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POROUS DEVICES OF THERMAL POWER INSTALLATIONS, METHODS OF THEIR DESIGN AND MECHANISM OF PROCESSES PROCEEDING IN THEM

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Abstract. There were conducted experimental studies of heatchange in a porous material covering a heating surface from regime (thermal loading, cooler expenses) and constructive factors. Use of optical methods of research (high-speed filming and holography) revealed a physical picture of steam formation and allowed to outline the principles of porous structures design for decrease in probability of destructive cracks emergence. There was described a mechanism of steam formation process in an offered porous cooling system with use of internal characteristics observed by holography and high-speed filming. Researches have practical value in the areas of initial, developed boiling processes and for a limit condition of material.

ПОРИСТЫЕ УСТРОЙСТВА ТЕПЛОВЫХ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК, МЕТОДЫ ИХ ПРОЕКТИРОВАНИЯ И МЕХАНИЗМ ПРОТЕКАЮЩИХ В НИХ ПРОЦЕССОВ

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Ключевые слова: теплообмен, пористая структура, тепловые электрические станций

Аннотация. Проведены экспериментальные исследования теплообмена в пористом материале, покрывающем поверхность нагрева от режимных (тепловая нагрузка, расходы охладителя) и конструктивных факторов.

Использование оптических методов исследования (скоростной киносъемки и голографии) выявили физическую картину парообразования и позволили наметить принципы конструирования пористых структур для снижения вероятности возникновения разрушительных трещин.

Описан механизм процесса парообразования в предложенной пористой системе охлаждения с использованием внутренних характеристик, наблюдаемых голографией и скоростной киносъемкой.

Исследования имеют практическое значение в областях начального, развитого процессов кипения и для предельного состояния материала.

There are offered new porous devices executed as capillary – porous systems which differ in that they have mainly gravitational supply of liquid and according to heat transfer intensity they have intermediate position between thin-film evaporators and porous evaporators with mainly capillary supply of liquid (thermal pipes). Therefore, such systems should be allocated in a separate class of heat-removing systems [1-7].

There are thoroughly given diverse issues which were solved in the research work for various devices of thermal power installations (a heatcoolant choice, a calculation of its circulation type, a geometry choice and devices material and heat exchange intensifiers, an operating condition of system under pressure (depression), a supply and a type of energy, system orientation) [1,3,5,6].

Use of porous materials in heat-intense elements of aircraft constructions [8,9], heat exchangers [1-6], melting aggregates [2] for cooling torches of rocket type [3] demands to ensure reliable functioning of heating surface and not to allow dangerous temperature of a wall causing destroying cyclic temperature tension.

On the basis of the conducted research of capillary and porous systems we developed new technical solutions for improvement of thermal power installations operational characteristics in relation to a vigorous power unit of thermal power-station.

There are proposed following technical solutions to increase reliability, efficiency, flexibility of boiler installations and improvement of environmental protection [1-4,7,11,12]:

1. Placement in furnace cameras of thermal pipes to decrease nitrogen oxides formation;
2. Drums of coppers and steam cooler with porous formations for reduction of cyclic tension in walls;
3. The "tail" surfaces of coppers heating executed in the form of porous elements for fight against low-temperature corrosion;
4. In fuel and transport shops to apply operated porous systems of dust suppression and fire extinguishing;
5. In car dumpers and bunkers to install porous concentrators for fight against fuel lag; similar concentrators allow to frighten off whitebaits of fishes of valuable breeds;
6. To make dust-gas purification of combustion gases with porous operated system that does not demand regeneration;
7. To cool fuel torches with porous elements;
8. To supply screen pipes with porous structures for expansion of heat-transmitting opportunities;
9. To make cutting of boiler slags with thermoreactive torches;
10. To carry out detonation burning of fuel in a porous environment;
11. To utilize warmth of drifting gases with thermal pipes;
12. To carry out heat exchange and hydrodynamics of two-phase streams in porous structures in elements, joints and paths of a boiler aggregate;
13. To carry out processes of hydrodynamics in porous bubble systems;
14. To separate steam in porous structures;
15. To carry out noise suppression in gas flues and on waste steam lines with porous systems;
16. To carry out acceleration of start-up and a stop of steam boilers due to decrease in low-cyclic fatigue and creep by porous systems;
17. To intensify heat exchange with thermal pipes in fire chambers with boiling layer;
18. To organize low-temperature to – and the supersonic multiphase rotating pulsing streams in fire chambers with porous elements;
19. To cool fastenings, support, suspension brackets, gates and other joints in the boiler aggregate with capillary and porous structures.

