Heat exchangers with spring-twisted heat-exchange elements made of wire with sections of various geometries

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Abstract. The use of heat exchangers in the industry is quite large, it makes up a large share of all heat consumption in Russia, and therefore it is important to have equipment that meets modern requirements. In this regard, there are issues of improving and modernizing obsolete and developing new equipment. The authors proposed a heat exchanger based on effective thermal elements, the working surface of which is made by tightly winding wire having a cross-section in the form of an ovoid on a circular cylinder. In the places where the coils of wire adjoin each other, they are rigidly coupled by means of microplasma or laser welding, which eliminates the phenomenon of work hardening taking place in knurled pipes. To justify the effectiveness of the proposed apparatus, a computer model of the heat transfer process was applied and a physical experiment of the installation was carried out, showing the adequacy of the computer model. Numerical results of heat and hydrodynamic characteristics showed the consistency of the application of the proposed heat exchange equipment, based on spring-twisted elements, in industry, in the field of housing and communal services, as well as in related industries. Research in this direction contributes to the creation of small-sized heat-exchange equipment of large unit capacity.

Keywords: heat-exchangers, heat transfer intensification, hydrodynamics.

1 Introduction

In connection with the active development of large-capacity production, including high costs of heat carriers, their heating or cooling, and also due to physical wear and tear due to the long-term use of a large part of industrial heat-exchange equipment, which service life exceeds forty years, there is a need to create new or modernize serial heat exchangers, characterized by a large unit capacity. The criteria for the effectiveness of such devices are economic, energy, thermodynamic characteristics. Both in Russia and abroad, the question of creating effective devices is very acute. This is evidenced by many patents for the creation of heat exchange equipment, for example, European, American, Japanese patents [1-6]. It should also be noted that most patents abroad are associated with the creation of heat exchangers for the chemical industry [7], the food industry [8], for the production of ammonium, for example, for chemical reactors [10], for the mining industry [11]. Modification paths aim to improve their thermodynamic characteristics. For example, researchers Morozuyk, L., [12] considered a method for minimizing entropy, Shakhov Y., [13] - used to cool a jet cooler, Pramod S., [14] - studied the pressure drop in a conical coil heat exchanger, Gavade Pravin P. [15], - used spiral tubes in tubular heat exchangers, Ma Y., Vinodkumar K.V. [16, 17], - used nanofluids to cool the heat exchanger, Rizzi, Enrico [18] - optimized the design of the spiral heat exchanger, Zolotonosov Ya.D [19-22] - heat transfer is intensified due to finning of the heat transfer surface and channel shapes, heat transfer channels are created by winding, followed by laser welding of wire, round and oval sections, respectively. As the analysis of foreign literature presented in the public domain has shown, most of the work on creating effective heat exchangers are associated with their use mainly in the chemical industry. The scope of our scientific interests lies in the modernization and creation of innovative heat-exchange equipment of large unit capacity for the housing and communal services [23, 24]. As shown...
above, starting in 2010, the authors developed and patented heat exchangers, the analysis of the structures of which are described in detail in the publication [25].

This work is a continuation of the authors' research on the creation of compact heat exchangers of large unit capacity, which have a wide range of industrial applications, including in housing and communal services, chemistry and petrochemistry, energy, thermal power, medical and food industries, and several related industries.

2 Methods

As heat-exchange elements in heat-exchange equipment, the authors proposed the use of spring-twisted and twisted pipes (Figure1). Evaluation of the effectiveness of previously used twisted channels, round and elliptical sections is shown in [25]. Developing research in this direction, it was proposed to use twisted channels made of a wire section in the form of an ovoid, a mathematical description of which was proposed in [26]. The practical implementation of the proposed spring-twisted channel is carried out using a tight winding wire having a cross-section in the form of an ovoid on a circular cylinder. In places where the coils of wire are adjacent to each other, they are rigidly coupled using microplasma or laser welding. This technology eliminates the hardening phenomenon that occurs in knurled pipes.

