The enhanced plate heat exchanger for systems of housing and communal services

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Abstract. The problem of intensification of thermal processes and the process of heat exchange in a plate heat exchanger of the HHN02 type is considered. A comparison is made of two types of heat exchangers - shell-and-tube and plate. The formulas for calculating heat transfer and heat transfer coefficients are presented. The analysis of theoretical studies on the intensification of heat transfer in a plate heat exchanger with a corrugated surface of the plates is carried out. A full-scale experiment was carried out on a specially designed semi-industrial stand “Independent heating system of a residential building”. It has been found that the use of a corrugated surface is capable of providing a high value of the heat transfer coefficient. It has thus confirmed the advantages of the plate heat exchanger in comparison with the shell-and-tube.

The territory of the Russian Federation is located in five climatic zones, which could not but affect the timing of the heating season, which, depending on the climatic zone, can range from 72 to 365 days [1]. Heat supply systems are used to create comfortable working and living conditions for the population. The most widespread in Russia is district heating. This is due to the fact that this type of heat supply allows not only to reduce fuel consumption and operating costs, but also makes it possible to use low-grade fuel. In addition, during the operation of centralized systems, the level of environmental stress in the air basin decreases and the sanitary condition of settlements improves.

However, at present, the trend continues, which began in the second half of the 20th century, of the increasing spread of decentralized, autonomous and individual heat supply systems. This development is primarily caused by intensive cottage construction both in the Russian Federation and in other developed countries of the world.

The total amount of heat consumed in the country is 2060 million Gcal/year, taking into account the housing sector and the public sector, which consume 1086 million Gcal, while industry and other consumers - 974 million Gcal. In total, more than 400 million tons of fuel equivalent per year are spent on heat supply [2, 3].

Shell-and-tube and plate heat exchangers (figure 1) are most widely used in the production of heat energy. This equipment is used at thermal power plants, nuclear power plants, individual heating points (ITP) and boiler houses.
Figure 1. a - shell-and-tube heat exchanger; b - plate heat exchanger.

There are about 30 companies operating in the modern Russian market of heat exchange equipment, including both domestic manufacturers and subsidiaries of large foreign firms. The most widespread among all the companies represented on the Russian market are the following manufacturers: LLC "GEA Mashimpeks" (18%) (www.gea-mashimpeks.ru); Ridan CJSC (30%) (www.ridan.ru); Alfa Laval Potok OJSC (27%) (www.local.alfalaval.com/ru); Rosvep-service LLC (11%) (www.roswep.ru); Telotex APV LLC (3%) (www.teplotex.ru); Etra LLC (3%) (www.etrann.com) [4]. The structure of the Russian market of heat exchangers in percent for 2019 is shown in figure 2.

Figure 2. The structure of the Russian market for heat exchangers (2019).

Traditionally, shell-and-tube heat exchangers are used in the housing and communal services of the Russian Federation. First of all, this is due to their relatively low cost, ease of maintenance and ease of operation, however, shell-and-tube heat exchangers are characterized by a low heat transfer coefficient [5].

The introduction of plate heat exchangers instead of shell-and-tube devices promoted growth in the target product. This is due to the fact that the plate heat exchange equipment has a higher heat transfer coefficient $K$, W (m$^2$ °C), which contributes to an increase in energy consumption and optimization of the boiler house. [6].

One of the few negative aspects of the operation of plate heat exchangers is the overgrowth of the plates due to the high rigidity of the applied coolant, which leads to deformation of the main heat exchange part of the plate. To avoid this, it is necessary to use high-quality water treatment during operation.
The main elements of plate heat exchangers are thin corrugated plates that form slot-like channels of complex geometric shape, in which the heat exchange process takes place. This surface of the plate increases the turbulence of the flows of the working media, which leads to an increase in the heat transfer coefficient (figure 3).

