УДК 621.5:519.6

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COMPUTER METHODS OF THE ANALYSIS OF THERMO-TECHNICAL CHARACTERISTICS OF HEAT EXCHANGER-COOLER OF THE “PIPE-IN-PIPE” TYPE

In the given work we describe the results of the application of modern computational tools to analyze the thermal performance of the heat exchanger of the “pipe in pipe” type in which in the inner tube refrigerant is circulating – a 50% aqueous solution of propylene glycol, and in the ring backlash – the coolant (water). Thus, on the heat exchange surfaces of pipes variable (both in time and length) layers of deposits of organic and inorganic origin. This article discusses only the deposits on the surfaces in contact with the coolant.

Introduction. The heat exchangers of the “pipe in pipe” type are widely used in various industries, particularly in food industry as heat exchangers, coolers for various purposes. This may be explained not only by the relative simplicity of the design of these heat exchangers, but also the possibility of creating a reliable algorithm for the regulation of their regime parameters. However, such algorithms should take into account the dynamics of a wide range of interconnected both thermal and hydraulic characteristics of the heat transfer surfaces and help reduce energy costs for the maintenance of heat exchangers.

Currently, to analyze the heat transfer characteristics of the heat exchangers computer methods are increasingly used. An example of this approach is the work [1], which describes the application of Simulink package according with the system MATLAB applied to the problems of modeling and optimization of heat-mass transfer processes.

Formulation of the research problem. The procedure of constructing computational domains and the method of solution of non-stationary multidimensional conservation equations on the basis of formalized templates of software package *COMSOL Multiphysics* and the finite element method embedded in this package are adopted in this research. The counterflow heat exchanger of the “pipe in pipe” type in which the refrigerant – 50% aqueous solution of propylene glycol is circulating in the inner pipe, and the coolant (water) [2, 3] in the annular gap, was chosen as the research object, based on the formalized templates of software package *COMSOL Multiphysics*. The variable (both in time and in length) layers of deposits of organic and inorganic origin may be present on the surfaces of the heat transfer pipes.

In this model experiment, the following assumptions are accepted:

– deposits occur only on the heat exchange surfaces in the annular gap in contact with the coolant (50% aqueous solution of propylene glycol), they are identical both in thickness and composition;

– on the surface of the pipe with the coolant (water) deposit formation does not occur;

– thickness of the sediments is considered as a parameter, the time-varying discrete or linearly (quasistationary) from 0 to 5 mm;

– nature of deposits is seen in 2 versions: biofouling (thermal conductivity – 0.6 W/mK); salt toughness and corrosion products (thermal conductivity – 1.2W/mK).

