SIMULATION OF NEW DESIGN HEAT-EXCHANGE EQUIPMENT FOR MICROCLIMATE MAINTENANCE SYSTEMS IN POULTRY HOUSES

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Abstract. This article is a continuation of the improvement of the microclimate maintenance systems in poultry houses, and the goal is to develop and numerically simulate a new design heat exchanger as an element of the ventilation system. When developing new types of heat exchanger designs, an important role is played by factors, such as their weight and size characteristics, the efficiency of heat transfer through the surface, separating the heat carriers, the pressure losses in the pipes for each of the heat carriers, and other parameters, characterizing the heat exchanger. The paper considers a shell-and-tube heat exchanger with a shell of rectangular cross section with a transverse flow around the pipe bundles. The geometry of the arrangement of pipes with a diameter of d = 10 mm is peculiar, differing from the traditional chess-like, corridor, and compact bundles. The neighbouring pipes in such close bundles are displaced relative to each other by a distance of 1 mm. Besides, three types of a bundle design are considered, in which there is a displacement of the pipes in the transverse direction along the entire length of the pipe bundle by 10 mm, 12 mm and 15 mm. Since the entire row is offset by different distances, the number of the rows of the pipes changes. The number of pipes in one row, with a diameter of 10 mm, contains 102 pc, consisting of 2 collectors. Height of the pipes is 1 m. Computer mathematical modelling of the heat and mass transfer processes in the pipe bundles of different geometry with a compact arrangement of tubes was carried out, using the ANSYS Fluent software package. A mathematical model is based on the Navier-Stokes equation, the energy conservation equation for convective flows, and the continuity equation. The standard k-ε turbulence model was used in the calculations. The fields of velocities, temperatures, pressures in the studied channels are obtained. Conditions of the hydrodynamic flow in the channels are analysed, and the intensity of the heat transfer between the hot and the cold coolant through the wall, separating them, is estimated. More efficient heat exchange surfaces are determined and the prospects of using the proposed designs of the pipe bundles in the design of the heat exchangers for various purposes are shown.

Keywords: heat exchange equipment, numerical simulation, heat exchanger, pipe bundle, inter-tubular channels.

Introduction

In [1; 2], based on the theoretical and experimental studies, a new system for maintaining the microclimate in the poultry house was proposed and developed, using water from the underground wells and heat exchangers-recuperators for cooling and heating the supply air in the summer and winter periods of the year. The most common designs of heat exchangers, mainly used in the heat exchange equipment, are recuperative devices. By their design difference, recuperative heat exchangers are divided into shell-and-tube and plate heat exchangers. Each of these designs has its own advantages and disadvantages, depending on the operating conditions, hydrodynamic and temperature operating conditions. For energy-saving ventilation systems more efficient are the shell-and-tube type heat exchangers. When developing new types of designs of heat exchangers (HE), an important role is played by such factors as their weight and size characteristics, the efficiency of heat transfer through the surface separating heat carriers, the pressure losses in the pipes for each of the heat carriers, and other parameters characterizing the heat exchanger [3-6]. In addition to evaluating these factors, there is used, for example, such a parameter as thermal-hydraulic efficiency [7-9], which characterizes the thermal performance of the heat exchanger, related to the unit of power, required for pumping the coolant in the heat exchanger path. The paper considers shell-and-tube type heat exchangers, which have a new design that differs from traditional ones [10-16].

Materials and methods

Let us consider a shell-and-tube heat exchanger with a shell of rectangular cross section and with a transverse flow around pipe bundles. The geometry of the arrangement of pipes with a diameter of d = 10 mm is peculiar, differing from the traditional chess-like corridor and compact bundles. The neighbouring tubes in such close bundles are displaced relative to each other by a distance of 1 mm. In addition, there are considered three types of bundle design, in which there is a displacement of tubes in the transverse direction along the entire length of the pipe bundle by 10 mm, 12 mm and 15 mm (see Fig. 1). Since a shift of a whole row at different distances is applied, the number of rows of the pipes changes (see Table 1). The number of pipes in one row, with a diameter of 10 mm, contains 102 pc, consisting of 2 collectors. The height of the pipes is 1 m.

