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Computational fluid dynamics investigation of heat-exchangers for various air-cooling systems in poultry houses

The increase in the productivity of poultry plants is connected with the necessity to create the optimal controlled environment in poultry houses. This problem is of prime importance due to the decrease of poultry plant productivity caused by the imperfection of the existing controlled environment systems. The paper presents the improved environment control system in a poultry house. The processes of heat- and mass-exchange in the developed heat-exchangers for various ventilation systems have been investigated. Computational Fluid Dynamics analysis of the heat-exchangers of two various designs for tunnel and side ventilation systems has been carried out. The fields of velocities, temperatures and pressures in the channels under study have been obtained. The conditions of a hydrodynamic flow in the channels have been analyzed. The intensity of heat-transfer between a hot heat carrier and a cold one through their separating wall has been estimated. The most efficient heat-exchanging apparatus has been determined and the application potential of such a design has been substantiated. The aim of the research is the development and numerical modelling of a shell-and-tube heat-exchanger of a new design as an element of environment control system used in various types of ventilations systems in summer seasons.

Keywords: Heat-exchanger, Computational Fluid Dynamics, poultry house, tunnel ventilation system, side ventilation system.

Introduction

The increase in the productivity of poultry plants is connected with the necessity to create the optimal controlled environment in poultry houses. Here, an important task is the development of new approaches and principles of solving the problem of incoming-air cooling and heating in poultry houses during summer and winter periods. This problem is of prime importance due to the decrease of poultry plant productivity caused by the imperfection of the existing controlled environment systems in summer seasons under high temperatures and moisture of the outside air. It is worth mentioning that the existing power supply systems in poultry houses require heavy energy expenditures and costs for providing a controlled environment in poultry buildings. Thus, the necessary prerequisite to resource conservation in this branch is conducting new investigations on the improvement of controlled environment systems at poultry plants.

Papers [1, 2] present Computational Fluid Dynamics (CFD) modelling of the flows of air and heat-mass exchange in the poultry buildings equipped with a side ventilation system. The authors of [1, 2] suggest that the method of side mechanical ventilation is more effective compared to other methods and is able to decrease heat stress and increase poultry operation productivity in summer seasons. As a result of the mathematical modelling conducted in [1, 2], the distributions of air flow velocities, pressures and temperatures in poultry houses with side ventilation systems have been obtained. The results of the conducted mathematical modelling have been compared to the experimental research data and the difference does not exceed 12 %. According to the calculations presented by the authors of the research [1, 2], it has been concluded that insufficient air velocity as well as the absence of a cooling system increases poultry heat stress resulting in the decrease of beeding productivity. This is promoted by non-uniform air flow in the area of bird location and dead-air zones, that make the conditions for poultry thermoregulation worse.

The paper [3] presents the CFD solution of miscellaneously improved cases for the various flow and shape configurations of the broiler house. Effects of the transversal and longitudinal ventilation are combined with the changes of inlet air streams directions and also with the different cross-section shaping obtained using curtains.

The paper [4, 5] considers the system of outside air cooling by means of a heat-exchanger of a specific design [6, 7], which uses subterranean well water as a cooling medium. Mathematical modelling of heat- and mass-exchange processes in the course of air ventilation in the poultry buildings, where the arrangement of ventilation equipment is high adjusted, has been conducted. As a result of the numerical modelling, the fields of velocities, temperatures and pressures in a poultry house have been determined.

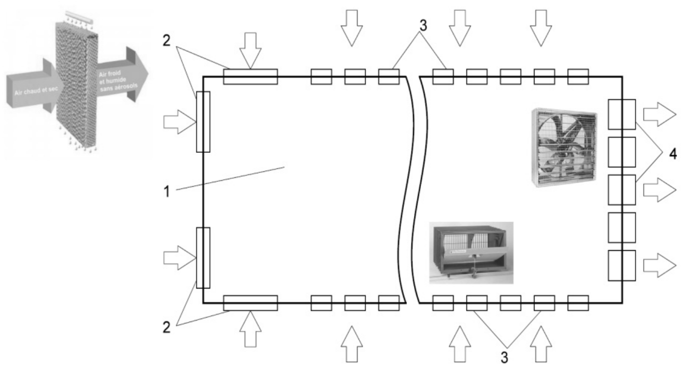
In the course of developing new types of heat-exchanger designs, such factors as their small-size characteristics, the efficiency of heat transfer through the surface that separates heat carriers, pressure loss in the circuits of every heat carrier and other parameters that characterize heat exchange units are of great importance [8]. Another important analysis tool for determining the efficiency of the developed heat exchanger design is a detailed mathematical modelling of mass and energy transfer processes in a heat exchanger [9–17]. Such modelling allows for analyzing local hydraulic and thermal characteristics on heat exchange surfaces, determining their thermal efficiency and estimating hydraulic losses that determine the capacity of the pumps used for bleeding heat carriers.

The most wide-spread designs of heat-exchangers, which are mainly used in heat-exchange equipment, are recuperative heat-exchangers. As a rule, shell-and-tube heat-exchangers have staggered or in-line arrangement of tube banks and their conditions of hydrodynamic flow and heat transfer have been investigated in details in a number of scientific papers [18–21]. However, hydrodynamics and hear transfer in the case of small-diameter tube banks have been under-investigated. It is worth mentioning that the use of such heat exchange surfaces in shell-and-tube heat-exchangers allows for improving their physical and cost performance compared to the known designs.