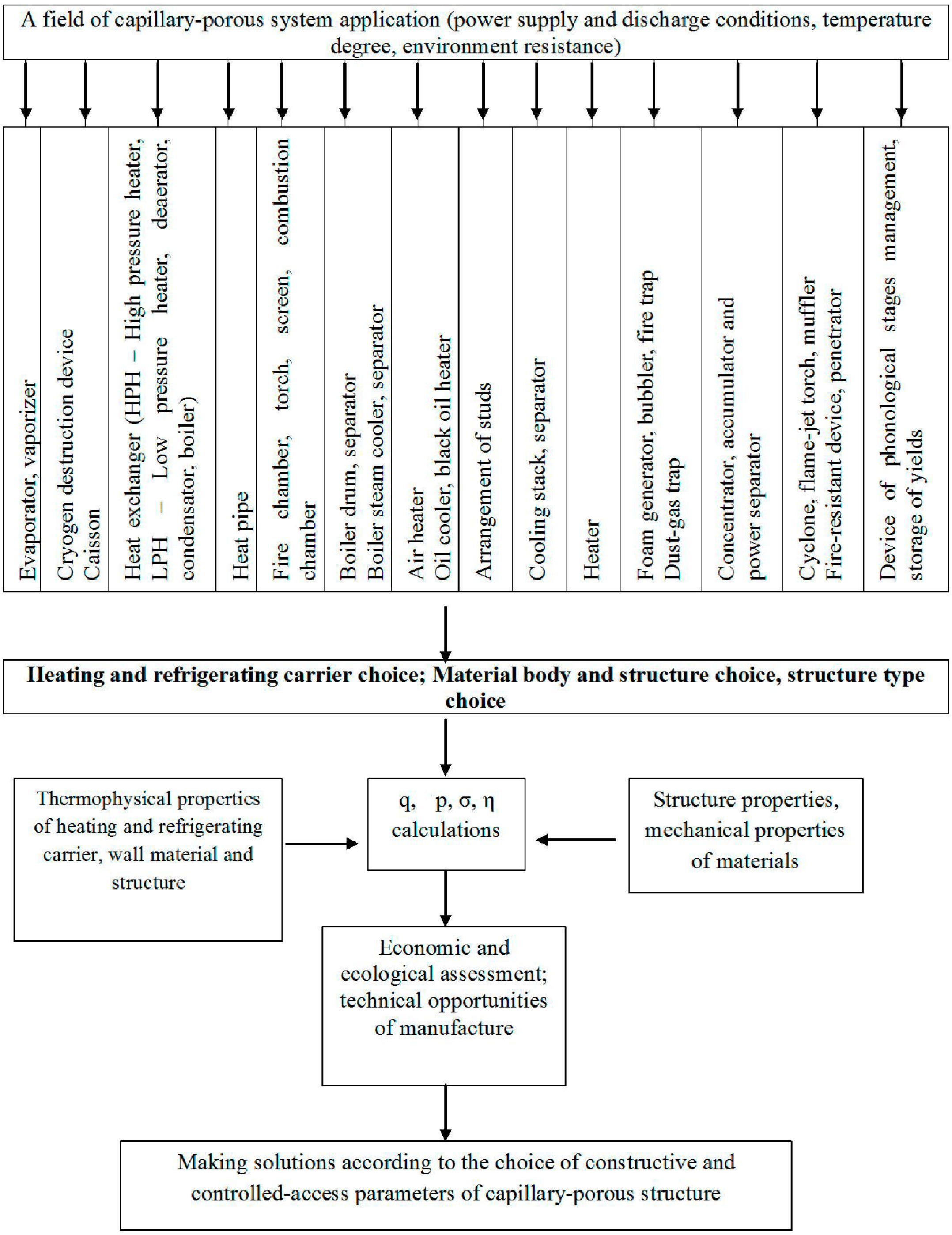
Actions are effective to increase reliability, efficiency and flexibility of turbine installations taking into account ecology [1-4, 7, 11, 12]:

