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Hydraulic heat tests of the shell and tube heat exchanger using heated liquid of higher turbulization

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Abstract. A short characteristic of the heat power industry of the Russian Federation is analysed. Special attention is paid to the technological condition of the central thermal electric main lines and boiler equipment, thermal networks and heat consumption systems. Moreover, it is specified that the important heat supply equipment systems are shell and tube heat exchangers. The emphasis is that the use of shell and tube heat exchanger devices is based on reliable technical solution, financial viability, and convenience in its operation and repair. Based on the analysis of local and foreign scientists' research, the classification of approaches of heat exchange intensification in shell and tube heat exchanger devices is propounded. The article presents the results of thermal and hydraulic tests of an intensive shell-and-tube heat exchanger with increased turbulization of the heated fluid. When carrying out tests, modern high-precision measuring devices are used. A test objective comparison of hydrodynamics (losses of pressure) and heat technical characteristics (heat transfer coefficient) of two heat exchangers has been conducted. These are serial (state standard No. 27590.) and intensive (RU 185391 patent) exchangers.

1. Introduction

In the Russian Federation, the systems of heat supply are the most important component of fuel and energy balance of the country. Annually for the preparation of thermal energy in the form of steam, hot and super heated water more than 600 million tons of conditional fuel is utilized. This accounts for more than 30 % of all used primary fuel and energy resources [1].

For a long period of time, the thermal power industry of the Russian Federation has been developed through the approaches to concentration of thermal values, centralization of heat supply and the combined development of heat and electric power. Thus, the central heating has become the most rational method of fuel resources use for heat supply. Besides the central heating power supply and economic boiler installations, heat recovery plants are rationally utilised.

However currently, the power system of the Russian Federation is facing a number of technological constraints. So the proportion of boiler houses with outdated equipment has reached about 60 %. The thermal electric main lines (TEL) of boiler generators accounting for only 25 % and those of turbines – 36 % have been used in the service life span. The average depreciation percent level of thermal and steam

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networks is estimated at 60-70 %. About 60 % of the equipment in the heat utilisation systems requires reconstruction and entire replacement [2].

It is also necessary to note that the development of a high-quality power system using modern highly effective equipment increases the thermal production profitability, ensuring high-quality thermal energy deliveries for housing and public utilities and industry. This leads to improvement of the ecological situation in rural and industrial urban areas, reduction of labour costs at the heat power industry.

One of the types of highly effective heat mechanical equipment for boilers, thermal and nuclear power plants and thermal grids is the heat exchanger [3, 4].

2. Heat exchangers for heating systems

Traditionally, shell and tube exchangers are widely used in the heat supply systems of the Russian Federation. The advantage of such devices consists in: rather low hydraulic resistance, the operation possibility with different aggregate state working environments (heating contour – steam, heated – water). Also these devices can be used in case of the increased rigidity of water (over 700 mg-equal/l), temperature (up to 550°) and high pressure (up to 14 MPa). The main advantage of shell and tube heat exchangers is the reliability and simplicity in operation [5].

In addition to shell and tube heat exchanger devices, the use of lamellar heat exchangers is widespread. At the end of the 20th and beginning of the 21st centuries, foreign companies began actively introducing lamellar heat exchangers of various designs into the fuel and energy industries of the Russian Federation. Their higher coefficient of the heat transfer K, W/(m^2K) is characteristic.

However during the practical operation of these devices it became clear that they quickly failed because of plates' deformability which intensively increased due to the increased heat carrier rigidity. The main disadvantage of lamellar heat exchangers is the high cost of high-quality water treatment and quick failure of the polymeric consolidations which are necessary for these devices.

To clean the plates, it is necessary to disassemble the lamellar device during which there is a destruction of the rubber sealants (NBR or Nitril) having irregular shape. It should be noted that the cost of repairing the kit and aligning there can be more than 50 % of the cost of a new lamellar heat exchanger. Only highly skilled personnel can perform this work. It leads to considerable financial expenses. The life span service of the rubber consolidations according to the technical characteristics is 5 years that is achieved only with the use of sealants.

Thus, within the 5-10 year-term of operation of the lamellar heat exchanger, it is necessary to replace the consolidations at least twice.