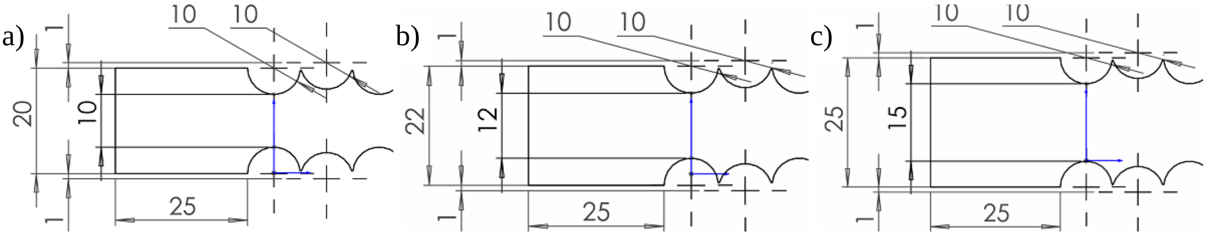


Fig. 1. **Location of the compact pipe bundle (top view):** a – pipe displacement by 10 mm; b – pipe displacement by 12 mm; c – pipe displacement by 15 mm

Table 1

Geometric parameters of heat exchangers of a new design

HE width, mm	Width of the annular passage, mm	Number of pipes in 1 collector, pc	Number of collectors, pc	Number of pipe rows, pc
2640	10	51	2	132
2640	12	51	2	120
2650	15	51	2	106

There has been carried out numerical simulation of the hydrodynamic processes and the heat transfer processes in channels with a compact arrangement of the pipe bundles. For this, the CFD modelling method and the ANSYS Fluent software package were used. The mathematical model is based on the Navier-Stokes equation, the energy conservation equation Sfor convective flows, and the continuity equation. The standard k-ε turbulence model was used in the calculations.

All the calculations were made at an air volume flow rate of 86392 $m^3 \cdot h^{-1}$. There was chosen as a heat carrier air with a temperature of +40 ºC at the inlet, flowing in the channels for cooling the outdoor heated air in the poultry house in the summer period of the year, where water from the underground wells is used as a coolant. In turn, cold water, moving inside the pipes, has an inlet temperature of +10 ºC. The scheme of the movement of the heat carriers has a cross character.

In the numerical calculation of the problems of hydrodynamics and heat and mass transfer, the finite element method (FEM) is used. The mesh was constructed in the ANSYS Meshing generator, based on the Workbench platform. When constructing a mesh for the heat exchanger of all designs, there was used local grid control. Building of a quadrangular mesh, using the construction of a boundary layer by the Total Thickness method, the thickness of the first layer is 5·10-5 m with the number of 6 layers (see Fig. 2).

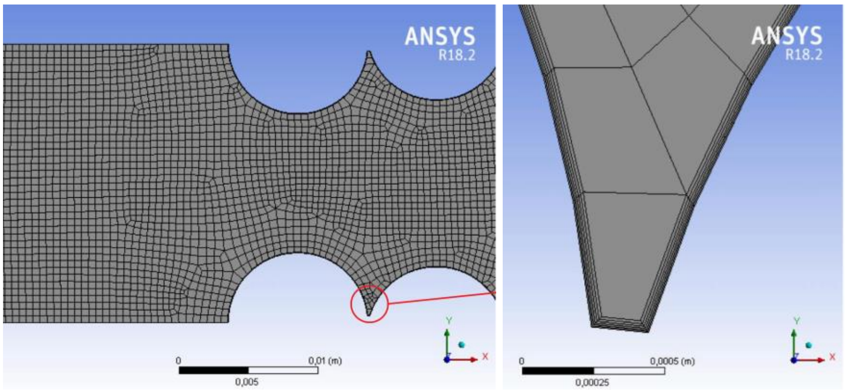


Fig. 2. **Building of a quadrangular FEM mesh with a boundary layer and a shell passage width of 10 mm**

The mesh quality index Orthogonal Quality [13-15] for all types of heat exchangers varied and ranged from 0.599 to 0.625. The minimum size of elements was $5 \cdot 10^{-4}$ m. The number of elements and nodes, and the mesh quality are presented in Table 2.

Table 2

Indicators of building of the FEM grid of heat exchangers of a new design

Width of the annular passage, mm	Number of elements, pc	Number of nodes, pc	Indicator of the mesh quality (Orthogonal Quality)
10	99043	102313	0.625
12	107601	110875	0.613
15	121934	125214	0.599

Results and discussion

The results of numerical calculations are presented in Figures 3-6. Fig. 3-5 show the change in various thermophysical parameters of a heat exchanger of various designs. The above shows TA with pipe displacements by 15 mm, in the middle by 12 mm and, respectively, from below by 10 mm. Fig. 3 shows the distribution of the temperature field in the channels of the heat exchanger. As evident from the figure, the temperature of the coolant drops as it approaches the exit from the heat exchanger. If at the inlet to the heat exchanger the temperature was +40 ºC, then at the output the average value for the three types of heat exchangers ranges from +23 to +27 ºC. In more detail the change in the thermophysical parameters of the heat carrier for different types of heat exchanger-recuperator designs is shown in Table 3.