The aim of the research is the development and numerical modelling of a shell-and-tube heat-exchanger of a new design as an element of environment control system used in various types of ventilations systems in summer seasons.

Material and method

Two types of ventilation systems were considered, namely, a tunnel one and a side one. Heat-exchangers aimed at cooling the incoming air in a summer season were designed for those ventilation systems. A poultry house was of a traditional type for 50000 birds used for breeding floor meat birds. There were automatic blinds arranged in the side walls with the total of 80 pieces 0.3×0.85 m in size (Fig. 1). In addition, on the front end walls, there were wetted pads 5.3×1.1 m is size arranged. When considering those two separate systems, heat-exchangers were mounted instead of wetted pads and automatic blinds.



1 — poultry building; *2* — wetted pads; *3* — ventilating blinds; *4* — exhaust blowers

Figure1. Layout of an evaporating cooling system and side ventilating blinds in a poultry house

Let us consider a heat-exchanger with a rectangular-section shell under transverse tube bank flow. There is a distinctive arrangement geometry of tubes d = 10 mm in diameter (Fig. 2). It is different from traditional staggered and in-line tube banks. The heat-exchangers, which contain transverse tube bank flow, are made of tube rows, where the adjacent tubes of every row are tangent to each other and the tubes of every row are arranged with a sequential displacement about the row axis, here, the adjacent tubes are displaced by 1 mm apart from each other [22]. In both types of heat-exchangers (HE), the width between the tubes is equal to 15 mm, the number of tubes in depth in one header is equal to 51 pcs.

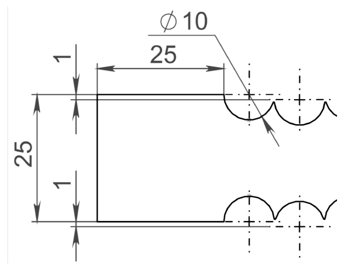


Figure 2. Arrangement of tubes in a matrix, (view from above)

All the calculations were performed under the air-flow rate of 1036 thousand m^3/h. The air being +40 ºC at the entry, which flows through the outside hot-air cooling channels in a poultry house in summer seasons, was chosen to be a heat carrier. On the exit from a heat-exchanger, the air temperature decreased to nearly +20 ºC. Subterranean well water [4–5] was used as a coolant. In its turn, the temperature of the cold water, which moved inside the tubes, was equal to +10 ºC at the entry.

The system of heat carrier movement is of cross pattern. In order to obtain sufficient cooling of the incoming air from +40 to +20 ºC, heat-exchangers were designed by the entry size of blinds and wetted pads. Due to the requirement of such a substantial air exchange (1036 thousand m^3/h) and heat transfer between heat carriers, the number of headers in heat-exchanging units is different.

Table 1 presents the design data of both heat exchangers for various ventilation systems.

Table 1

Design data of heat-exchangers for various ventilation systems

Ventilation system	Air consumption for all HEs, m^3/h	Water consumption for all HEs, m^3/h	Air consumption for one HE, m^3/h	Height of HE, m	Width of HE, m	Number of headers, pcs	Number of tubes in one HE, pcs	Number of HE, pcs	Total length of tubes, m
Side	1036880	382.4	12961	0.3	0.85	3	5202	80	124848
Tunnel	1036704	372.0	86392	1.0	2.65	2	5406	12	64872

CFD modelling of hydrodynamic processes and heat transfer processes in the channels with close-together arrangement of tube banks was conducted. For this purpose, ANSYS Fluent software package was used. The mathematical model is based on Navier-Stokes equation [23], energy-conservation equation applied for convective currents and the equation of continuity. The standard k-ε turbulence model was used in the calculations [24].

Navier-Stokes equation:

$$\left.\begin{aligned}\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)\\ \rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)\end{aligned}\right\},$$

where ρ — medium density, kg/m^3; μ — medium dynamic viscosity, Pa·s; p — pressure, Pa; u, v — velocity field of vectors; t — time, s.

A continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0.$$

An energy-conservation equation:

$$\rho C_p\left(V_x\frac{\partial T}{\partial x}+V_z\frac{\partial T}{\partial y}\right)=\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right).$$

where T — point temperature, K; λ — coefficient of medium heat transfer capacity, W/m·K; C_p — specific heat capacity of a medium, J/kg·K.

Boundary Conditions

The boundary conditions are given in the following form (see Fig. 1).