![Figure 1. The element of the spring-twisted channel.](image)

A theoretical study of the efficiency of a heat exchanger based on the proposed element was carried out using computer simulation, which was based on a hybrid Mentor model. The implementation of computer simulation was carried out in the SolidWorks Flow Simulation software module, which allows to integrate the complex geometry of the heat transfer channel. Hydrodynamic characteristics were obtained in it for the calculation model according to the given physical conditions and certain boundary and initial conditions.

To verify the adequacy of the calculation results according to the Mentor model, an experimental setup and a technique for experimental studies of the apparatus (Figure 2) were developed and mounted, the heat-exchange element of which was a spring-twisted channel made of wire in the form of an ovoid.
Figure 2. Experimental setup (general form).

The pipe-in-pipe heat exchanger consists of an external pipe made of stainless steel with a diameter of 64 mm. The length of the pipe is 3000 mm with a thickness of 4 mm steel. The surface of the outer pipe was double-layer insulated with an asbestos cord and additionally covered with a heat-resistant polymer film. The internal heat exchange element of the apparatus is made of stainless steel in the form of a twisted pipe made of wire in the form of an ovoid, 2920 mm long and a wall thickness of 1.5 mm.

Coldwater from the equalization tank, equipped with an overflow and a mixing device that ensures uniform distribution of the temperature of the liquid in the tank, passing the inlet pipe and the stilling grate, entered the pipe with a twisted heat transfer surface.

The exit of hot water from the twisted pipe was carried out through the outlet pipe. In countercurrent to cold water, saturated water vapor was supplied through the inlet pipe from the steam pipe of the factory boiler room with a pressure of 3.2 atm and a temperature of 133.8 °C, which, passing the annulus through the outlet pipe, was discharged from the apparatus. To maintain constant water temperature in the equalization tank, heating elements and temperature regulators are installed. Water and steam consumption was measured using DKS 06-20 diaphragms equipped with SAPFIR 22D measuring instruments of model 2430 with an accuracy of ± 0.25 %, power supply, conversion, and root recovery units BPK-40M. The flow rate was supplied to an 8-channel signal control device from the SAPFIR 22D converter with a unified current output of 4 ... 20 mA– with an accuracy of ± 0.5 %.

To measure the water pressure at the inlet to the twisted pipe, the MIDA-DI-13P converter was used with a measurement limit of 0 ... 0.6 MPa and accuracy of ± 0.5 % with access to the multi-channel monitoring device UKT38-Shch4-AN. At the outlet, the pressure of water and steam was controlled by an exemplary pressure gauge model 1227 with an accuracy class of 0.25.

To measure water temperatures, nine Ferro constantan thermoelectric transducers KTZhK-0299-03 were used with tolerance class 1. Thermoelectric transducers were installed in drilled holes of a twisted pipe, then were soldered, and the free end was rigidly fixed in fittings welded to the walls of
the outer pipe. The temperature of the steam was measured in the center of the annular space by four thermoelectric converters KTZhK-0299-03 with tolerance class 1.

The temperature of water and steam from the heat exchanger was measured by KTZhK surface thermocouples of modification 02.18 with tolerance class 1.

Also, the water and steam temperatures at the outlet were additionally measured with an expansion thermometer of a mercury-type DST with a scale of up to 120 °C and a division value of 0.1 °C for water and a scale of up to 200 °C with a division temperature of 0.1 °C for steam.

Measurement of water temperature in the central part of the twisted pipe was carried out by a sliding junction made of a thermoelectric graduation cable KTZhK with a diameter of 1.5 mm inserted through the opening of the mechanical seal in the central part of the twisted pipe. Moving the sliding junction allows to scan the temperature parameters along the axis of the flowing part of the twisted pipe.

Upon reaching the stationary operating mode of the installation, which in the experiment was considered achieved after 3–4 times change in the volume of water and steam in the flow part of the channels, experimental studies were conducted with measurements of the temperature of water and steam.

It should be noted that the beginning of the subsequent experiment was carried out after the channel part of the channels of the previous experiment was completely cooled, which was established by the value of the water temperature in the tank, determined by the reading of the mercury thermometer.

At given water and steam flow rates, the water pressure at the inlet and outlet of the twisted pipe, as well as the temperature of the outer and inner walls of the heat exchange element, were measured. The inlet temperature was constant, equal to 16 °C.