The lamellar heat exchangers are delivered by foreign firms generally from the European Union. The cost of devices drastically increased because of devaluation of the Russian currency that leads to excessive expenses. Finally, it leads to an increase in thermal energy tariffs for the municipalities.

One of the major factors defining the overall performance of heat exchangers is the quality of water treatment (generally - decrease in rigidity, G, mg-equal/l) influencing the devices expansion.

It is also necessary to note that the expansion of heat-exchanging surfaces with thickness of scum of 0.3 mm reduces the coefficient of the heat transfer of the shell and tube heat exchanger device only by 10 %. At the same time the lamellar heat exchangers can decrease heat transfer coefficient K, W/(m^2K), by 70 % [6, 7]. Figure 1 shows the diagram of the serial shell and tube heat exchanger [8].

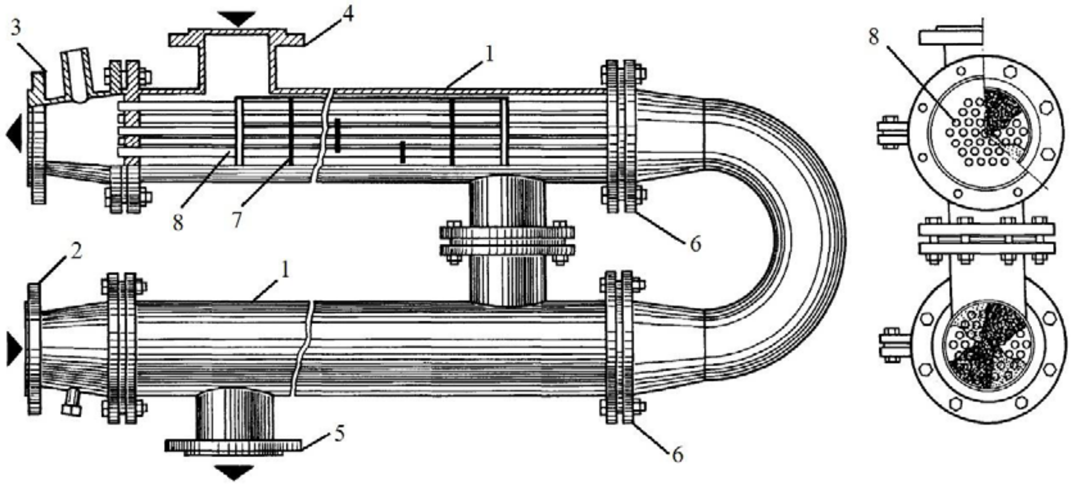

Figure 1. Shell and tube heat exchanger; a longitudinal section of the shell and tube heat exchanger, a section, a general view of a heat-exchanging tube. 1 – the case, 2 – a branch pipe for supply of hot liquid, 3 – a branch pipe of removal of the cooled liquid, 4 – a branch pipe for supply of the heated liquid, 5 – a branch pipe of removal of heated liquid, 6 – flange connection, 7 – cross partitions, 8 – heat-exchanging tubes.

Thus, analyzing the advantages and disadvantages of heat exchangers, it is advisable to develop shell and tube heat exchanger devices with intensified heat-exchanging processes due to turbulization of the heat carrier.

In the Russian Federation, as well as in the developed countries (such as the USA, Canada, the European Union - England, Germany, France, developing countries – India, China, Iraq), theoretical and pilot studies are actively being conducted on the overall performance increase of shell and tube heat exchangers [5, 9-16]. The classification approaches of the intensified processes of heat exchange of shell and tube heat exchanger devices are presented in figure 2:

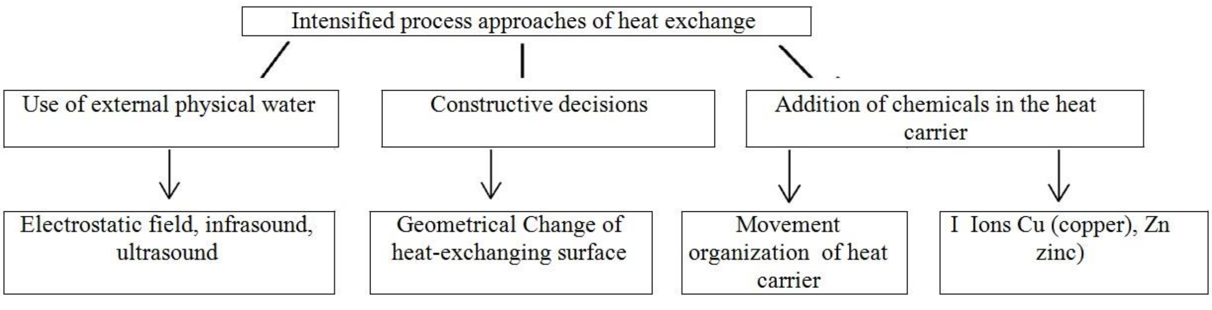

Figure 2. Classification of approaches to intensified processes of heat exchange in shell and tube heat exchangers.