At the inlet to the channel:

$$x=0;\ W=W_0;\ T=T_0\,.$$

At the outlet from the channel:

$$x=H;\ \partial W/\partial x=0\,.$$

On the walls of the tubes:

$$T(x=x_{tube\,inside})(y=y_{tube\,inside})=T_{wall\,0}\,.$$

On the walls of the casing:

$$\left|\frac{\partial T_{tube\ shall.}}{\partial y}\right|_{y=0}=0\,.$$

Conditions for sticking the liquid on the tubes walls:

$$x=x_{tube\ ext.};\ y=y_{tube\ ext.}\,.$$

Conditions for sticking on the walls of the casing:

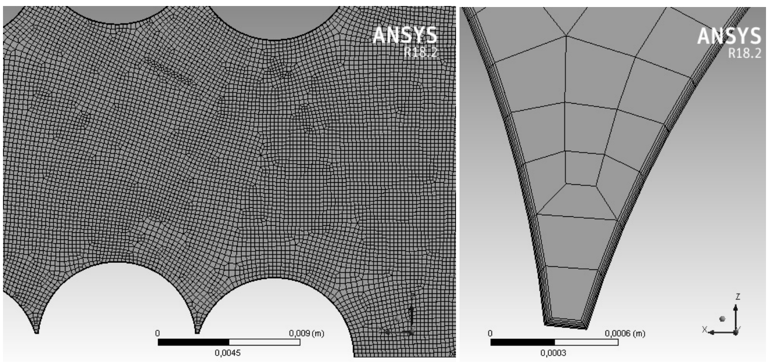
$$y=H;\ W=0;\ y=0.$$

For a standard k–ε model, the equation of turbulence has the following form:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k\,;$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k+C_{3\varepsilon}G_b\right)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon\,,$$

where G_k — the generation of turbulence kinetic energy due to the mean velocity gradients; G_b — the generation of turbulence kinetic energy due to buoyancy; Y_M — the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate; $C_{1\varepsilon}$, $C_{2\varepsilon}$, and $C_{3\varepsilon}$ — constants; σ_k and σ_ε — the turbulent Prandtl numbers for k and ε, respectively; S_k and S_ε — user-defined source terms.



a — complete channel; *b* — boundary layer

Figure 3. Grid generated in ANSYS Meshing

Grid generation was performed in ANSYS Meshing generator based on Workbench framework. In the course of grid generation for a heat-exchanger of all the designs, local grid control was applied. The minimum bound size was $2.5\cdot10^{-4}$ m. The generation of a quadrilateral grid was conducted with the use of boundary layer construction with total thickness approach (Total Thickness). The thickness of the first layer was $5\cdot10^{-5}$ m, the number of layers was 6 (Fig. 3). Grid quality index, that is Orthogonal Quality, for both types of heat-exchangers is within the limits from 0.561 to 0.564.

Numerical Results and Discussion

The results of the conducted numerical calculations are presented in Figures 2–6. The incoming hot air enters a heat-exchanger on the right side. Figures 2, 3 show the change in temperatures for various ventilation systems. In the case of a tunnel ventilation, the temperature in a heat-exchanger decreases from +40 to +22.5 ºC (Fig. 4), and in the case of a side one, it decreases from +40 to +19.7 ºC (Fig. 5).

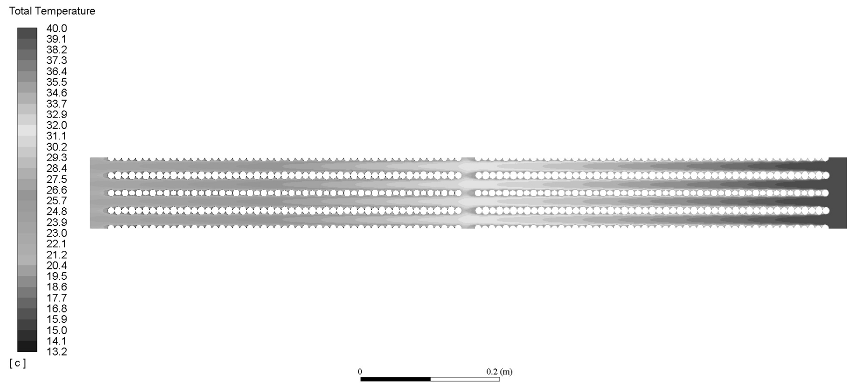


Figure 4. Air temperature field in a heat exchanger for a tunnel ventilation system, ^{o}C

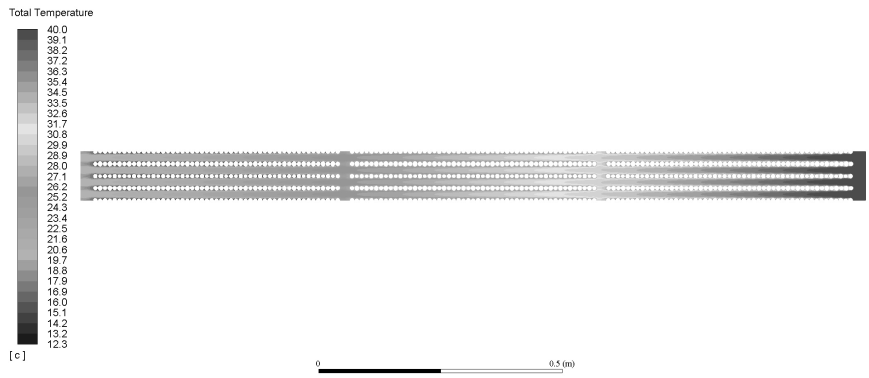


Figure 5. Air temperature field in a heat exchanger for a side ventilation system, ^{o}C