3 Results and Discussion

As a result of computer and experimental studies, the values \( \varphi/\zeta_0 \) of hydraulic efficiency of thermal efficiency \( Nu/Nu_0 \), thermohydrodynamic efficiency \( \eta=(Nu/Nu_0)/(\varphi/\zeta_0) \) were obtained, where the index ‘0’ means the indicators corresponding to a smooth cylindrical heat exchange surface.

As it is known, the experimental results are generalized by criterion equations in which the equivalent diameter is defined by the formula \( d_{eqv} = \frac{4S}{P} \), or the equivalent formula \( d_{eqv} = \frac{4V}{F} \), where \( V \) is the volume of the tube space and \( F \) is the area moistened surface. However, for channels of complex geometry, calculation can be difficult. The authors [24] proposed an algorithm for determining the equivalent diameter of a twisted channel from a wire with a cross section in the form of an ovoid. So, for the given geometric dimensions of the installation (mm), setting \( R = 0.77, a = 11.73, R_j = 17.5 \), and substituting them in the equations treated in [26], we calculated the equivalent diameter of the tube space equal to \( d_t = 22.6 \) mm, the equivalent diameter of the annulus, equal to \( d_{eqv} = 9.77 \) mm.

The equivalent diameters of the pipe and annular spaces of the pipe-in-pipe heat exchanger calculated in [26] use in designing and calculating new heat-exchange equipment, that is, after substituting it into the criterion equations, we can determine the Reynolds number for the above geometric characteristics: \( Re_{eqv} = \frac{u d_{eqv} \rho}{\mu} = 0.06 * 9.77 * 10^2 / 0.601 * 10^6 = 0.975 * 10^4 \).

The numerical values obtained as a result of a real experiment at the installation of the authors confirm the computer results of theoretical modeling of the studied heat and hydrodynamic process in the proposed heat transfer channel, consisting of spring-coiled channels formed by winding an ovoid-shaped cross-section wire (Figure 3).

![Figure 3. Ovoid.](image-url)
Comparative analysis of the results is given. The change in hydrodynamic efficiency $\zeta/\zeta_0$ depending on the Reynolds numbers is shown (Figure 4).

![Figure 4](image)

**Figure 4.** The dependence of hydraulic efficiency $\zeta/\zeta_0$ on Reynolds numbers for pipes: a. from wire of ovoid section; b. smooth pipe.

Studies have shown that in the considered range of Reynolds numbers, an increase in the coefficient $\zeta$ compared to a smooth cylindrical pipe is increased by an average of 1.95 times. An analysis of the changes in thermohydrodynamic efficiency $\eta$ (Figure 5) depending on the Reynolds numbers showed that the growth rate of hydraulic resistance when using a heat exchange channel in the form of spring coiled pipes increased by 15-20 % compared to a smooth pipe.

![Figure 5](image)

**Figure 5.** The dependence of heat of hydrodynamic efficiency $\eta$ on Reynolds numbers for pipes: a. from wire of ovoid section; b. from round wire; c. smooth pipe.

4 Conclusions

The need to improve, modernize and reconstruct a part of the industrial power equipment used in several production areas in Russia is relevant today and is practically one of the ways to increase efficiency in the operation of power plants. Despite the variety of presented intensification methods, in particular, in this work, the authors proposed methods based on the modernization of the heat exchange surface, which provides increased heat transfer efficiency.

In this regard, the authors created a series of heat exchangers using efficient heat exchange elements formed in the form of spring-twisted pipes, the production of which is patented by the authors. The proposed surfaces make it possible to intensify heat transfer due to the occurrence of a swirling flow, an increase in the heat transfer surface and the resulting fins.

It is shown that the use of such pipes leads to an almost twofold improvement in hydrodynamic efficiency and an increase in thermohydrodynamic efficiency by 15-20 %.

We consider it appropriate to conduct further research in this direction, the creation of compact heat exchangers, since the intensification methods give positive results, in addition, the use of such heat exchange elements also leads to savings in metal consumption of the apparatus.
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