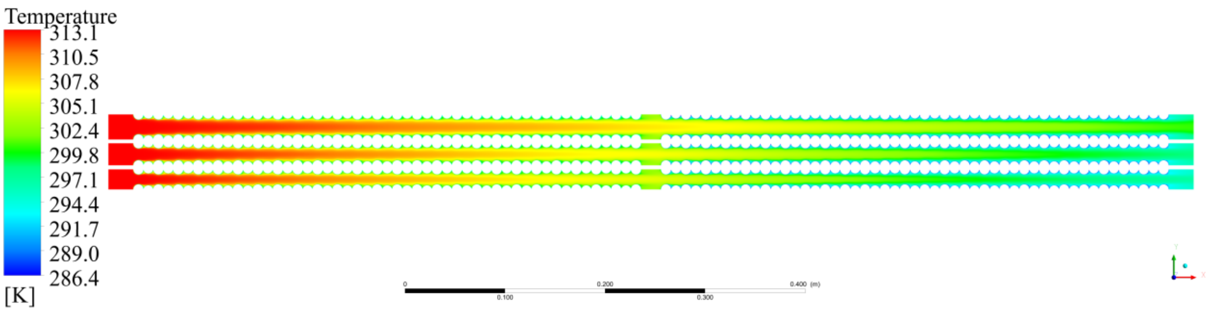


Fig. 3. **Temperature field of the coolant for different types of HE structures, ºK**

Fig. 4 shows the distribution of the pressure field in the studied channels of the heat exchanger structures. From the obtained pressure distribution, it follows that the total pressure drop is about 930 Pa for the design with the displacement of 10 mm. For the other two drops the pressure is somewhat less.

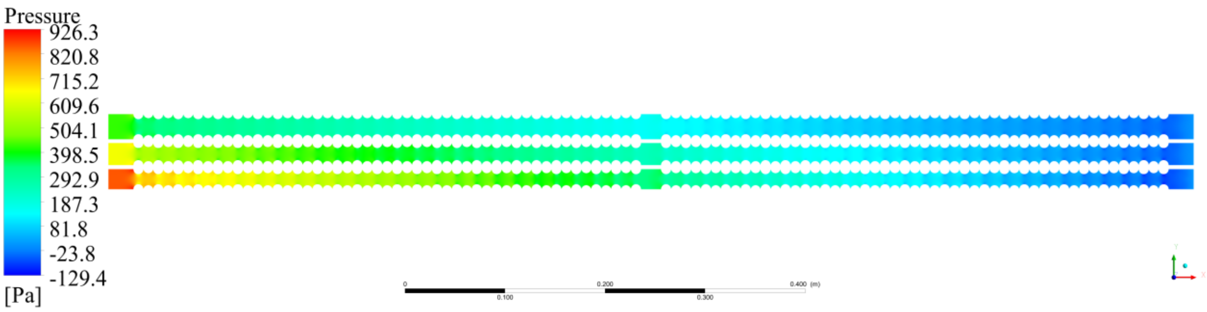
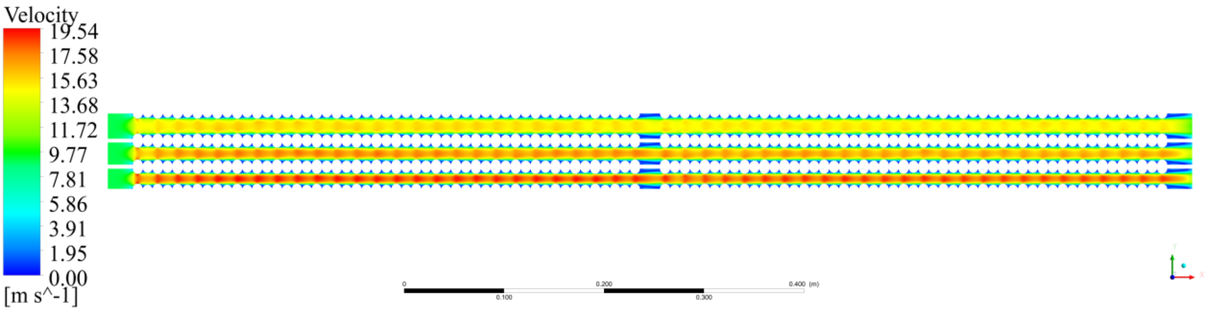


Fig. 4. **Coolant pressure drop for different types of HE structures, Pa**

Fig. 5 shows the velocity fields in the heat exchanger channels. An analysis of the acquired velocity field indicates that the highest flow rates are observed in narrower heat exchanger channels. At some points of the channel the air velocity reaches 19.5 $m \cdot s^{-1}$, and the average air velocity in the narrow cross section of the channel, with a displacement of 10 mm, is about 18 $m \cdot s^{-1}$. In sections of the channel, separating two sections of the pipe bundle, there are stagnant zones on the last tube of each bundle. In addition, such zones are observed in sections of the curved channel for individual elements of the pipe bundle.