The purpose of all this research is the turbulization of (heating or heated) liquid stream on the heat-exchanging surface. In this case the heat transfer coefficient of K, W/(m^2K), the shell and tube heat exchanger will increase, which will finally lead to dimensions reduction of the device and decrease in its metal consumption.

The most perspective one is the geometrical change of the heat-exchanging surface of the device, as a result of which the increased turbulization of liquid on the heat-exchanging surface will be obtained [5, 16].

The department of heat, gas supply and ventilation of BSTU (Belgorod) conducts research on the intensification of thermal processes of shell and tube heat exchangers by geometry changing of heat-exchanging surface. The intensive shell and tube heat exchanger whose construction feature is the equipment of heat-exchanging surface (tube) plates and edges of the round section (the patent of the Russian Federation, No. 185391) of [17] (figure 3) has been developed.

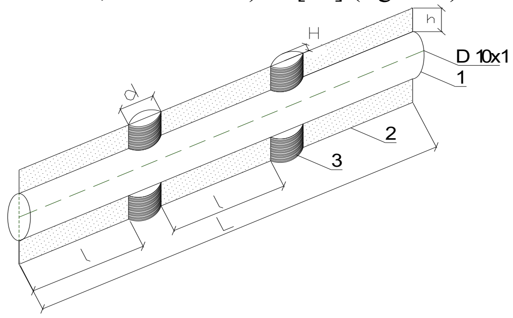

Figure 3. Element of a heat-exchanging surface of the shell and tube heat exchanger: 1 – a tube, 2 – a plate, 3 – edges of a cylindrical form.

This technical solution allows the heat-exchanging surface expansion and the most important thing is to increase stream turbulization of the heated liquid at the flowing edges. It, finally, allows the main objective solution – increasing the coefficient of the heat transfer of the shell and tube heat exchanger.
Research into turbulization change of the flat plate of the equipment edges of the cylindrical form was conducted with the modern program system application of "Ansys CFX" and its aspects have been considered [17].

From the results analysis the conclusion was drawn that the increase in heat exchange due to turbulization of the heated liquid (finally heat transfer coefficient *K*) in the intensive shell and tube device from the surface of heat exchange changed by geometry can be reached the height of edge of 4 mm, the speed of 0.7 - 1.3 m/s, length of the turbulence zone of 12 N.

3. Thermal (natural) tests

The semi-plant with the intensive shell and tube heat exchanger has been developed. The hydrodynamic and temperature conditions of the semi-plant correspond to joint venture 41-101-95 "Design of thermal stations". The installation has been developed for the temperature schedule delivery of thermal energy from the heating boiler house in Streletskoye of the Belgorod region (figure 4).

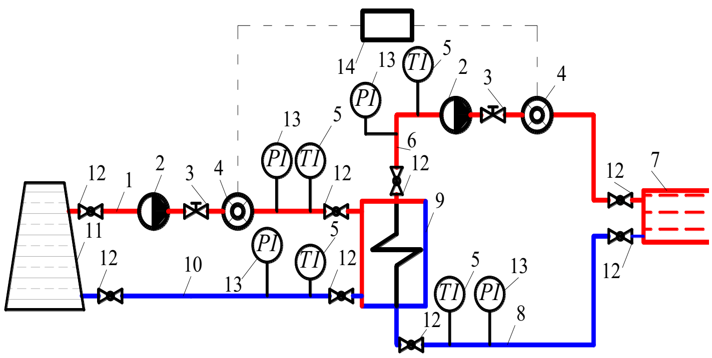

Figure 4. Independent heating system of a multi-storey residential building: 1 - supply pipe from heat source, 2 - circulation pump, 3 - control device, 4 - flow meter, 5 - thermometer, 6 - feeding pipe from heat exchanger, 7 - consumers, 8 - return pipe from heating system, 9 - intensive shell-and-tube heat exchanger, 10 - return pipeline to the heat supply source, 11 - heat supply source, 12 - disconnecting device, 13 - pressure gauge, 14 - heat calculator.

