Modern methods of intensification of heat exchange processes in plate apparatuses

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Abstract. The heat supply system of the Russian Federation is characterized by significant wear and tear of equipment: heating networks and boilers. At the same time, an important element of heat supply systems equipment is heat exchangers of various designs, which are used in boilers, IHP, thermal power plants, and nuclear power plants. Various heat exchange equipment used in modern heat power engineering is considered. It is established that the use of plate heat exchangers is a more appropriate engineering solution than shell-and-tube heat exchangers, due to economic factors and operational advantages. The method of intensification of heat transfer of the heated liquid by means of technological depressions of spherical shape located according to the linear law is considered.

1. Introduction
In the Russian Federation, centralized heat supply is the most widespread, as this type of heat supply reduces fuel consumption and operating costs, makes it possible to use low-grade fuel, reduces the degree of pollution of the air basin and improves the sanitary condition of settlements.

However, in the second half of the XX century and at the beginning of the XXI century, decentralized, autonomous and individual heat supply systems are becoming more widespread. This is primarily due to intensive suburban house construction both in the Russian Federation and in developed countries.

In the Russian Federation, housing and communal services are one of the most important branches of the national economy, which is confirmed by the state policy. To form a strong and sustainable growth of the economy, the modernization of heating networks is carried out in accordance with Federal Law No. 261 of 23.11.2009 “On energy saving and improving energy efficiency” [1], as well as the Order of the Government of the Russian Federation of 13.11.2009 N 1715-R “On the Energy strategy of Russia for the period up to 2030”[2].

For 2018, according to the Ministry of Energy, the total sales of heat in the country is 2060 million Gcal/ year, including the housing sector and the budget sector consume 1086 million Gcal, industry and other consumers 974 million Gcal. More than 400 million t.c.f./year is spent on heat supply [3].
2. Materials and methods

2.1. Materials
The main type of heat exchange equipment in the production of heat energy are plate and shell-and-tube heat exchangers (figure 1). This equipment is used in boiler houses, individual heat points (IHP), as well as in thermal power plants and nuclear power plants.

![a) shell and tube heat exchanger; b) plate heat exchanger.](image)

Figure 1. a – shell and tube heat exchanger; b – plate heat exchanger.

Housing and communal services in the Russian Federation traditionally use shell-and-tube heat exchangers. This is primarily due to their low cost and ease of operation, but they are characterized by a relatively low coefficient of heat transfer. When comparing two heat exchangers of the same thermal power Q, W, the heat transfer coefficient of the plate apparatus is at least 2.5 times higher [4].

To increase the heat transfer coefficient of the shell and tube heat exchanger an original design of the heat exchanger with increased turbulence of the heated liquid is proposed [5, 6].

A new solution in the heat supply systems of the Russian Federation is the use of plate heat exchangers, which are characterized by higher values of the heat transfer coefficient with significantly smaller dimensions. These devices can also work with various types of heat carrier (water, gas, oil, etc.), which expands the scope of application of these devices [7]

2.2. Methods
In Russia and developed industrial countries, active theoretical and experimental research is being conducted on the intensification of heat exchange in plate heat exchangers for various industries. The intensification of heat transfer is considered in the work of A.Yu. Maskinskaya [8]. A method for increasing the efficiency of a plate heat exchanger by using a surface with holes is proposed. It was possible to achieve an increase in the heat transfer coefficient by 25% compared to a smooth surface. However, when using a surface with holes, the hydraulic resistance increased.

In [9], the use of cationic and magnetic filters for cleaning the working fluid in plate heat exchangers is proposed. Due to these measures, there was no reduction in efficiency and, as a result, it allowed increasing it. However, the technology of installing a cationic filter requires a large amount of reagents, so it is better to use a magnetic filter.

As A.A. Gukhman noted [10] - the main task of the intensification of convective heat transfer is such an impact on the boundary layer that would make it thinner or partially destroy it. It is confirmed that increasing the speed of the incoming flow reduces the thickness of the boundary layer, but, in turn, there is a rapid increase in hydraulic resistance. In addition, the use of this method is limited by the growth of energy costs.

Studies on the influence of a heat exchange surface with a geometrically altered shape, namely rough surfaces, on the flow in the wall area, and, consequently, on the total hydrodynamic characteris-
tics of streamlined bodies were first conducted by William Froude, the work was performed in 1869 in Great Britain [11].

Samara State Technical University conducted research on the flow of heat exchange surfaces with welded separation spikes [12]. This modernization allowed not only preventing deformation of the plates under the influence of pressure, but also turbulizing further the flow of the coolant. It is important to note that the height of the spikes determines the height of the channel, and the frequency of their location (longitudinal and transverse step) – the allowable pressure in the device. The disadvantages of such a design solution are the complexity of manufacturing, cleaning and repair.