1. Separation of moisture in a stage with capillary and porous structure;
2. Carrying out a hydraulic gas dynamics, mass exchange of two-phase streams in a stage in the presence of porous inserts (natural and artificial);
3. An organization of the movement of moisture particles and liquid films in porous channels of a stage;
4. An intensification of processes in porous separators of flowing part of a turbine;
5. Carrying out porous cooling of shovels and GTU (gas-turbine unit) combustion chambers;
6. Suppression of nitrogen oxides formation in GTU combustion chambers with thermal pipes;
7. Detonation burning in porous formations in the GTU chambers;
8. Warmth utilization in GTU with thermal pipes;
9. Holographings of deformations and thermal expansions in stator joints and a turbine rotor for the purpose of diagnostics;
10. Porous cooling of turbine rotor elements at its start-up and stop;
11. Porous cooling of turbine stator at its start-up and stop;
12. Increases of turbine flexibility at the expense of porous systems use;
13. Protection of turbine shafting against earthquakes with porous power dividers;

14. Turbine-installation bases cutting with thermoreactive torches while manufacturing installation and construction works;
15. Protection against cavitation of turbine shovels by means of porous structures;
16. Fight against heatstrokes in steam pipelines and valves with porous systems;
17. Holographic diagnosing of turbine shafting;
18. Holographic diagnosing of two-phase streams in a turbine stage;
19. Installations of porous screens of diaphragms of the first steps of HPC (high-pressure cylinder) and IPC (intermediate-pressure cylinder);
20. Photoelastic diagnosing of shafting, disks, labyrinth consolidations;
21. Applications of wave theory of two-phase streams in nozzle and working shovels on the basis of division, concentration and a drain of moisture energy and an easy phase;
22. Development of the wave theory of heat exchange in rotor and stator elements at the explosive birth of steam bubbles;
23. Fixture of flange junctions studs of turbines with thermal pipes;
24. Management of an oil film in turbines bearings with capillary and porous structures;
25. Acceleration of start-up and stop of turbines at the expense of porous systems use;
26. Fight against noise by vibration with porous structures;
27. Management of low-cyclic fatigue in zones of tension concentrators of rotor and stator elements by means of porous systems;
28. Increase of vibrostability of labyrinth consolidations by means of porous systems;
29. Fight against constraint of thermal expansions of turbine on the base by means of porous systems;
30. Realization of an isothermal cycle of steam expansion in turbine by means of porous systems;
31. Increase of operation reliability of the scapular device at vibration modes while installing porous fixings;
32. Management of the multispan shafting behavior, rotating on an oil film by use of porous systems;
33. Increase of turbine details durability at non-stationary thermal modes (variables and transitional modes) at the expense of their cooling with porous structures;
34. Management of axial effort by use of porous system;
35. Increase of work reliability of regulating and last stage at the expense of applying porous structure;
36. Management of a temperature field of an exhaust branch pipe of the turbine at its unloading by means of porous structure;
37. Management of a rotor limit deformation concerning the stator at transitional operating modes at the expense of porous system;
38. Management of a rotor thermal bend by means of porous system;
39. Management of turbine body deformation as a result of asymmetrical warming up of porous system;
40. Decrease in starting losses of fuel at the expense of a turbine thermal condition management of porous system;
41. Management of an oil film of bearings for fight against low-frequency vibration (shaft self-sustaining precession) by means of porous system;
42. Fight against rotor fragile sudden destruction by management of turbine start-up by means of porous system.

In figure 1 there is presented a design technique of porous systems in relation to the developed device of thermal power installations. The conducted researches [1-7] allow to introduce cooling liquid, body material and structure, a type of porous covering, to carry out calculations of heatlimits, resistance, thermal tension and to give an economic and ecological assessment.

Experimental studies on boiling of liquid were conducted on tubes and flat heaters. The water supply was carried out from a tank of constant level. Needle gates provided rather exact adjustment of an expense. There was provided liquid discharge. The wall heating was made by electric heaters, or haloid quartz lamps.



qi - *specific thermal streams in TEU elements;* Δp *-hydraulic resistance; σ-thermal tension; η - coefficient of efficiency TEU.*

Figure 1 - Scheme of capillary and porous structure design

As porous structure there were applied smooth brass and corrosion-resistant grids with a width of cells in light (0,08 … 1) $\cdot 10^{-3}$ m. Experiments were made with one, two and three layers of grids at their various set.

The greatest opportunity an error while measuring electric power - ± 1,6%. The liquid temperature (cooling, discharge, circulating) was measured by mercury thermometers with an accuracy of $0,1^0$C. Temperature of steam and wall and **CC** with thermosteams with wires diameter of $0,2\cdot 10^{-3}$ m.

