-13]:

1. Separation of moisture in the stage of capillary-porous structure;
2. Conducting of the fluid dynamics, mass exchange of two-phase streams in turbine stage in the presence of porous inserts (natural and artificial);
3. Movement organization of liquid films moisture particles in porous channels of a stage;
4. An intensification of processes in porous separators of a flowing part of the turbine;
5. Conducting a porous cooling of blades and gas turbine combustion chambers;
6. Suppression of nitrogen oxides formation in the combustion chambers of gas turbine by heat pipes;
7. Detonation combustion in porous formations in gas turbine chambers;
8. Heat recovery in the gas turbine by heat pipes;
9. Heliographing of deformations and heat expansions in rotor and stator nodes of turbine for the purpose of diagnostics;
10. Porous cooling of turbine rotor elements during its starting and stopping;
11. Porous cooling of turbine stator elements during its starting and stopping;
12. Increase in maneuverability of the turbine using the porous systems;

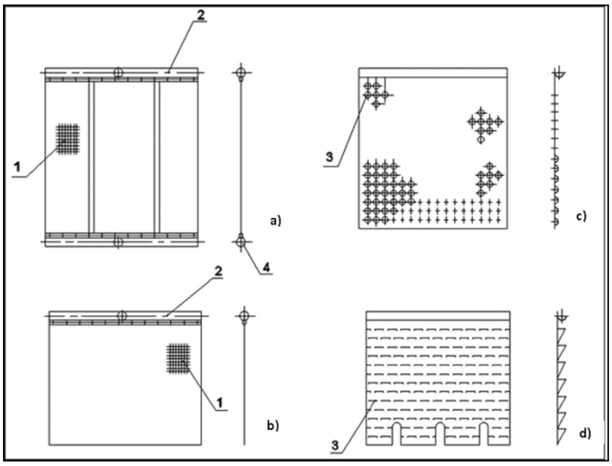
Research of dependence for various factors on a heat mass exchange
in various capillary – porous systems of the thermal energy installations.

<table>
<tr><td colspan="12">Type of heat-absorbing medium</td></tr>
<tr><td colspan="3">Suspended matter</td><td colspan="3">Pure fluid</td><td colspan="4">Vapor-phase dispersoid (air-to-water mixture)</td><td colspan="2">Solution (froth)</td></tr>
<tr><td colspan="12">Circulation of heat-absorbing medium</td></tr>
<tr><td colspan="6">Closed</td><td colspan="6">Opened</td></tr>
<tr><td colspan="3">natural</td><td colspan="3">forced</td><td colspan="6">forced</td></tr>
<tr><td colspan="12">Construction of systems</td></tr>
<tr><td colspan="12">Shel-and-tube (force-feed, depression)</td></tr>
<tr><td colspan="4">Elliptic systems</td><td colspan="4">Circular pipes</td><td colspan="4">Flat pipe</td></tr>
<tr><td colspan="4">Boiling, barbotage, transpiration, freezing, explosion</td><td colspan="2">boiling inside pipe</td><td colspan="2">boiling on pipe</td><td colspan="2">contoured (profiled)</td><td colspan="1">straight</td><td colspan="1">finned</td></tr>
<tr><td colspan="12">Housing material</td></tr>
<tr><td colspan="2">brass</td><td colspan="2">copper</td><td colspan="3">stainless steel</td><td colspan="2">glass, alundum</td><td colspan="3">nickel</td></tr>
<tr><td colspan="12">Type of systems</td></tr>
<tr><td colspan="2">Irrigation</td><td colspan="2">Saturated</td><td colspan="2">Air-lift</td><td colspan="2">Flooded</td><td colspan="4">Fluid excess (forced flow with underheating)</td></tr>
<tr><td colspan="12">Power supply line</td></tr>
<tr><td colspan="6">By perimeter</td><td colspan="6">One-direction</td></tr>
<tr><td colspan="12">Type of energy</td></tr>
<tr><td colspan="2">Electrical</td><td colspan="1">Steam</td><td colspan="2">Radiant</td><td colspan="2">Explosion</td><td colspan="2">Ultrasonic</td><td colspan="3">Gaseous</td></tr>
<tr><td colspan="12">System orientation</td></tr>
<tr><td colspan="3">Vertical</td><td colspan="4">Inclined plane</td><td colspan="5">Horizontal</td></tr>
</table>

