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BASE PROGRAM COMPLEX OF THE METHOD OF ANALYSIS OF THERMAL CHARACTERISTICS OF HEAT-EXCHANGE SURFACES OF COMPLEX SHAPES

A method of the analysis of thermal hydraulic parameters of multilayered surfaces of heat exchange is based on the procedure of the use of a real configuration of these surfaces when calculating the introduced constructions. Thus, one of the key moments is realization of a described method in the form of the base program complex including some of modeling blocks, the general user interface and the general information-analytical database.

The described modeling blocks contain some N-dimensional and various thematic orientation computing templates including the modeling block of the analysis of tubular surfaces of heat exchange; the modeling block of the analysis of lamellar heat exchangers; the modeling block of the analysis of processes of the carry of fulfilled nuclear fuel in the storage systems of the atomic power station. The uniform information-analytical database contains the data about thermo physical properties of working bodies and constructional materials; classification and design features of heat-exchange devices; the methods of analysis and optimization of thermal parameters of heat-exchange devices.

The results of application of the program complex indicate its efficiency while analyzing the processes of the carry in areas with the irregular shape. The program complex is supposed to be upgraded.

Key words: heat-exchange devices, transfer processes, modeling, computing template.

Introduction. The market of power equipment of Belarus has a wide range of heat exchangers, which differ by the purpose and configuration of heat-exchange surfaces and methods of their arrangement.

One of the conditions for the advancement of a number of heat exchangers of these types is the certification of thermal and hydrodynamic parameters of the equipment.

Currently, due to the construction of the Belarusian nuclear power plant there is a particular interest to devices and methods of maintaining safe thermal conditions of near-station storage of fulfilled nuclear fuel and optimization of thermal characteristics.

Indicated diversity of forms of the heat exchange surfaces requires the individual field and wall tests (both production and certification), which certainly increase their market value and constrain updated line-up.

One of the ways to reduce production costs and simplify the procedure of advance to the market of this type of heat exchange devices may be the development of methods of computational analysis of their thermal and hydrodynamic characteristics with the use of samples of heat exchange surfaces. Such methods will significantly reduce the entire production cycle from design to implementation.

Main part. In the basis of the proposed analysis method of thermal hydraulic characteristics of multilayered surfaces of heat exchange is put the procedure of the use of real configuration of these surfaces as the basic in the calculation of the designs proposed for the introduction [1].

Under this method, the step by step algorithm is proposed to achieve the optimal parameters of developing heat exchangers.

There are the following interrelated steps in the algorithm:

– implementation and generalization on the base of integral dependencies of results of experimental investigations or tests of samples of a new heat exchange equipment;

– creation of electron analogues of investigated structural elements and profilograms of contact heat exchange surfaces, followed by their use when building geometry of computational areas [2];

– development of multi-dimensional numeral analogues based on the adaptation of computing templates of modern software packets to considered constructions of heat exchange equipment, and its mode of operation;

– analysis of thermal characteristics of the modeling range of heat exchangers and, in the final phase the introduction of a new heat exchange equipment, planning of certification tests of this equipment or confirmation of the declared characteristics with the use of its multi-dimensional computational analogues.

Thus one of the key points is the practical realization of a described method as a basic software complex, which includes several modeling blocks, the total user interface and overall informational and analytical data base.

Currently, the basic program complex is represented by the following blocks and templates (Fig. 1) [3–5]:

Fig. 1. The main window of the program complex

– modeling analysis block of pipe heat exchange surfaces (it includes templates for bimetallic contact surfaces of heat exchange and heat exchangers “pipe in pipe”);

– modeling analysis block of plate heat exchangers (templates for the integrated model and multivariate model based on the equations of conservation);

– modeling analysis block of transfer processes in systems of near-station storage of spent nuclear fuel (SNF) (templates for the “dry storage” of SNF and for the “storage pool” of SNF).

Unified informational and analytical database contains the following issues (Fig. 2):

1) thermal properties of working bodies and construction materials;

2) classification and constructive properties of considered heat exchangers;

3) methods of analysis and optimization of thermal parameters of the heat exchange devices;

4) inquiry information on characteristics of software complex, system requirements for its use, restrictions of the license; user guide. The software package is opened to modernization and can be supplied with new modeling blocks and computational templates [6].