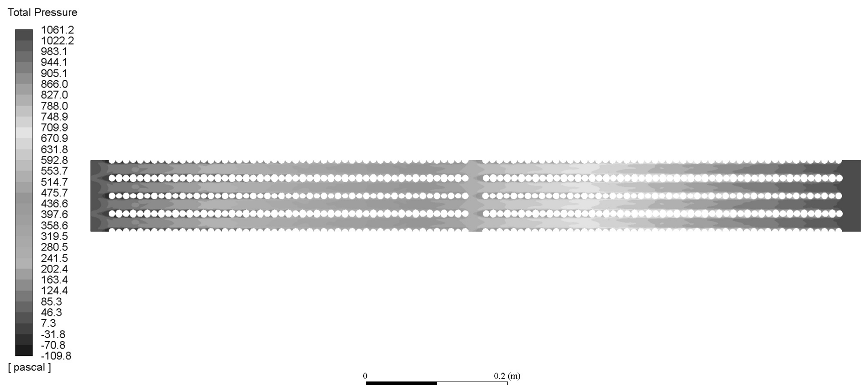


Figure 6. Pressure drop across a HE channel for a tunnel ventilation system, Pa

When comparing heat-exchangers by pressure drop across a channel (see Fig. 6, 7), which were designed for various system types, it is obvious that they differ in about 3.3 times. More detailed results can be seen in Table 2.

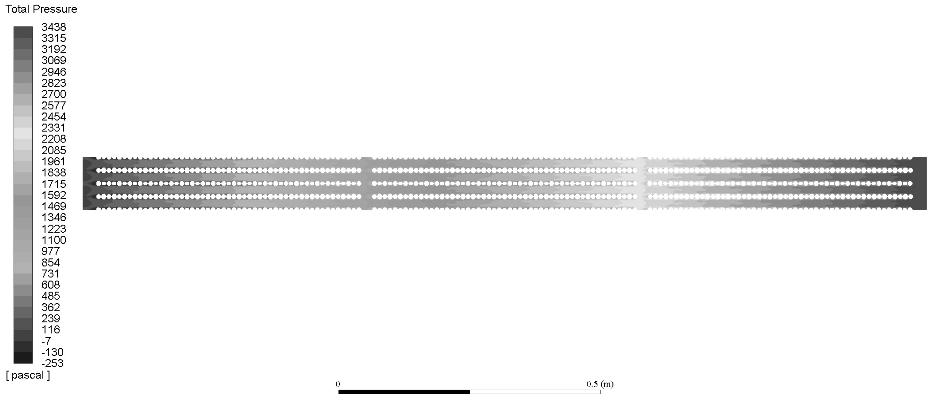
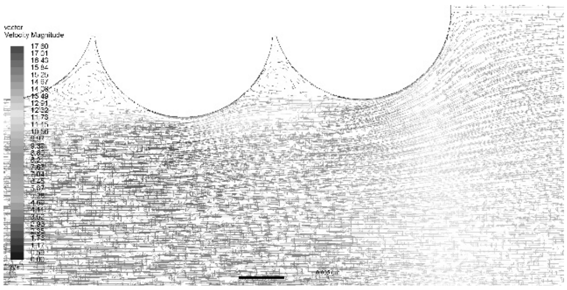
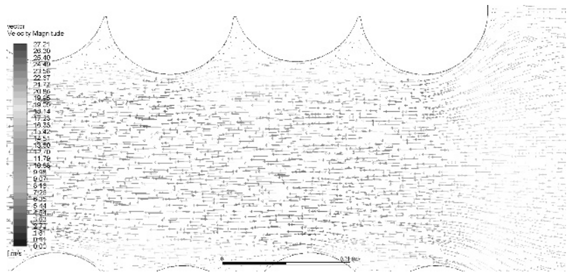


Figure 7. Pressure drop across a HE channel for a side ventilation system, Pa

Figure 8 presents a velocity vector at the entry to a HE channel for various ventilation systems. The process of air flowing about the tubes and boundary layer separation from its surface are shown. There are dead-air spaces in the form of a vortex observed between the tubes, thus the heat transfer coefficient in these spaces is decreased. In the case of a tunnel ventilation system (Fig. 8*a*, Fig. 9) the maximum air velocity at certain points is equal to 17.6 m/s and the average velocity in the narrowest channel passage is 15.1 m/s. In the case of a side ventilation system (Fig. 8*b*, Fig. 10) the maximum velocity is 27.2 m/s and the average one is equal to 23.5 m/s. Table 2 presents a more detailed review of the results of numerical modelling for various ventilation systems.