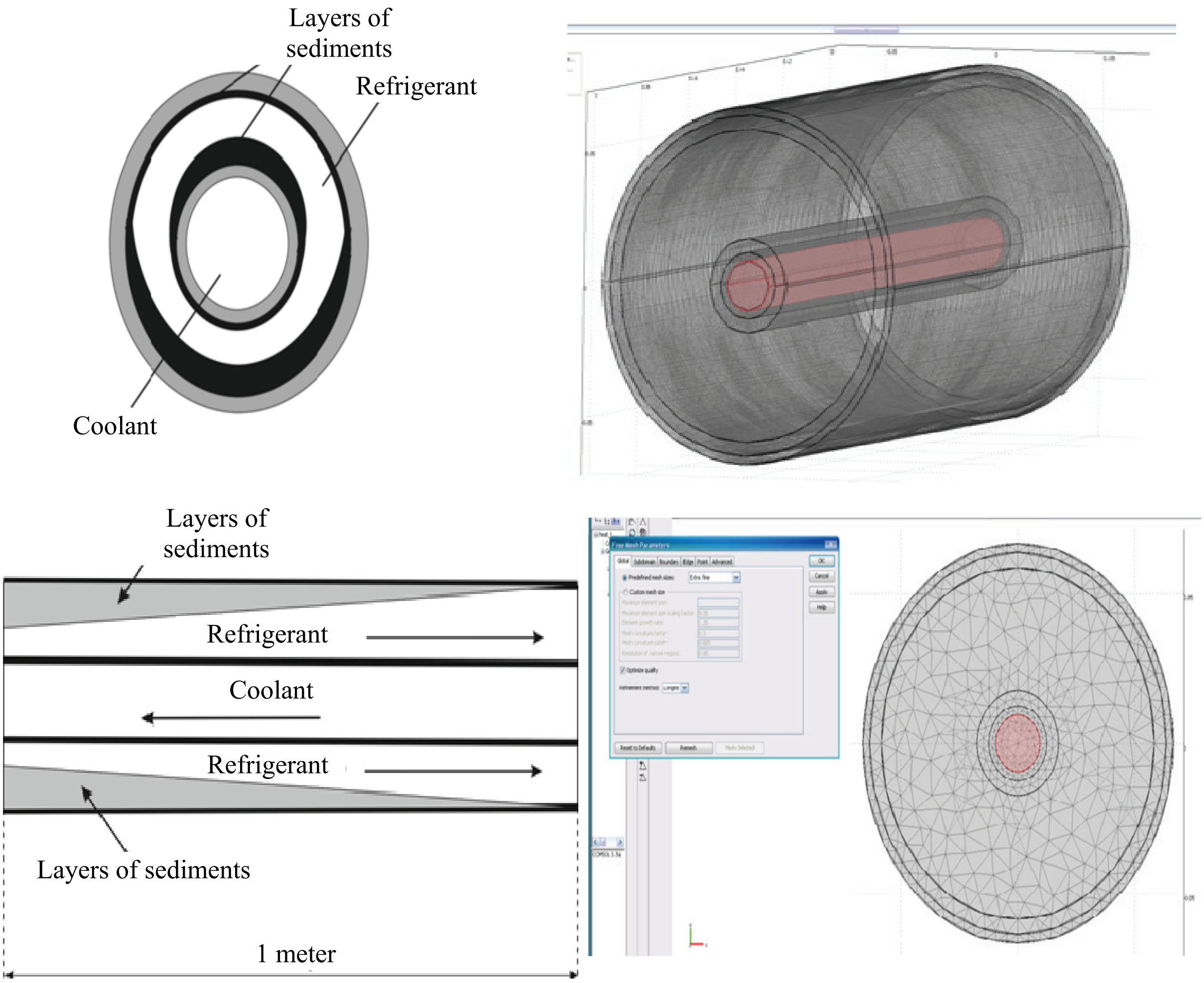
The above assumptions allow us to consider the axisymmetric problem in the setting of parameters of the heat exchanger. Fig. 1 shows an example of the calculated geometric pattern, composed on the assumptions made and the geometric characteristics of the heat exchanger, the outer radius of the outer pipe – 28 mm; the outer radius of the inner pipe – 12.5 mm; thickness of the pipe – 3 mm. Deposit thickness – 0, 1, 2, 3 and 4 mm.

Results of the research. The computational experiment was carried out in the framework of the formal calculation pattern *COMSOL Multiphysics* based on the non-stationary conservation equations with the assignment of the corresponding constants, correlating factors, closure relations, as well as boundary and initial conditions.

This series of computational experiments was conducted with the following parameters: maximum speed of working bodies of the inner pipe and the annular gap is 0.1 m/s; inlet temperature, refrigerant and coolant are respectively 353 and 293 K; output pressure equal to 10,350 Pa.

The graphical presentation of research results is illustrated in Fig. 2–5 on a series of computational experiments for the case of discrete time changing the thickness of deposits.

The task to determine the maximum flow rate of cooling water from the cooling conditions required for its 4°C with the predetermined limit values for the pressure drop along the side of the chilled water and sediment values respectively equal to 0.6 MPa and 4 mm was considered at the first stage of the research. These limitations are related to the maximum allowable energy costs for pumping coolant.



a *b*

Fig. 1. The geometric calculation template of the exchanger-cooler:
a – diagram of a heat exchanger with deposits;
b – finite element partition of a computational domain

As this computational experiment showed, under the above restrictions the limit water flow is ≈0,012 m^3/h.

Fig. 2 shows the profiles of the dynamic parameters of the heat exchanger of the propylene glycol and the temperature gradient in the cross section of the heat exchanger for the initial portion and at a predetermined cooling water flow.

As might be expected, the thermal resistance of the heat transfer wall proportionally decreases with a decrease in the deposits values. Respectively, the required heat removal is provided at a lower flow of propylene glycol, which in its turn requires a lower pressure drop and capacity of its pumping.