13. Protection of turbine shafting from earthquakes by porous separators;
14. Cutting of turbine basements by burners in the production of construction and installation works;
15. Protection against cavitations the turbine blades using porous structures;
16. Prevention of thermal shock in steam lines and valves by porous systems;
17. Holographic diagnostics of turbine shaft line;
18. The holographic diagnostics of two-phase flows in the turbine stage;
19. Diagnosing by fotoelasticity method the shaft line, disks, labyrinth seals;
20. Application of the wave theory of two-phase flow in the nozzle and rotor blades on the basis of separation, concentration and energy drain moisture and light phase;
21. The development of the wave theory of heat exchange in the rotor and stator elements with explosive birth of steam bubbles;
22. Accelerating the start and stop of the turbine due to the use of porous systems;
23. Reducing the noise and vibration with the porous systems;
24. Control of low cycle fatigue in areas of stress concentrators in the rotor and stator elements using porous turbine systems;
25. Increased vibration resistance for labyrinth seals using porous systems;
26. Implementation of the isothermal cycle expansion steam of turbine using porous systems;
27. Increasing the strength of the turbine parts in non-stationary thermal modes (variables and transients) due to the cooling of their porous structures;
28. Improving the reliability of the regulatory and the last turbine stage through the use of a porous structure;
29. Management of limit deformation of the rotor relative to the stator during transients due to the porous system;
30. Managing the heat bending of the rotor by means of porous system;
31. Management of the deformation of the turbine housing as a result of asymmetric warming of the porous system;
32. Reduction of start-up losses of fuel due to management of a thermal condition of the turbine by porous system.

The design of the porous system for the box-shaped heat exchanger is considered on figure 1. Heat exchanger consists of the case and a removable cover, hermetically bolted on perimeter. The internal surface of a wall is covered with the capillary-porous structure 1 pressed by perforated plates 3. Arteries 2 are connected to top ends of structure through the end face of which to the cooled surface liquid is supplied by mass and capillary forces. The lower ends of structure are usually free and immersed in trays 4 where liquid accumulates due to leaks, excess or droplets entrainment. On a plate surface the recesses with openings were stamped providing a steam output from structure in the channel and also serve as catchers of the drops thrown out from structure and the flowing-down the excess liquid on an external plate surface. The artery is connected to a branch pipe, with the distributing pipes and a collector. The excess of cooling liquid accumulates in the bottom and is removed by siphon to the lower collector and further to the store for return to the system.

The structure can be extended in the vertical (*a*) or horizontal direction, the upper or lower ends of which (or both) are connected to an artery. The perforated plates make in a form and the sizes according to structure. The stamped and perforated recesses in them can have the form of the truncated cone, or longitudinal slots with openings facing upwards.



Location of capillary-porous structures (a,b) and design realization of perforated plates (c, d):
1 – capillary-porous structures; 2 – feeding artery; 3 – perforated plates; 4 – water tray

In capillary-porous system cooling the presence of mass forces provides the supply of coolant to the heating surface at high heat loads (~1×10^6 W/m^2) and creates a stable two-phase boundary layer near the wall. The porous structure contains very small amount of liquid that saves water consumption up to 80 times and has environmental importance and provides explosion safety.

The critical thermal stream of q_{cr} for the optimized mesh structures using water is received on the basis of hydrodynamic crisis, and the constant is defined by holographic researches for P ≥ 0,1 MPa and in the SI has an appearance:

$$q_{cr} = 3{,}47\times10^{-2} r\left[g(\rho'-\rho'')\rho'' D_0\right]^{0,5}\left(\frac{b}{b_0}\right)^{0,3}\left(\frac{\delta}{\delta_0}\right)^{0,5}(1+\cos\beta)^{0,6},$$

where r – the heat of vaporization; g – standard gravity; ρ', ρ'' – the density of the liquid and vapor; b, δ – cell width and thickness of the structure; D_o – the distance along the surface of the heat exchange between the steam conglomerates; β – the angle of inclination to the vertical system; b_o = $0{,}28\times10^{-3}$ m; δ_o =$0{,}18\times10^{-3}$ m; $0{,}28\times10^{-3}$ m ≤ b ≤ $0{,}55\times10^{-3}$ m. In the case where $0{,}08\times10^{-3}$ m ≤ b ≤ $0{,}28\times10^{-3}$ m, the constant increases to 4, 54×10^{-2}, and indices of degrees of simplexes b and δ have a minus sign.