Expenses of cooling liquid and circulating water were defined by electric **RED** rotameters. The greatest possible mistake did not exceed ± 3%.

Discrepancy on heat which is supplied by current and heat which is taken away by circulating and excess water taking into account losses through isolation did not exceed ± 12%, and discrepancy of material balance - ± 10%.

At the set thermal stream the wall temperature had the smallest value for single-layer structure. For an area of the developed vesiculate boiling of essential influence of $m_ж$ cooling liquid consumption in limits, equal (1 … 14) m_n, for all studied structures is not revealed.

Cooling of a heating surface is studied from minimum possible liquid consumption at which discharge was equal to zero, to a liquid consumption exceeding consumption of m_n generated steam by 14 times. Necessary change of a liquid consumption is determined by violation of uniformity in temperature distribution on the surface of the cooled wall. Thus, there is provided reliable heat removal at the expense of preservation of the steady pulsing liquid film that favourably distinguishes the considered cooling system from thin-film evaporators [10] where there is a rupture of the flowing-down liquid film and there is a need for significant increase in a liquid consumption (in 100 … 10000 times).

However, even at such big density of an irrigation there is observed a loss of film stability, its disintegration into separate streams which are followed by stripping of the heated surface.

For cooling of the surface covered with porous structure in the field of moderate thermal loadings, it is enough to give liquid at a rate of $G_ж$=q/r as it takes place in thermal pipes [8,9]. For forcing and management of heat exchange process at the expense of gravitational forces use it is expedient to increase a liquid consumption a little. The further increase in an expense, though it reduces the average temperature of a wall, leads to significant increase in a share of heat removed by excess liquid. There is a redistribution of thermal streams which are taken away at the expense of discharging liquid and boiling that demands additional costs on liquid pumping and excludes the possibility of utilization of taken-away heat part.

Therefore, existence of liquid excess allows to use, unlike thermal pipes, porous structures of insignificant thickness and with large sizes of cells. Thus, there are taken away big thermal loadings in (3 … 4) times, and in the presence of intensifiers – (6 … 8) times.

For cooling of the surfaces having big height (to 0,7 m), there are required raised cooler expenses that tightens alignment of wall temperature at low and moderate thermal loadings. Therefore, in the generalizing dependences the α heat exchange coefficient is expressed with h wall height as $\alpha \sim$ to $h^{0,26}$.

For an area, close and critical, significant increase in liquid consumption has no impact on heat exchange processes.

$G_{опт}$ cooler's high expense for structures with a cell width $в_2 > 0,28\cdot 10^{-3}$ m is connected with reduction of capillary forces action influencing on uniformity of liquid distribution (especially at small e expenses).

Thus, at developed vesiculate boiling a specific density of thermal stream has the main impact on heat exchange. Influence of irrigation density is much less, than in case of transitional superficial boiling proceeding in initial area though at big values of Reynold's numbers heat conductivity of a film intensifies, so as arising whirlwinds lead to viscosity increase, stabilization of film thickness, that gives it additional resistance to boiling crisis.

As optical methods of research showed, executed by high-speed filming and a holographic interferometry [1,2,5], at small thermal loadings with growth of $m=m_ж/m_п$ parameter a detachable (destroyed) diameter of steam bubbles decreases, time of their "life" increases and generation centers density is reduced. At high sizes q increases excess of liquid, facilitates delivery of cooler fresh portions to the vicinity of generation center, improves a hydrodynamic picture in two-phase boiling superheated interface, however in the warmth transfer mechanism a defining role belongs to steam formation process that is a feature of boiling process in mesh porous structures for the studied interval of m parameter change in comparison with process of vesiculate boiling in the conditions of the directed movement of liquid on surfaces without porous coverings.

At big excess of m liquid and small thermal loadings of q, intensity of heat exchange starts decreasing, as far as liquid film thickness increases, density of active centers of steam formation decreases, and existing centers of steam generation work "inertly" and cannot conduct an additional contribution into turbulization of an interface at total selection of steam formation heat and an excess enthalpy of superheated liquid.

Reduction of liquid excess displaces an area of system work towards big thermal streams when the mode determined by steam formation process is set. New centers of steam generation start being initiated again. Thus, increased thermal streams compensate effects which lead to decrease in n size and growth of a turbulent component of a single-phase stream.