On the other hand, the nature of curve 3 in Fig. 2 shows that the dependence of the thermal resistance and thus the thermal efficiency of the heat exchanger on the operation time has an asymptotic nature with access to a quasi-stationary regime. These results lead to a preliminary conclusion about the ineffectiveness of the intensification of the process of heat transfer outside this area and the need to clean the surface of the heat transfer from the sediments. More detailed and well founded conclusions can be made after the consideration of the dynamics and sediment profile and optimization of thermal-hydraulic parameters of the heat exchanger.

Fig. 3 and 4 show the cross sections of the temperatures in different sections of the heat exchanger. The nature of the given profiles indicates, firstly, the presence of the maximum thermal resistance of the heat exchanger in the central part (at the largest deposits) and, secondly, its sharp increase in its sediment ≈4 mm.

One of the factors affecting the efficiency of the cooling process in this heat exchanger can be thermo-physical properties of sediments and coolant. The character of the influence of these parameters on the efficiency of the cooling water is illustrated in Fig. 5, which shows the profiles of the temperatures of heat carriers from the coolant and the cooling medium and coolant.

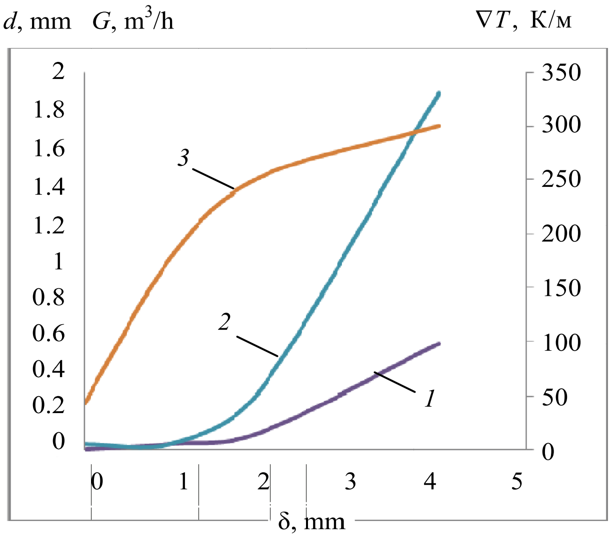


Fig. 2. Changing the parameters of the heat exchanger on the side of propylene glycol depending on the thickness of the sediment (δ), while ensuring a constant flow (0.012 m^3/h) and a constant temperature difference (4°C) on the water side:
1 – pressure drop (ΔP); *2* – volumetric flow rate (G); *3* – average temperature gradient (∇T) in the heat transfer wall

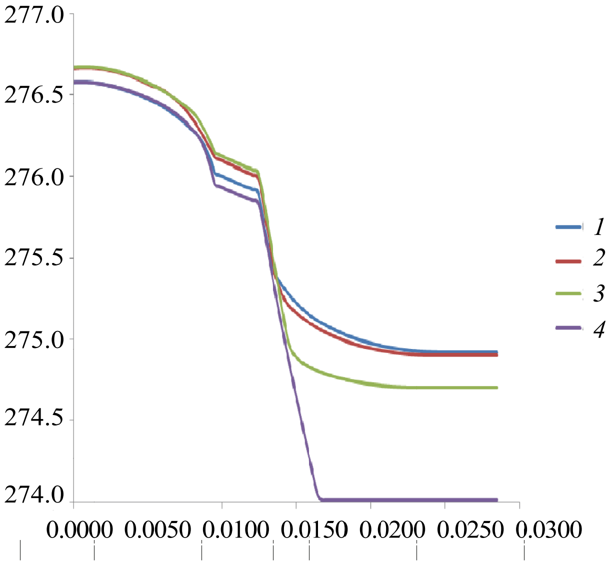


Fig. 3. Cross sections of the temperature in the heat exchanger at a height of 0.5 m in the case of deposits sized: *1*, *2*, *3*, *4* – 0, 1, 2, 4 mm

As follows from Fig. 5, the temperature profile along the length of the heat exchanger from the cooled liquid is concave in nature. With the increasing thermal resistance of the heat transfer surface this profile tends to a linear profile, which in its turn indicates the initially more efficient use of the heat transfer surface, and subsequently – its scarcity.

This result allows us to offer the optimal energy-saving algorithm of the regulation of the thermodynamic parameters of the heat exchanger.