At the Belgorod State Technological University named after V.G. Shukhov, at the Department of Heat and Gas Supply and Ventilation, active work and research are being carried out aimed at improving the processes of turbulization and intensification of heat transfer. At a specially designed semi-industrial stand "Independent heating system of a residential building" [7]. A heat exchanger of type HHN02 of the Ridan company, the official representative of Danfos LLC in the Russian Federation, is used as the investigated plate apparatus. The passport data of the investigated heat exchanger are presented in table 1.

**Table 1. Passport data of the plate heat exchanger HHN02.**

|                               | Hot environment | Cold environment |
|-------------------------------|-----------------|-----------------|
| Consumption, t/h              | 0.57            | 0.31            |
| Design pressure, kgf/cm² (MPa)| 16 (1.6)        | 16 (1.6)        |
| Test pressure, kgf/cm² (MPa)  | 22 (2.2)        | 22 (2.2)        |
| Design temperature, ºC        | 150             | 150             |
| Inlet temperature, ºC         | 70.0            | 5.0             |
| Outlet temperature, ºC        | 45.9            | 49.4            |
| Pressure loss, kgf/cm²        | 0.18            | 0.06            |
| Heat load, kcal/h             | 13744           |                 |
| Heat transfer coefficient, W/(m²K) | 3440           |                 |

**Constructional characteristics**

| Number of plates, pcs.        | 7               |
| Number of channel strokes on the heating side | 1x3+0x0 |
| Number of channel strokes on the heated side | 1x3+0x0 |
| Heat exchange surface area, m² | 0.14           |
| Surface reserve, %            | 10.00           |
| Plate material                | AISI316         |
| Gasket material               | EPDM            |
| Accessions                    | Branch pipe DN 25 st. 20 RDAM.752272.008 (with emphasis) |
| Internal volume, l            | 0.27            |
| Weight (net), kg              | 50              |
| Screed size min max., Mm     | 16/18           |
Calculation formula for determining the heat transfer coefficient \( K \), \( \text{W/(m}^2\text{K)} \) on the basis of the "Rules for the technical operation of thermal power plants", approved by order No. 115 dated March 24, 2003 (RF), SP 41-101-95 "Design of heat points" [4] looks like:

\[
K = \frac{\beta}{\alpha_1 + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}}
\]  
(1)

where \( \beta \) – the coefficient taking into account the degree of contamination of the heat exchange surface (plate) is taken equal to 0.7 - 0.85; \( \alpha_1 \) - heat transfer coefficient, \( \text{W/(m}^2\text{K)} \); \( \alpha_2 \) - thermal perception coefficient, \( \text{W/(m}^2\text{K)} \); \( \delta \) – thickness of the heat exchange surface (plate), m; \( \lambda \) – coefficient of thermal conductivity of the heat exchange surface (plate), \( \text{W/(m} \cdot \text{K)} \).

It is known that the higher the laminar sublayer, the lower the heat transfer efficiency. This means that a decrease in the laminar sublayer will lead to an increase in the heat transfer coefficient, determined by the formula:

\[
\alpha = \frac{\lambda \cdot Nu}{l}
\]  
(2)

where \( \lambda \) – thermal conductivity coefficient, \( \text{W/(m} \cdot \text{K)} \); \( Nu \) is the Nusselt number; \( l \) is the length of the heat exchange surface (plate), m.

The Nusselt criterion \( Nu \) depends on the Reynolds number \( Re \), which increases with increasing turbulence in the turbulent regime of fluid flow around the plate [8] and is determined by the formula:

\[
Nu = 0.037 \cdot Re^{0.8} \cdot Pr^{0.43} \cdot \left( \frac{Pr}{Pr'} \right)^{0.25}
\]  
(3)

where \( Pr' \) – the Prandtl number for the wall.

Thus, it follows from (3) that an increase in the turbulization of the coolant flowing around the heat exchange surface promotes the intensification of the heat transfer process in the plate heat exchanger. The use of plates with a corrugated surface is one of the ways to increase the intensification of heat transfer. There are many studies on this topic carried out by domestic scientists [9-11] and foreign [12, 13].