a— for a tunnel ventilation system



b— for a side ventilation system

Figure 8. Air flow velocity vector on entering HE, m/s

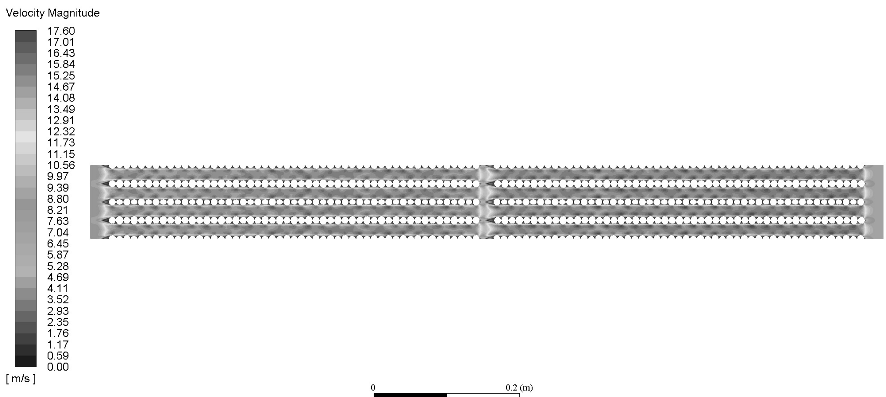


Figure 9. Air velocity in a channel for a tunnel ventilation system, m/s

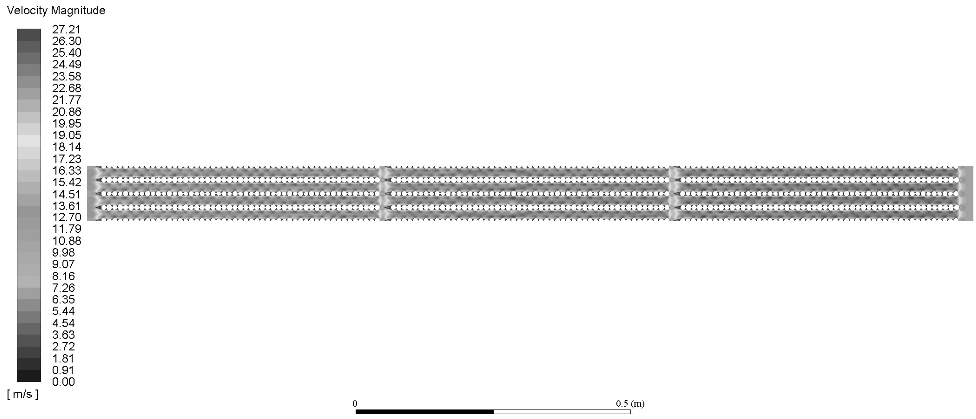


Figure 10. Air velocity in a channel for a side ventilation system, m/s

Table 2

Results of numerical modelling of various ventilation systems

Ventilation system	Air temperature on exit from HE, °C	Water temperature on exit from HE, °C	Pressure drop in a HE channel, Pa	Maximum air velocity in a HE channel, m/s	Average air velocity in the narrowest section of a HE channel, m/s	Heat power of one HE, kW	Heat power of all HEs, kW
Side	19.66	23.95	3286	27.21	23.53	77.550	6204.00
Tunnel	22.55	23.16	991	17.60	15.10	474.72	5696.64

In the course of designing and manufacturing a heat-exchanger for an environment control system in poultry houses, it is necessary to take into account numerous parameters. They include pressure drop in heat-exchanger channels that influences the capacity and the productivity of ventilation systems; the temperature on the exit from a HE, which enters a poultry house and cools down the inside air in the building and other. The project has been based on the development of a HE for two ventilation systems. In the case of a tunnel ventilation system, pressure drop is equal to 991 Pa, which is 3.3 times less compared to a side ventilation system. The exit temperature is equal to +23 ºC, which meets the requirements for project engineering. However, the disadvantage is financial costs for purchasing, tube cutting and HE welding. According to Table 1, in order to make a HE for a tunnel ventilation system, it is necessary to use 64872 m of tubes, which is in 1.92 less compared to the second option. Both a tunnel and a side ventilation system are effective enough. In order to provide normalized environment conditions in a poultry house, taking into account all the aspects of technical and economic analysis, it is offered to choose a HE for a tunnel ventilation system. Such expenditures are justified due to the increase of bird mass in summer periods. However, not all the poultry plants can afford to install such a system.

Conclusions

1. A new design of a shell-and-tube heat exchanger with close-together tube arrangement in tube banks has been suggested and developed.

2. CFD modelling of the processes of heat- and mass-exchange in tube banks of various geometry under close-together tube arrangement has been conducted with the help of ANSYS Fluent software package. The fields of velocities, temperatures and pressures in the channels under study have been obtained. The conditions of the hydrodynamic flow in the channels have been analyzed and the intensity of heat transfer between a hot and a cold heat carrier through a separating wall has been estimated.

3. The most efficient and the most cost-effective HE has been determined to be for a tunnel ventilation system due to the decrease of the number of tubes in 1.92 times and the decrease in pressure drop in 3.3 times.

References

1 Blanes-Vidal V. Application of computational fluid dynamics to the prediction of airflow in a mechanically ventilated commercial poultry building. / V. Blanes-Vidal, E. Guijarro, S. Balasch, A.G. Torres. // Biosystems Engineering. — 2008. — Vol. 100, No. 1. — P. 105–116.

2 Bustamante E. Measurement and numerical simulation of single-sided mechanical ventilation in broiler houses / E. Bustamante, S. Calvet, F. Estelles, A.G. Torres, A. Hospitaler // Biosystems Engineering. — 2017. — Vol. 160. — P. 55–68.

3 Zajicek M. Improvement of the broiler house ventilation using the CFD simulation. / M. Zajicek, P. Kic. // Agronomy Research. — 2012. — Vol. 10, Special Issue 1. — P. 235–242.