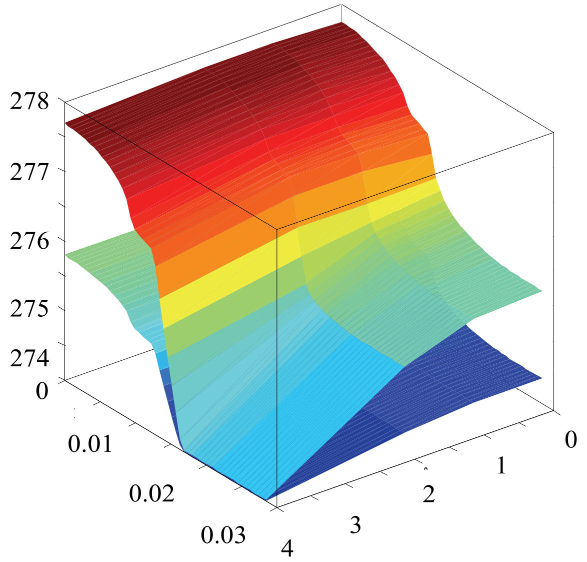


Fig. 4. Dependence of temperature profiles (variation range 274–278 K) over the radius of the heat exchanger (variation range 0–0.03 m) on the thickness of deposits (variation range 0–4 mm) for the cross sections at a height of 0.25 m (lower profile) and 0.75 m (upper profile)

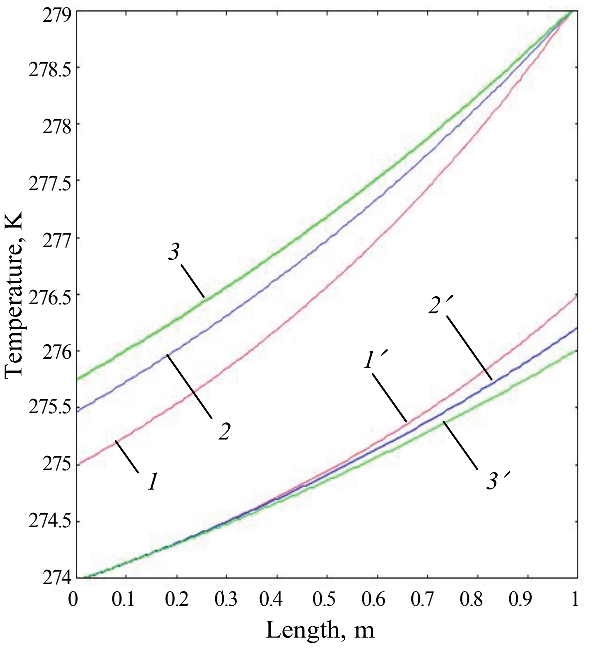


Fig. 5. Profiles of the temperature of heat carriers from the cooled medium (curves *1*, *2*, *3*) and coolant (curves *1′*, *2′*, *3′*):
1, *1′* – basic variant with the sediments of thickness 1 mm (coefficient of thermal conductivity of sediment – 1.2 W/(m · K), the viscosity coefficient of propylene glycol – 0.015 (mPa · s); *2*, *2′* – thermal conductivity coefficient of sediment – 0.56 W/(m · K), the viscosity of propylene glycol – 0.015 mPa · s); thermal conductivity coefficient of sediment – 0.56 W/(m · K), the viscosity of propylene glycol – 0.038 mPa · s); *3*, *3′* – thermal conductivity coefficient of sediment – 0.56 W/(m · K), the viscosity of propylene glycol – 0,038 mPa · s

Conclusion. The models and computer programs for calculating the thermal characteristics of the heat exchanger-cooler of the "pipe in pipe" type with regard to deposits on the heat transfer surfaces in relation to food industry devices based on propylene glycol were developed.

1. 1. The solution of the complete system of equations taking into account the conservation of thermal energy on the heat transfer surface allowed excluding the calculation of the heat transfer coefficients from the model. This approach is most appropriate when calculating the heat exchangers with considerably varying thickness of deposits.

2. As a result of the computational experiments the influence of deposits on the thermal performance of heat exchange equipment in the food industry by using propylene glycol as the coolant was determined.

3. The results obtained can be used to optimize the timing of cleaning equipment at the enterprises exploiting heat exchangers and the development of optimal power saving algorithms to regulate their thermal parameters.

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Received 05.03.2014