In many developed countries - the United States, Canada, the European Union (Germany, France), as well as China and India, intensive theoretical and experimental research is being conducted to improve the efficiency of plate devices [13]. This work is particularly active in Denmark (firms “Ridan”, “Alfa Laval”, “Danfoss”). The devices of these manufacturers are widely used in the heat power industry of the Russian Federation. Largely, the research is aimed at increasing the turbulence of the liquid flow both at the heated surface and at the cooled surface because of original technical solutions.

E.A. Mikulich defined ring stresses on the border of holes and radial stresses in plate elements. The analysis of numerical calculations showed that the action of the pulse load when the holes come together increases the ring stresses at their borders and reduces the radial stresses at the internal points of the plate elements [14].

Qian H. studied the effect of pulsations on the heat transfer characteristics of plate heat exchangers. Thus, with constant mass flow of hot water, at a ripple frequency of 1.78 Hz, it was possible to achieve the maximum value of the heat transfer coefficient of 4415.73 W/(m² K). It was found that the average increase in the heat transfer coefficient at the transition to the pulsating mode was 20% [15].

According to A.A. Zhukauskas’ fundamental research, the amount of heat energy transferred from a heated solid to a lower-temperature liquid is directly dependent on the nature of the fluid flow around this body [16]. Therefore, for Reynolds numbers $2 \cdot 10^4 – 10^5$ on flat surfaces, the increase in heat transfer is more than 10%.

L.M. Kovalenko and A.F. Glushkov showed the basics of calculation and design of heat exchangers with a complex shape of the heat exchange surface are given. The possibilities of reducing the metal and energy consumption of industrial heat exchange equipment are shown, and the problem of rational, careful attitude to fuel is considered [17].

It is important to improve the designs of existing plate heat exchangers. Convective heat exchange with surfaces of complex shape made of a thin sheet is of particular interest. The main task of intensifying convective heat transfer is to influence the boundary layer in a way that would make it thinner or partially destroy it. This is shown in the works of L.G. Loytsyansky [18] and G. Shlichting [19].

Thus, to intensify heat exchange in a plate heat exchanger, it is necessary to increase the turbulence of the coolant flowing around the heat exchange surface.

3. Results

3.1. Facility

The Heat and Gas Supply and Ventilation Department of the Belgorod State Technological University named after V.G. Shukhov conducts research on the intensification of the plate heat exchanger. The semi-industrial facility “Independent heating system of a residential building”, shown in figure 2, was developed.

The main elements of which are 1 - supply pipeline from the heat supply source; 2 - pump; 3 - regulating device; 4 - flow meter; 5 - temperature sensor; 6 - supply pipeline from the heat exchanger; 7 - heating system consumers; 8 - return pipeline (from the heating system to the heat exchanger); 9 - plate heat exchanger; 10 - return pipeline to the heat supply source; 11 - heat supply source; 12 - ball valve; 13 - pressure gauge; 14 - heat calculator.
3.2. The heat transfer coefficient

The research results are shown in figure 3. All the studies discussed above are aimed at turbulization of the coolant flow at the heat exchange surface in the heating and heated circuits. As a result, the heat transfer coefficient $K$, $W/(m^2K)$, plate heat exchanger increases, which leads to the reduction of metal consumption (reducing the size), increasing efficiency of heat-exchange equipment.

The graph shows that the heat transfer coefficient $K$, $W/(m^2K)$ increases almost linearly with an increase in the average temperature pressure $\Delta t$, and on average up to 5% more than that of a serial heat exchanger.

Conclusions. As a result of the conducted research, it is confirmed that the use of an intensified heat exchanger leads to an intensification of the heat exchange process. The increase in the heat transfer coefficient with a seasonal increase in the temperature pressure is more intense (pay attention to the...
trend line) in the device under study than in the serial one. A high value of \( K \) will eventually reduce the metal consumption of the device.

Operation of an intensified heat exchanger, in our opinion, will increase the advantages of the plate device, reduce the cost of current and planned repairs, and will increase the operational reliability of heat supply systems.

4. Discussion
All the studies discussed above are aimed at turbulization of the coolant flow at the heat exchange surface in the heating and heated circuits. As a result, the heat transfer coefficient \( K \), \( W/(m^2K) \), plate heat exchanger increases, which leads to the reduction of metal consumption (reducing the size), increasing efficiency of heat-exchange equipment.

In our opinion, studies aimed at improving the usability, extending the service life and intensifying thermal processes associated with changes in the geometry of the heat exchange surface of the device are the most promising, which will result in increased turbulence of the liquid flow at the heat exchange surface.

5. Summary
The increase in the heat transfer coefficient with an increase in the temperature pressure occurs more intensively in the device with modified plates than in the serial one. A high value of \( K \) will reduce the metal consumption of the device.

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