4 Gorobets V.G. The numerical simulation of heat and mass transfer processes in tunneling air ventilation system in poultry houses / V.G. Gorobets, V.I. Trokhaniak, I.O. Antypov, Yu.O. Bohdan // INMATEH: Agricultural Engineering. — 2018. — Vol. 55, No. 2. — P. 87–96.

5 Gorobets V.G. The numerical simulation of hydrodynamics and mass transfer processes for ventilating system effective location / V.G. Gorobets, V.I. Trokhaniak, I.L. Rogovskii, L.L. Titova, T.I. Lendiel, A.O. Dudnyk, M.Y. Masiuk // INMATEH: Agricultural Engineering. — 2018. — Vol. 56, No. 3. — P. 185–192.

6 Gorobets V. Investigations of heat transfer and hydrodynamics in heat exchangers with compact arrangements of tubes / V.G. Gorobets, Yu. O. Bohdan, V.I. Trokhaniak, I.O. Antypov // Applied Thermal Engineering. — 2019. — Vol. 151. — P. 46–54.

7 Gorobets V.G. Experimental studies and numerical modelling of heat and mass transfer process in shell-and-tube heat exchangers with compact arrangements of tube bundles / V.G. Gorobets, Yu.O. Bohdan, V.I. Trokhaniak, I.O. Antypov // MATEC Web of Conferences. — 2018. — Vol. 240, 02006.

8 Жукаускас А.А. Конвективный перенос в теплообменниках / А.А. Жукаускас. — М.: Наука, 1982. — 472 с.

9 Ambekar A.S. CFD simulation study of shell and tube heat exchangers with different baffle segment configurations / A.S. Ambekar, R. Sivakumar, N. Anantharaman, M. Vivekenandan // Applied Thermal Engineering. — 2016. — Vol. 108. — P. 999–1007.

10 Bayram H. Numerical Investigation of the Effect of Variable Baffle Spacing on the Thermal Performance of a Shell and Tube Heat Exchanger / H. Bayram, G. Sevilgen // Energies. — 2017. — Vol. 10, No. 8. — P. 19.

11 El Maakoul A. Numerical comparison of shell-side performance for shell and tube heat exchangers with trefoil-hole, helical and segmental baffles / A. El Maakoul, A. Laknizi, S. Saadeddine, M. El Metoui, A. Zaite, M. Meziane, A. Ben Abdellah // Applied Thermal Engineering. — 2016. — Vol. 109. — P. 175–185.

12 Kim G.W. Numerical studies of heat transfer enhancement by cross-cut flow control in wavy fin heat exchangers / G.W. Kim, H.M. Lim, G.H. Rhee // International Journal of Heat and Mass Transfer. — 2016. — Vol. 96. — P. 110–117.

13 Leoni G.B. Assessment with computational fluid dynamics of the effects of baffle clearances on the shell side flow in a shell and tube heat exchanger / G.B. Leoni, T.S. Klein, R.D. Medronho // Applied Thermal Engineering. — 2017. — Vol. 112. — P. 497–506.

14 Ling Z.Y. Experimental and Numerical Investigation on Non-Newtonian Nanofluids Flowing in Shell Side of Helical Baffled Heat Exchanger Combined with Elliptic Tubes / Z.Y. Ling, Z.B. He, T. Xu, X.M. Fang, X. N Gao., Z.G. Zhang // Applied Sciences-Basel. — 2017. — Vol. 7, No. 1. — P. 17.

15 Mellal M. Hydro-thermal shell-side performance evaluation of a shell and tube heat exchanger under different baffle arrangement and orientation / M. Mellal, R. Benzeguir, D. Sahel, H. Ameur // International Journal of Thermal Sciences. — 2017. — Vol. 121. — P. 138–149.

16 Pal E. CFD simulations of shell-side flow in a shell-and-tube type heat exchanger with and without baffles / E. Pal, I. Kumar, J.B. Joshi, N.K. Maheshwari // Chemical Engineering Science. — 2016. — Vol. 143. — P. 314–340.

17 Shahril S.M. Thermo hydraulic performance analysis of a shell-and-double concentric tube heat exchanger using CFD / S.M. Shahril, G.A. Quadir, N.A.M. Amin, I.A. Badruddin // International Journal of Heat and Mass Transfer. — 2017. — Vol. 105. — P. 781–798.

18 Cabezas-Gomez L. Analysis of a new cross flow heat exchanger flow arrangement — Extension to several rows / L. Cabezas-Gomez, H.A. Navarro, J.M. Saiz-Jabardo, S.D. Hanriot, C.B. Maia // International Journal of Thermal Sciences. — 2012. — Vol. 55. — P. 122–132.

19 Draganov B. Kh. Exergoeconomic optimization of surface heat exchangers / B.Kh. Draganov, A.A. Khalatov // Thermal Engineering. — 2010. — Vol. 57, No. 10. — P. 888–891.

20 Thakre P.B. Performance Analysis on Compact Heat Exchanger / P.B. Thakre, P.R. Pachghare // Materials Today-Proceedings. — 2017. — Vol. 4, No. 8. — P. 8447–8453.

21 Cabezas-Gomez L. New thermal effectiveness data and formulae for some cross-flow arrangements of practical interest / L. Cabezas-Gomez, J.M. Saiz-Jabardo, H.A. Navarro, P. E.L. Barbieri // International Journal of Heat and Mass Transfer. — 2014. — Vol. 69. — P. 237–246.