4. Conclusion. Capillary-porous cooling system replaces the water system, stripped of its essential shortcomings (explosiveness, expenditure of water, the occurrence of cyclic stresses in the wall), and has merits: self-adaptability, the ability to stabilize the temperature of the heat-stressed surfaces, compactness, simplicity, reliability, ecological clean environment in further saving of natural resources (water).

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ЖЫЛУ ЭНЕРГЕТИКАЛЫҚ ҚОНДЫРҒАЛАРДЫҢ КАПИЛЛЯРЛЫҚ-КЕУЕКТІК ЖАҢА КЛАСТЫ САЛҚЫНДАТУ ЖҮЙЕЛЕРІНДЕГІ ЖЫЛУМАССААЛМАСУДЫ ЗЕРТТЕУ

Аннотация. Әртүрлі жылулық энергетикалық қондырғыларда қолданылатын салқындату жүйесінің жылу өткізгіш капиллярлық-кеуектік түрдегі жаңа класы құрастырылып, зерттелген. Мұндай жүйе энергетикалық процестерді бөлу арқылы жылу берілуін басқарады, сонымен қатар, сұйықтың артық мөлшері есебінен, қайнау процесінің ішкі (термогидравликалық) сипаттамаларын өзгерте орырып, ағынның қызып кетпеуіне және ағу жылдамдығын арттыруға мүмкіндік жасайды. Жылу алмасу процесіне (түріне және жылу- мен салқын-тасымалдағыштың айналымына; жүйенің конструкциясына; корпусының материалына; жүйенің түріне; энергияның келуіне және түріне; жүйенің бағыт бағдарына) әсер ететін әртүрлі факторларды зерттеу алгоритмі келтіріледі. Экология жағдайларын ескере отырып, жүйенің сенімділігі мен тиімділігін, маневршілдігін арттыру мақсатында әртүрлі энергетикалық қондырғыларда қолданылатын кеуектік жүйені жасау тізімі берілген және капиллярлық-кеуектік құрылымның орналасу сұлбасы жетілдіріліп, қысқыш перфорациялық қабатты орындау сұлбасы жасалған. Гидродинамикалық кризиса негізінде сұйықтың жылу физикалық қасиеттеріне, булық конгломераттар арасының қалыңдығына, кеуектік құрылымның түріне және оның бағыт бағдарына тәуелді болатын кризистік жылулық ағын алынды.

Тірек сөздер: капиллярлық-кеуектік жүйе; жылуалмасу процестері; кризистік жылулық ағын; жылулық энергетикалық қондырғылар.

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ИССЛЕДОВАНИЕ ТЕПЛОМАССООБМЕНА В КАПИЛЛЯРНО-ПОРИСТЫХ СИСТЕМАХ ОХЛАЖДЕНИЯ НОВОГО КЛАССА ТЕПЛОВЫХ ЭНЕРГОУСТАНОВОК

Аннотация. Разработана и исследована теплоотводящая капиллярно-пористая система охлаждения нового класса применительно к различным тепловым энергоустановкам. Она позволяет управлять теплопередачей путем разделения энергетических процессов и, также, за счет избытка жидкости создавать недогрев и скорость потока, изменяя внутренние (термогидравлические) характеристики процесса кипения. Приводится алгоритм по исследованию влияния различных факторов на процесс тепломассообмена (вид и циркуляция теплохолодоносителя; конструкции системы; материал корпуса; тип системы; подвод и вид энергии; ориентация системы). Дан перечень разработок пористой системы к различным энергоустановкам с целью повышения их надежности, экономичности и маневренности с учетом экологии и разработана схема расположения капиллярно-пористой структуры и выполнения прижимных перфорированных пластин. Получен на основе гидродинамического кризиса критический тепловой поток в зависимости от теплофизических свойств жидкости, расстояния между паровыми конгломератами, вида пористой структуры и ее ориентации.

Ключевые слова: капиллярно-пористая система; процессы тепломассообмена; критический тепловой поток; тепловые энергоустановки.

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