Fig. 6 also shows the distribution of the velocity vectors in a single pipe bundle element. At the top point of the pipe the boundary layer is separated, and there are stagnant zones at the junction of neighbouring pipes. In these zones two separation vortices are observed in which the flow velocity is significantly lower than in the main flow. In addition, in Fig. 6a there are shown the velocity streamlines for the selected section of the channel.



Rice. 5. **Coolant velocity in HE channels for different types of structures, m·s^{-1}**

a) b)

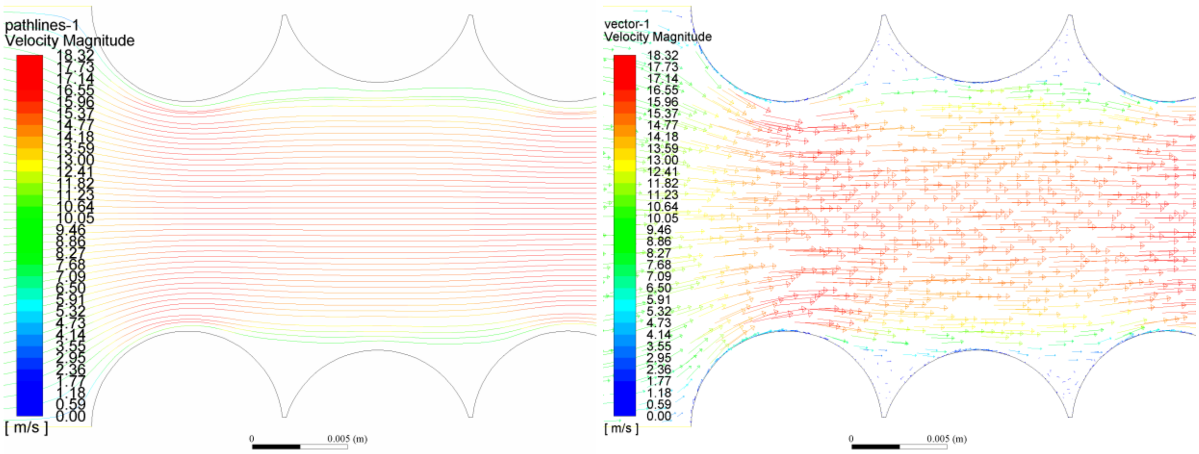


Fig. 6. **Coolant velocity in the HE channel at a displacement of 12 mm (m·s^{-1}):**
a – flow lines; b – velocity vector

Table 3

Geometrical and averaged thermophysical parameters of heat exchangers of new design

Width of annular passage, mm	Inlet pressure, Pa	Outlet pressure, Pa	Outlet air temperature, ºC	Outlet water temperature, ºC	Number of pipes in TA, pc
10	902	52	22.75	26.70	6732
12	685	53	23.90	25.03	6120
15	472	48	25.81	22.82	5406

When designing and manufacturing heat exchangers for the microclimate maintenance systems in poultry houses, it is necessary to take into account many parameters, namely, the pressure drop in the heat exchange channels, which affects the power and performance of the ventilation units; the initial temperature in TA that will enter the house, which is the own cooling of the internal air in the house, etc. Taking into account all aspects of the technical and economic analysis, it is proposed to choose TA with an offset of 12 mm. Computer simulation makes it possible to analyze the conditions of the hydrodynamic flow and the heat transfer in the studied channels. The pressure drop reaches 700 Pa, the initial temperature is up to +24 ºC, which fully complies with the technical design standards for the poultry houses. However, as in every system, there is a drawback, and these are the financial costs for the purchase and cutting of pipes, welding of TA. It can be seen from the data in Table 3 that 6120 m of pipe is needed to manufacture such HE. Such costs are justified by increasing the weight of the birds in the summer season and reducing the use of gas in the winter season.

Conclusions

1. A new design of a shell-and-tube heat exchanger with a compact arrangement of tubes in tube bundles has been proposed and developed.
2. Computer mathematical modeling of heat and mass transfer processes in tube bundles of different geometry with a compact arrangement of tubes was carried out using the ANSYS Fluent software package. The fields of velocities, temperatures, pressures in the studied channels are obtained. The conditions of the hydrodynamic flow in the channels are analyzed and the intensity of heat transfer between the hot and cold coolant through the wall separating them is estimated.
3. More efficient heat exchange surfaces are determined and the prospects of using the proposed designs of tube bundles in the design of heat exchangers for various purposes are shown.

Author contributions

All the authors have contributed equally to creation of this article.

All authors have read and agreed to the published version of the manuscript.

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