22 Gorobets V.G. Heat exchanger / V.G. Gorobets, V.I. Trokhaniak, Yu.O. Bohdan // UA Patent No. 111751. — 2016.

23 Khmelnik S.I. Navier-Stokes equations. On the existence and the search method for global solutions. Mathematics in Computers / S.I. Khmelnik // MiC, Bene-Ayish, Israel. — 2016.

24 ANSYS FLUENT Theory Guide (Release 18). (2017). Canonsburg, Inc. Southpointe 275 Technology Drive.

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Құс асырайтын орындағы ауаны салқындатудың әртүрлі жүйелері үшін есептеу гидродинамикасына негізделген жылуалмастырғыш аппараттарын зерттеу

Құс фабрикаларының өнімділігін арттыру оларды асырау орнында оңтайлы микроклимат құру қажеттілігімен байланысты. Бұл мәселе құс фабрикаларының өнімділігінің төмендеуімен, қолданыстағы микроклимат жүйелерінің жетілмегендігімен байланысты. Мақалада ғимараттағы микроклиматты сақтаудың жетілдірілген жүйесі ұсынылған. Әртүрлі желдету жүйелеріне арналған жылу алмастырғыштардағы жылу және масса алмасу процестері зерттелген. Бүйірлік және туннельді желдету жүйелеріне арналған екі түрлі конструкциялардың жылу алмастырғыштарының есептеу гидродинамикасы жүргізілген. Зерттелген каналдардан жылдамдықтың, температураның және қысым өрістері алынған. Арналардағы гидродинамикалық ағындардың жағдайлары талданған. Оларды қабырға арқылы бөліп тұрған ыстық және салқын салқындатқыш арасындағы жылу берудің қарқындылығы бағаланған. Неғұрлым тиімді жылу алмастырғыш орнату және ұсынылған дизайнды қолдану перспективалары көрсетілген. Зерттеудің мақсаты — жазғы маусымда әртүрлі желдету жүйелеріне арналған микроклиматты қолдау жүйесінің элементі ретінде жаңа дизайндағы қабық-құбырлы жылу алмастырғышты дамыту және сандық модельдеу.

Кілт сөздер: жылу алмастырғыш, сұйықтықтың есептік динамикасы, құс үйі, туннельді желдету жүйесі, бүйірлік желдету жүйесі.

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Исследование теплообменных аппаратов на основе вычислительной гидродинамики для различных систем охлаждения воздуха в птичниках

Повышение производительности птицефабрик связано с необходимостью создания оптимального микроклимата в помещениях птичников. Эта проблема особенно важна в связи со снижением производительности работы птицеферм, что обусловлено несовершенством существующих систем микроклимата. В статье представлена усовершенствованная система поддержания микроклимата в птичнике. Исследованы тепло-массообменные процессы в разработанных теплообменных аппаратах для различных систем вентиляции. Проведена вычислительная гидродинамика теплообменников двух различных конструкций для боковой и туннельной системы вентиляции. Получены поля скоростей, температур, давлений в исследуемых каналах. Проанализированы условия гидродинамических течений в каналах. Проведена оценка интенсивности теплопереноса между горячим и холодным теплоносителями через стенку, разделяющую их. Установлен более эффективный теплообменный аппарат, и показана перспективность применения предложенной конструкции. Целью исследования являются разработка и численное моделирование кожухотрубного теплообменника новой конструкции как элемента системы поддержания микроклимата для различных типов систем вентиляции в летний период года.

Ключевые слова: теплообменный аппарат, вычислительная гидродинамика, птичник, туннельная система вентиляции, боковая система вентиляции.

References

1 Blanes-Vidal, V., Guijarro, E., Balasch, S. & Torres, A.G. (2008). Application of computational fluid dynamics to the prediction of airflow in a mechanically ventilated commercial poultry building. *Biosystems Engineering, 100, 1,* 105–116.

2 Bustamante, E., Calvet, S., Estelles, F., Torres, A.G. & Hospitaler, A. (2017). Measurement and numerical simulation of single-sided mechanical ventilation in broiler houses. *Biosystems Engineering, 160,* 55–68.

3 Zajicek, M. & Kic, P. (2012). Improvement of the broiler house ventilation using the CFD simulation. *Agronomy Research, 10, Special Issue 1,* 235–242.

4 Gorobets, V.G., Trokhaniak, V.I., Antypov, I.O. & Bohdan, Yu.O. (2018). The numerical simulation of heat and mass transfer processes in tunneling air ventilation system in poultry houses. *INMATEH: Agricultural Engineering, 55, 2,* 87–96.

5 Gorobets, V.G., Trokhaniak, V.I., Rogovskii, I.L., Titova, L.L., Lendiel, T.I., & Dudnyk, A.O., et al. (2018). The numerical simulation of hydrodynamics and mass transfer processes for ventilating system effective location. *INMATEH: Agricultural Engineering, 56, 3,* 185–192.

6 Gorobets, V., Bohdan, Y., Trokhaniak, V. & Antypov, I. (2019). Investigations of heat transfer and hydrodynamics in heat exchangers with compact arrangements of tubes. *Applied Thermal Engineering, 151,* 46–54, DOI: 10.1016/j.applthermaleng.2019.01.059.