To carry out experiments, the natural semi-industrial shell and tube heat exchanger was used. The parameters of the device are presented in table 1.

Table 1. Parameters of the shell and tube heat exchanger.

Parameter	Unit Measurement	Parameter Value
Device Length	m	1
Diameter of device casing	mm	32x2
Diameter of heat-exchanging tube	mm	10x1
Plate Height	mm	4
Diameter of round section edge	mm	4
Cross-sectional area of inter-pipe space	m^2	0,00045
Number of edge items	item	23
Link to pipelines carving of the device	screw-thread	3/4"

The pilot studies of thermal characteristics of the shell and tube heat exchanger from the surface of heat exchange changed in the geometry have been conducted. The purpose of an experiment was comparison of coefficient of heat transfer *K*, W/(m ² °C), the serial shell and tube heat exchanger device with a smooth tube [18] and the intensive device from the surface of heat exchange changed in geometry [17].

Average temperature pressures for temperatures of external air 4, 0,-5,-15,-17 of °C were defined for the serial device of speed of liquids in the heating and heated contours (the hydraulic mode). The schedule of thermal network made 95–70 °C (the heating contour), and the schedule of an internal heating system of 80-60 °C (the heated contour). All schedules are made for consumers of thermal energy of the Belgorod region of the Russian Federation.

The same hydraulic modes and temperature pressures were applied to a research of the shell and tube heat exchanger from the surface of heat exchange changed in geometry. The direction of streams of heat carriers in the heated and heating contours is chosen as a cross section of the most effective operation in the systems of heat supply [1]. Test results are presented in figure 5.

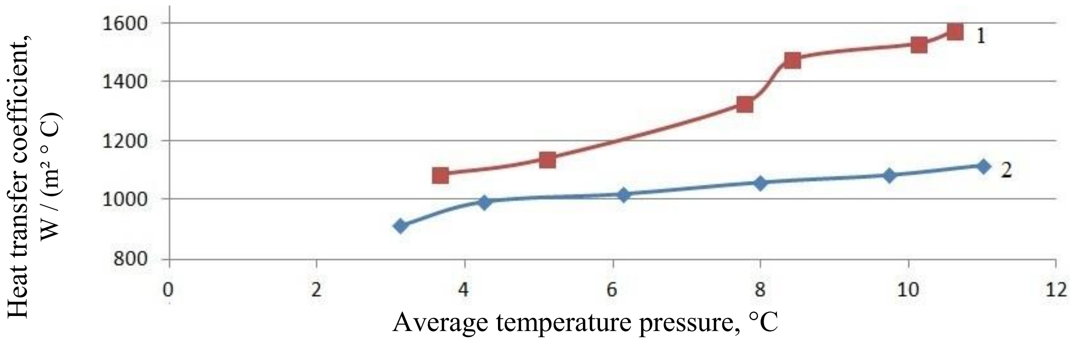

Figure 5. Graph of heat transfer coefficient versus temperature head: 1 - shell-and-tube heat exchanger with a modified heat exchange surface geometry, 2 - apparatus according to GOST 27590-2005.

The schedule shows that heat transfer coefficient *K*, W/(m²°*K)*, increases with rising average temperature pressure, and is more than 20 % of the serial heat exchanger [8].

4. Hydraulic (natural) tests

Undertaking pilot studies provides the influence of the definition of the changed heat exchange geometry on the hydraulic resistance of the shell and tube heat exchanger.

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During the experiment it is necessary to establish experimental dependence on size of hydraulic resistance, on liquid speed in the inter-pipe device space. Pilot studies were conducted in the laboratory of "Hydrodynamics and hydrocars" of BSTU.

The scheme of experimental installation is represented in figure 6. A basic element of installation is the shell and tube heat exchanger.