The basic model of software. As a basic model of transfer processes was selected the following system of equations of storage:

$$\rho\frac{\partial U}{\partial t}-\nabla\left[\left(\eta+\rho\frac{C_{\mu}}{\sigma_k}\frac{k^2}{\varepsilon}\right)\cdot\left(\nabla U+(\nabla U)^T\right)\right]+$$

$$+\rho U\cdot\nabla U+\nabla P=0;$$

$$\nabla U=0;$$

$$\frac{\partial T}{\partial T}+U_j\frac{\partial T}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\lambda\frac{\partial T}{\partial x_j}\right)+J_T,$$

where ρ – density of the fluid; U – component of flow rate; x – spatial coordinate; η – laminar component of turbo valence coefficient of viscosity; P – hydrostatic pressure; λ – coefficient of thermal conductivity; JT – volumetric thermal power; j – index of the projections on the axis of coordinates.

The calculation of a turbulent component of a kinematic viscosity coefficient is performed according to the k–ε turbulence model in the COMSOL Multiphysics interpretation:

$$\rho\frac{\partial k}{\partial t}-\nabla\left[\left(\eta+\rho\frac{C_{\mu}}{\sigma_k}\frac{k^2}{\varepsilon}\right)\cdot\nabla k\right]+\rho U\cdot\nabla k=$$

$$=\rho C_{\mu}\frac{k^2}{\varepsilon}\left(\nabla U+(\nabla U)^T\right)^2-\rho\varepsilon;$$

$$\rho\frac{\partial \varepsilon}{\partial t}-\nabla\left[\left(\eta+\rho\frac{C_{\mu}}{\sigma_k}\frac{k^2}{\varepsilon}\right)\cdot\nabla \varepsilon\right]+\rho U\cdot\nabla \varepsilon=$$

$$=\rho C_{\varepsilon 1}C_{\mu}\frac{k^2}{\varepsilon}\left(\nabla U+(\nabla U)^T\right)^2-\rho C_{\varepsilon 2}\frac{\varepsilon^2}{k},$$

where k – kinetic energy of turbulence; ε – dissipation of turbulence energy; C_{μ}, σ_k – model constants.

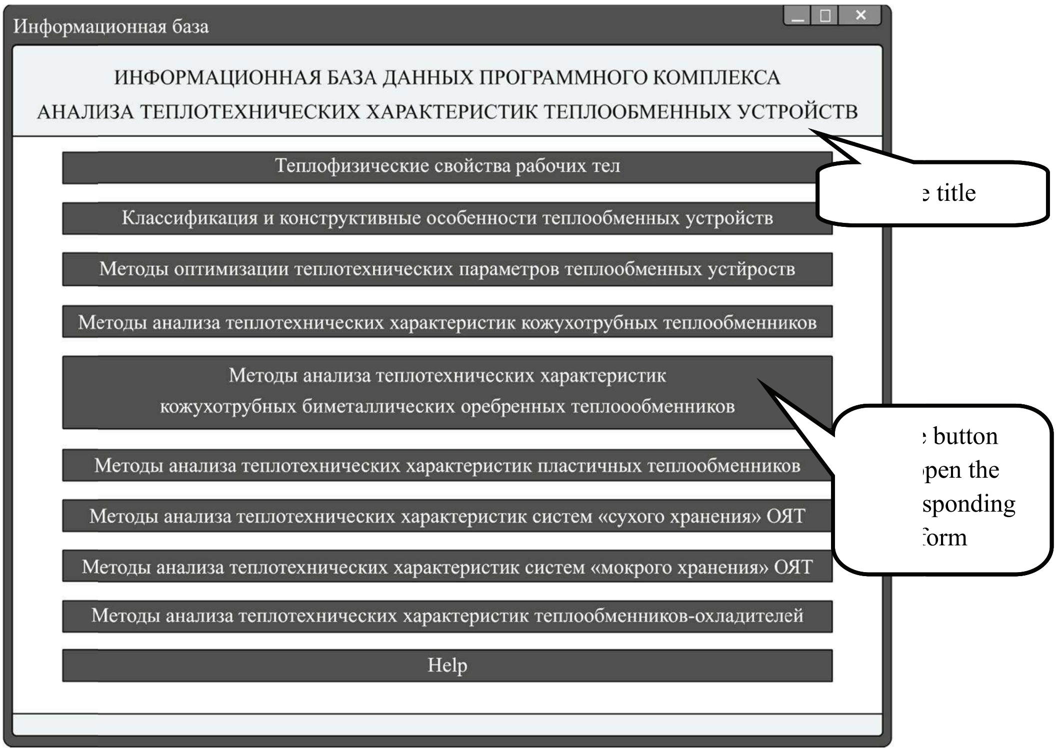

Fig. 2. The uniform information-analytical database

Values of model constants are determined on the basis of experimental data and located in COMSOL Multiphysics database.