Thus, m relation in the studied porous system establishes border when heat exchange in a homogeneous environment brings a considerable smaller value in the general mechanism of a heat transfer, than the process defined by warmth of liquid steam formation in steam bubbles.

Creation of liquid big excess leads not only to increase in stream speed, but also to the growth of liquid underheat. In two-phase liquid boundary layer it is at least heated up to the saturation temperature, and on its external surface, where in this case there can be a partial movement of a stream, liquid is underheated up to the saturation temperature. There are created conditions of superficial boiling (boiling with underheating). Boiling of overcooled liquid is realized in close proximity to a wall superheated zone. The top part of bubbles which can adjoin to undreheated liquid, starts being condensed partially. On records there is observed an increase in time of "life" of steam bubbles for those cases when there is set a balance of heat inflow from a wall and superheated liquid and its flow by means of condensation warmth in a kernel of the flowing-down underheated stream. Growth of a steam bubble within a cell that, in general, increases time of its "life".

A feature of the studied system is that heatmass exchange processes proceed in thin layers of liquid, the expense and speed of a stream have small sizes and liquid in structure begins to boil practically at once at an entrance to a heatexchange surface. However, at big excess of liquid on a surface of structure there was a stream flow of underheated liquid, expense of which could exceed a liquid consumption in a wall superheated layer. It allows colder liquid to get from a stream kernel into a wall heated layer, to force it out, reducing thickness of a superheated layer and consequently, steam formation speed, and at the expense of the increased gradient of temperature to influence on condensation speed of that part of a steam bubble which was a superheated zone, however, remaining within thickness of porous structure.

Unlike liquid boiling on surfaces without porous coverings, in the studied system bubbles do not slide on a heating surface, but fluctuate within a cell of mesh porous structure. Sizes of speed and liquid underheating have smaller values, therefore a detachable diameter of a bubble poorly depends on the liquid excess. It is necessary to expect higher content of steam in porous structure volume, than when boiling underheated liquid in smooth pipes (without porous coverings).

The analysis of skilled and calculated dependences shows [3-6] that the growth of liquid excess (speed and underheating) until establishment of the developed vesiculate boiling leads to turbulization of two-phase and a boundary (wall) layer, i.e. to their specification, but at the developed boiling the intensity of a heatmass transfer is automodel concerning parameter m. The ratio of thickness of two-phase boiling layer and a wall (superheated) layer in porous structures is characterized by mark-to-space ratio.

With growth of thermal loading and increase in the optimum liquid excess corresponding to it, a thickness of a wall (superheated) layer is specified, as well as a microlayer under steam bubbles, and a thickness of a two-phase layer increases to some value q., corresponding about crisis area when volume steam content reaches critical value. With a further growth of q size, a superfluous expense of a cooler does not allow to operate heat exchange process that leads to approach of a heat transfer crisis.

Thus, there are developed and introduced porous devices for thermal power installations, methods of their design and there is described a mechanism of the proceeding processes on the basis of optical supervision by high-speed filming and a holographic interferometry.

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ЖЫЛУ ЭНЕРГЕТИКАЛЫҚ ҚОНДЫРҒЫЛАРДЫҢ КЕУЕКТІ ҚҰРЫЛҒЫЛАРЫ, ОЛАРДЫ ЖОБАЛАУ ӘДІСТЕРІ ЖӘНЕ ОЛАРДА ӨТЕТІН ҚҰБЫЛЫСТАРДЫҢ МЕХАНИЗМІ

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Түйін сөздер: жылуалмасу, кеуектік құрылым, жылу электр станция.

Аннотация. Тәртіпті (жылулық жүктеме, салқындатқыш шығыны) және конструктивті факторлардан қыздыру бетін жабатын, кеуекті материалдарда жылуалмасуға экспериментталды зерттеулер жүргізілді.

Оптикалық әдіспен зерттеуді пайдалану (жылдам түсіру және голография) буландырудың физикалық бейнесін айқындады және бұзатын жарықтың мумкіндігін азайту үшін кеуекті құрылымдардың құрылысының қағидалары ескертілді.

Голографиямен және жылдам кино түсіріліммен бақыланатын ішкі сипаттамаларын қолдану арқылы ұсынылған салқындатудың кеуекті жүйесін буландыру процессінің механизмі сипатталған.

Зерттеулердің қайнау процесінің бастапқы және дамытылған аймақтарында және материалдың шекті күйі үшін практикалық маңыздылығы бар.

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