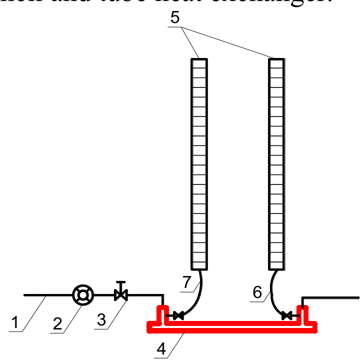

Figure 6. Experimental installation for hydraulic tests: 1 – pipeline of cold water; 2 – flow meter; 3 – the regulating gate, 4 - the shell and tube heat exchanger from the surface of heat exchange changed by geometry; 5 – piezo-metres of open type on an entrance and the output of the device; 6, 7 – flexible polymeric tubes for connection of piezo-metres.

Since the flow meter Elf-2.5-20 device was used (the measurement range of expense is 0.025 - 5 m^3/h, with relative error measurements – 0.1 %). Liquid piezo-metres of open type with the division of 1 mm were used to measure the pressure on an entrance and exit from the heat exchanger [19].

To carry out the experiment of the liquid speeds in the inter-pipe space, using set rules of 41-01-95, "Design of thermal grids" was calculated. The estimated usages have been presented in table 2.

Table 2. Estimated speed and liquid usage in inter-pipe device space

speed, m/s	0.1	0.16	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Liquid usage G, m^3/w.h.	0.173	0.276	0.346	0.518	0.691	0.864	1.037	1.21	1.382	1.56	1.728

Results of the experiment are presented in figure 7. The dependence of pressure losses and liquid speed in inter-pipe space of the serial device is also shown [8].

According to the results of pilot studies, the hydraulic resistance of the device with the changed surface of heat exchange on average is 16 % higher than that of the serial device [8].

However the research of thermal processes shows (figure 5) that heat transfer coefficient *K*, W/(m^2°*C*), is more than shell and tube heat exchanger from the heat-exchanging surface, changed in geometry on average of 20 %, than that in the serial heat exchanger.

Thus, turbulization of the heated liquid in the shell and tube device [17] along the cylindrical form leads to the intensification process of heat exchange and coefficient of the heat transfer *K*, W/(m^2°C), and, finally, decreases the overall dimensions of the heat exchanger.

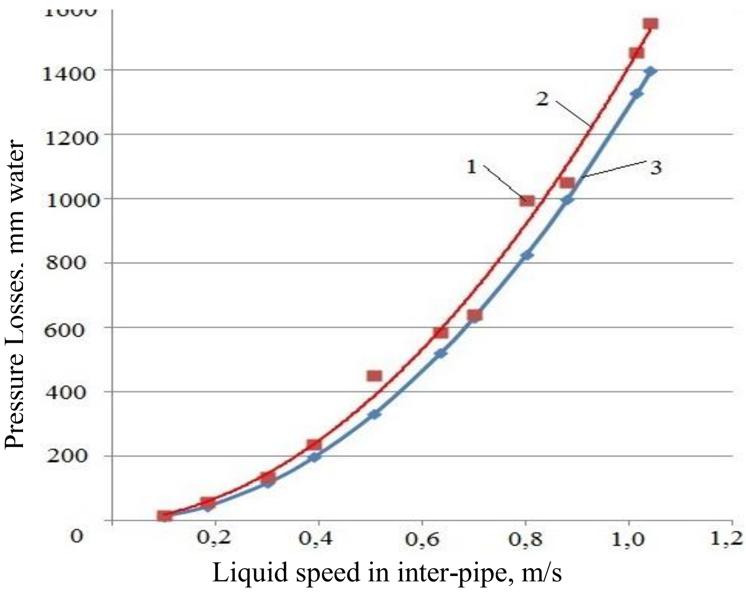

Figure 7. Schedule dependence of pressure losses on liquid speed in inter-pipe space: 1 – experimental values, 2 – the line of the schedule of the studied device, 3 - the line of the schedule of the serial device.

5. Conclusion

For standard operating conditions of the centralized heat supply system of a multi-storey house with heat exchanger diameters from 57 mm to 325 mm and heat carrier usage from 3m^3/h to 150m^3/h, the serial device [18] should have 4 sections 4 m long, and of highly effective 3 sections [17].

All this will lead to a considerable decrease in metal usage, convenience in operation and repair of the shell and tube heat exchanger, and money economy of construction and reconstruction of heat supply systems that is very important for the development of the housing-and-municipal sector of fuel and energy systems of the Russian Federation.

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