If you want to describe the vapor -gas systems a suggested system of equations of conservation is adopted for steam air mixture, and is supplied by the equation of mass conservation of a vapor phase:

$$\frac{\partial c''}{\partial t} + \vec{u} \cdot \nabla c'' = \nabla\left(D'' \cdot c''\right),$$

where c'' – vapor concentration; D'' – vapor diffusion coefficient in air.

At the border of a phase division this condition is accepted

$$q_{\text{sum}} = q_{\text{ev}} + q_{\text{con}},$$

where q_{ev} – the heat flow due to evaporation; q_{con} – the heat flow due to convection.

The heat flow as a result of evaporation for one gas molecule (suggested by Landau) is equal to:

$$q_{\text{ev}} = k\left(c_s'' - c_{\text{sf}}''\right)\left(\frac{m''}{2\pi K T_{\text{sf}}}\right)^{0.5},$$

where k – the latent heat of evaporation; c_s'' – saturation vapor concentration; c_{sf}'' – vapor concentration on the border areas; m''– mass of a vapor molecule; K – constant by Boltzmann; T_{sf} – saturation temperature. The description of the conditions of application of 3D-computation templates included in the software package is presented below.

The general view of computation areas of modeled objects is shown in Fig. 3.

Fig. 3, *a* shows a 3D-computing template assigned to describe transfer processes in bimetallic ribbed shell and tube structures of heat exchange devices. A calculation area of this type of heat-exchange surface in accordance with the objectives of the study is divided into four conjugate calculation sub-areas:

1) the area between the finned tubes (free convection, air);

2) the outer tube with fins (heat conductivity, aluminium);

3) the contact zone between the outer and the inner tube (thermal resistance);

4) the inner tube (thermal conductivity, steel).

The external boundary condition is adiabatic condition of the course of physical processes.

Fig. 3, *b* shows a 3D-computing template assigned to describe transfer processes in a tubular heat exchanger-cooler.

In the construction of a given model analogue the following assumptions are accepted:

– eposits occur only on the surfaces of the heat exchanger in the annular space in contact with the coolant (50% water-propylene glycol solution) and are the same by thickness and composition;

– on the surface of the pipe with cooling liquid (water) deposits are not formed;

– thickness of deposits is examined as a discrete or linear parameter changing during the time (quasi-stationary mode) from 0 to 5 mm;

– nature of deposits is examined in versions: biological growth (thermal conductivity – 0.6 W/mK); salts of hardness and products of corrosion (thermal conductivity – 1.2 W/mK).

The above assumptions allow to consider a symmetric axis problem on the determination of parameters of the heat exchanger.

Fig. 3, *c* shows a 3D-computing template assigned to describe the transfer processes in the systems of “dry” near-station storage of spent nuclear fuel.