In BSTU named after V. G. Shukhov at the Department of Heat and Gas Supply and Ventilation, experimental studies were carried out on the laboratory installation "Independent Heating System of a Residential Building", shown in figure 4.

The main elements of this installation are two circuits. The heating circuit consists of a heat source 11, a plate heat exchanger 9. The heated circuit from a consumer 7 and a plate apparatus 9.

![Figure 4. Block diagram of the laboratory installation "Independent heating system of a residential building".](image)
where: 1 - supply pipeline from a heat supply source; 2 - pump; 3 - regulating device; 4 - flow meter; 5 - temperature sensor; 6 - supply pipeline from the heat exchanger; 7 - consumers of the heating system; 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 - manometer; 14 - heat calculator.

The tasks of field experimental studies are:

- Determination of the heat transfer coefficient of an intensified lamellar apparatus with technological depressions of a spherical shape of channels with a seasonal change in the average temperature head $\Delta t$, °C and different flow rates of the coolant $G, m^3/h$;
- Comparison of heat transfer coefficients $K, W/(m^2\cdot K)$, and head losses $H, m$. Water. Art., the intensified apparatus, the parameters of which are presented in table 2, and serial HHN02, designed for the same thermal power.

**Table 2. Parameters of the intensified lamellar apparatus.**

| №  | Parameter name                        | Value  |
|----|--------------------------------------|--------|
| 1  | Height of the device, m              | 0.34   |
| 2  | Width of the apparatus, m            | 0.18   |
| 3  | Number of plates, pcs                | 7      |
| 4  | Plate height, m                      | 0.29   |
| 5  | Plate width, m                       | 0.125  |
| 6  | Free cross-section of the interplate channel, m² | 0.00007 |
| 7  | Connection of the apparatus to pipelines - threaded | 1"    |

The range of selected temperatures correlates with the temperature graphs of the heat source and consumer for heat supply systems in the Belgorod region. Outside air temperature range is presented in the plan of the experiment on the laboratory setup (table 3) and figure 5 shows the results of a field experiment.

**Table 3. Plan of the experiment on the laboratory unit.**

| Outdoor temperature, °C | -23 | -17 | -15 | -10 | -5  | 0   | +5 | +8 |
|-------------------------|-----|-----|-----|-----|-----|-----|----|----|
| Temperature $t_0$, °C   | 95  | 85  | 82.3| 74.1| 65.6| 56.9| 47.7| 43 |
| Average temperature     | 12.33 | 9.86 | 9.09 | 8.45 | 8.31 | 3.8 | 3.24 | 2.9 |
| head $\Delta t_{cp}$ °C |     |     |     |     |     |     |     |     |
| Coolant velocity in the heating circuit, m/s | 0.27 |
| Coolant velocity in the heated circuit, m/s | 0.33 |

**Figure 5.** Graph of the dependence of the heat transfer coefficient on the temperature head: 1 - serial heat exchanger HHN02; 2 - intensified heat exchanger.
It can be seen that the heat transfer coefficient $K$, W/(m$^2$K), of the intensified plate heat exchanger, is, on average, 5% higher than that of the serial device at various values of the average temperature head, determined by the formula:

$$\Delta t = \frac{(t_1 - t_2) - (t_2 - t_1)}{\ln \frac{t_1 - t_1}{t_2 - t_2}},$$

(4)

where $t_1$, $t_2$ – liquid temperature in the supply pipe of the heating and heated circuits, respectively, °C; $t_2$, $t_2$ - liquid temperature in the return pipe of the heating and heated circuits, respectively, °C.

Ultimately, a high value of $K$, W/(m$^2$K), will lead to a decrease in the metal consumption of heat exchange equipment.

Operation of the intensified heat exchanger, in our opinion, will reduce the cost of current and scheduled repairs, and will also improve the operational reliability of heat supply systems.

Heat exchangers are an important type of technological equipment for heat supply systems for housing and communal services. Increasing the energy efficiency of such devices allows you to get a positive economic effect.

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