7 Gorobets, V.G., Bohdan, Yu.O., Trokhaniak, V.I. & Antypov, I.O. (2018). Experimental studies and numerical modelling of heat and mass transfer process in shell-and-tube heat exchangers with compact arrangements of tube bundles. *MATEC Web of Conferences*, *240, 02006*, DOI: 10.1051/matecconf/201824002006.

8 Zhukauskas, A.A. (1982). *Konvektivnyi perenos v teploobmennikakh [Convective heat transfer in heat exchangers]*. Moscow: Nauka [in Russian].

9 Ambekar, A.S., Sivakumar, R., Anantharaman, N. & Vivekenandan, M. (2016). CFD simulation study of shell and tube heat exchangers with different baffle segment configurations. *Applied Thermal Engineering, 108,* 999–1007, DOI: 10.1016/j.applthermaleng.2016.08.013.

10 Bayram, H., Sevilgen, G. (2017). Numerical Investigation of the Effect of Variable Baffle Spacing on the Thermal Performance of a Shell and Tube Heat Exchanger. *Energies, 10, 8,* 19, DOI: 10.3390/en10081156.

11 El Maakoul, A., Laknizi, A., Saadeddine, S., El Metoui, M., Zaite, A., Meziane, M. et al. (2016). Numerical comparison of shell-side performance for shell and tube heat exchangers with trefoil-hole, helical and segmental baffles. *Applied Thermal Engineering, 109*, 175–185, DOI: 10.1016/j.applthermaleng.2016.08.067.

12 Kim, G.W., Lim, H.M. & Rhee, G.H. (2016). Numerical studies of heat transfer enhancement by cross-cut flow control in wavy fin heat exchangers. *International Journal of Heat and Mass Transfer, 96,* 110–117, DOI: 10.1016/j.ijheatmasstransfer.2016.01.023.

13 Leoni, G.B., Klein, T.S. & Medronho, R.D. (2017). Assessment with computational fluid dynamics of the effects of baffle clearances on the shell side flow in a shell and tube heat exchanger. *Applied Thermal Engineering, 112*, 497–506, DOI: 10.1016/j.applthermaleng.2016.10.097.

14 Ling, Z.Y., He, Z.B., Xu, T., Fang, X.M., Gao, X.N. & Zhang, Z.G. (2017). Experimental and Numerical Investigation on Non-Newtonian Nanofluids Flowing in Shell Side of Helical Baffled Heat Exchanger Combined with Elliptic Tubes. *Applied Sciences-Basel, 7, 1,* 17, DOI: 10.3390/app7010048.

15 Mellal, M., Benzeguir, R., Sahel, D. & Ameur, H. (2017). Hydro-thermal shell-side performance evaluation of a shell and tube heat exchanger under different baffle arrangement and orientation. *International Journal of Thermal Sciences, 121,* 138–149, DOI: 10.1016/j.ijthermalsci.2017.07.011.

16 Pal, E., Kumar, I., Joshi, J.B. & Maheshwari, N.K. (2016). CFD simulations of shell-side flow in a shell-and-tube type heat exchanger with and without baffles. *Chemical Engineering Science, 143,* 314–340, DOI: 10.1016/j.ces.2016.01.011.

17 Shahril, S.M., Quadir, G.A., Amin, N.A.M. & Badruddin, I.A. (2017). Thermo hydraulic performance analysis of a shell-and-double concentric tube heat exchanger using CFD. *International Journal of Heat and Mass Transfer, 105,* 781–798, DOI: 10.1016/j.ijheatmasstransfer.2016.10.021.

18 Cabezas-Gomez, L., Navarro, H.A., Saiz-Jabardo, J.M., Hanriot, S.D. & Maia, C.B. (2012). Analysis of a new cross flow heat exchanger flow arrangement — Extension to several rows. *International Journal of Thermal Sciences, 55,* 122–132, DOI: 10.1016/j.ijthermalsci.2012.01.001.

19 Draganov, B.Kh. & Khalatov, A.A. (2010). Exergoeconomic optimization of surface heat exchangers. *Thermal Engineering, 57, 10,* 888–891, DOI: 10.1134/S0040601510100113.

20 Thakre, P.B. & Pachghare, P.R. (2017). Performance Analysis on Compact Heat Exchanger. *Materials Today-Proceedings, 4, 8,* 8447–8453.

21 Cabezas-Gomez, L., Saiz-Jabardo, J.M., Navarro, H.A. & Barbieri, P.E.L. (2014). New thermal effectiveness data and formulae for some cross-flow arrangements of practical interest. *International Journal of Heat and Mass Transfer, 69*, 237–246, DOI: 10.1016/j.ijheatmasstransfer.2013.10.022.

22 Gorobets, V.G., Trokhaniak, V.I. & Bohdan, Yu.O. (2016). Heat exchanger. *UA Patent No. 111751*.

23 Khmelnik, S.I. (2018). *Navier-Stokes equations. On the existence and the search method for global solutions*. *Mathematics in Computers.* Bene-Ayish: MiC.

24 *ANSYS FLUENT Theory Guide* (Release 18) (2017). Canonsburg, Inc. Southpointe 275 Technology Drive.