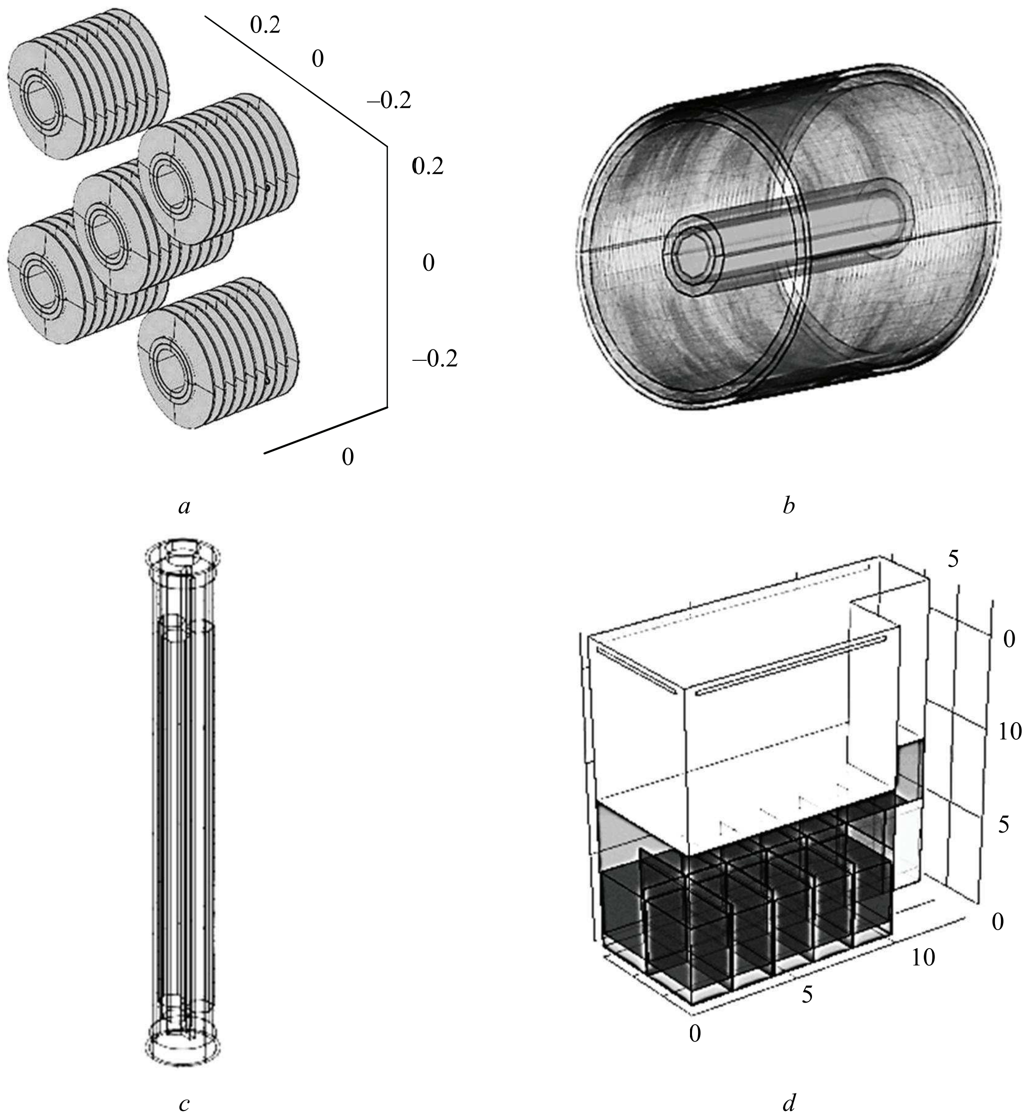

Fig. 3. Model analogues of heat exchange systems and surfaces:
a – bimetallic shell and tube heat exchanger with external ribbing; *b* – heat exchanger-cooler of type “pipe in pipe”; *c* – tube of a system of the “dry” near-station storage of spent nuclear fuel (without additional plates, with longitudinal cooling aluminum plates); *d* – element of the “wet” near-station storage of spent nuclear fuel in a storage pool

A model analogue of the pipe to store three spent heat releasing assemblies (SFA) had the following geometric parameters: the height of the pipe – 5 m, diameter – 0.65 m. The dimensions of the SFA: the height of a hot part – 3.8 m (without a tail part), diameter – 0.468 m.

Two versions of the model were considered:

1) without additional plates;

2) with cooling aluminum plates along SFA with the height of 3.8 m.

Furthermore, it was developed a model analogue of dry storage, which is a rectangular space which includes holes for charge and discharge of the cooling gas, and a set of cylindrical containers on whose surface can be set the boundary conditions that are typical modes of storage of spent nuclear fuel. With regard to the storages of spent nuclear fuel some cooling methods were considered:

– natural air circulation;

– forced air circulation;

– combined method of cooling.

Fig. 3, *d* presents a 3D-computing template assigned to describe the transfer processes in systems of "wet" near-station storage of spent nuclear fuel. In the construction of a calculation model of BV, the following basic assumptions are accepted:

– movement of the gas phase is described in terms of two-component vapor mixture;

– physical properties of water and solid media are received as constant and properties of vapor-air mixture – depending on the temperature, pressure and relative air humidity;

– bottom and pool walls of storage are considered to be heat insulated and heat removal is accomplished only through the ventilation ducts

Two mechanisms of heat removal are taken into account: by convection in the upper part of BV and forced injection and intake of water through the drain header and through regular intake near the upper level of liquid. Radiation heat exchange was not considered.

The results of the application of a basic program complex of the method of analysis of thermal characteristics of industrial design of heat exchange systems and surfaces of complex configuration are presented in [1–6].

Conclusion. The developed software package of the method of analysis of thermal characteristics of heat exchange surfaces of a complex shape includes some model units, the general user interface and the general information-analytical database.

The results of the application of the entering in a complex model blocks, including calculations of temperature fields and functions of the current in the conditions of natural and forced convection in the fields of complex configuration, showed their physical consistency and accuracy in describing thermal parameters of industrial designs of heat exchangers and systems.

Software implementation of the method of expert analysis and optimization of the thermal characteristics of heat exchangers will allow to develop, plan tests and conduct a computational analysis of the parameters of industrial heat exchangers and, accordingly, to reduce financial costs and speed up the implementation of the heat-exchange equipment in practice.

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