SIMULATION OF CONVECTIVE HEAT EXCHANGE OF COOLING SYSTEM ELEMENTS OF STERILE PROCESS AIR PREPARATION STAGE

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МОДЕЛЮВАННЯ КОНВЕКТИВНОГО ТЕПЛООБМІНУ ЕЛЕМЕНТІВ СИТЕМИ ОХОЛОДЖЕННЯ СТАДІЇ ПІДГОТОВКИ СТЕРИЛЬНОГО ТЕХНОЛОГІЧНОГО ПОВІТРЯ

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A computer model of convective heat transfer near the finned heat exchange elements of the heat exchanger in the sterile process air cooling system has been created. By using the universal software system of finite element analysis ANSYS, the distribution fields of the coolant flows near the heat exchange elements were obtained. The data obtained can be used in the design of heat exchange equipment for highly efficient heating of liquid and gaseous coolants.
Keywords: *heat exchange, ribbing, ANSYS, convection*

Построено компьютерную модель конвектиного теплообмена вблизи оребренных теплообменных элементов теплообменника в системе охлаждения стерильного технологического воздуха. С помощью универсальной программной системы конечно-элементного анализа ANSYS получено поля распределения потоков теплоносителей вблизи теплообменных элементов. Полученные данные могут быть использованы при проектировании теплообменного оборудования для высокоэффективного нагрева жидких и газообразных теплоносителей.
Ключові слова: *теплообмін, оребрення, ANSYS, конвекція*

Построено компьютерную модель воздухообмена в рабочей камере ламинарного бокса. С помощью универсальной программной системы конечно-элементного анализа ANSYS получено поля распределения воздушных потоков в средине рабочей камеры ламинарного бокса. Проанализировано влияние размеров вентиляционных отверстий ламинатора на параметры потока воздуха и потери давления при прохождении ламинатора.
Ключевые слова: *теплообмен, оребрение, ANSYS, конвекция*

INTRODUCTION

In the pharmaceutical and biotechnological industries, high demands are placed on technological coolants, such as sterile process air and purified water. Obtaining such working substances requires the use of separate technological lines, with strict adherence to regulations and special equipment. In this article the technological scheme for obtaining sterile aeration air is considered, namely, the stage of air cooling after compression and the results of modeling of typical elements of heat exchange equipment are given.

ANALYSIS OF THE STATE OF THE PROBLEM AND STATEMENT OF TASKS OF THE STUDY

Figure 1 shows the technological scheme of the stage of preparation of technological sterile aeration air for aerobic microorganism cultivation. The hardware design of the process can be divided into preliminary purification of atmospheric air from abrasive contaminants of mechanical origin, stabilization of thermodynamic parameters in regulating the uniformity of flow and regulation of temperature and humidity and cleaning from microbial contaminants on the main filter and terminal sterilizing on individual filter [1].

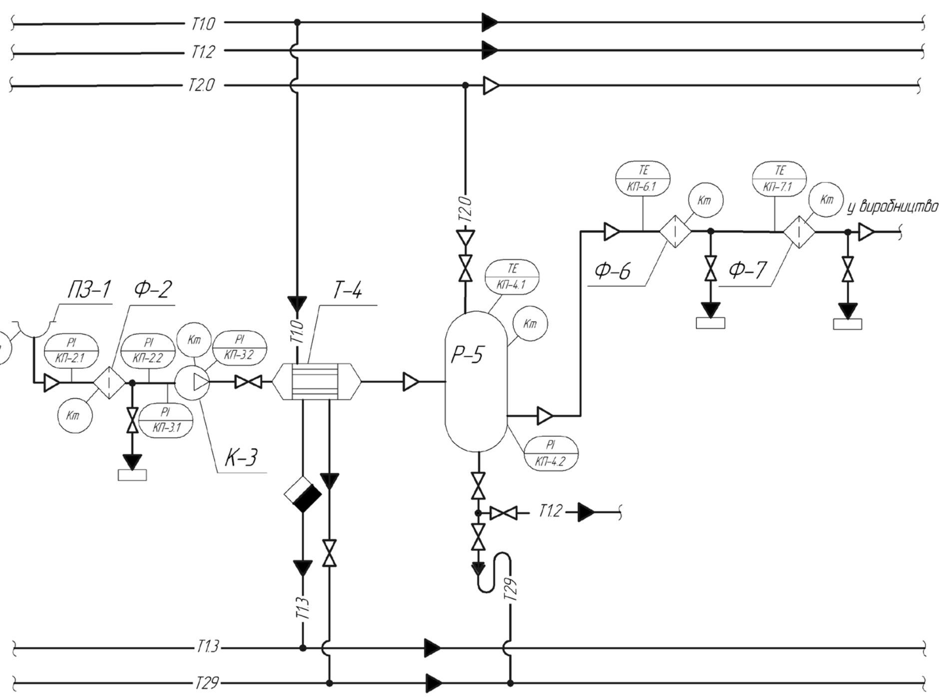


Fig. 1. The technological scheme of a stage of aeration-technological air preparation:
Pz-1 – air intake; F-2 – pre-purification filter; K-3 – compressor;
T-4 – heat exchanger; P-5 – receiver; F-6 – main filter; F-7 – individual filter

A key step in terms of heat transfer and hydrodynamics is the cooling of compressed air, which is pumped by the compressor K-3. The use of the compressor is due to the need to create a high difference in air pressure at the inlet and outlet of the cascade of filters, which create a significant hydraulic resistance. It is known that during compression the temperature of gaseous bodies increases, and in this process can reach 160 °C. Therefore, in the line of technological air preparation, the obligatory device is a heat exchangerrefrigerator T-4, the main task of which is fast and intensive heat removal of excess heat from the air after its compression. It should be noted that the R-5 receiver is used to stabilize the thermodynamic and hydraulic parameters after the heat exchanger.

The efficiency of heat exchange equipment directly depends on the temperature gradient, the geometry of the apparatus, the materials from which the equipment elements are made and the surface area of heat exchange. Usually, it is impossible to influence on the temperature difference of coolants, because it is due to the technological regulations of production of a specific target product. However, to intensify heat transfer, it is possible to use various design features, such as finning [6].

The amount of heat transfer coefficient in the case of heat exchange during the flow of gaseous substances, such as air and other gases, is usually not high (except for saturated water vapor), so the intensification of heat transfer in such processes is important. This is due to the fact that air, in terms of thermophysical properties, is not an efficient coolant, i.e. it has high inertial properties, slowly heats up and cools down, so heat exchange elements with a developed heat transfer surface (finning) are usually used.

THE AIM OF THE STUDY

The aim of the study is to establish the heat transfer efficiency of the finned surface of the heat exchange element under conditions of forced convection. To achieve this goal, the task is to develop a computer model of the contact zone of the coolant with the surface of the heat exchanger element of three different designs (smooth tube, tube with spiral coiled finning and tube with sector finning) taking into account all boundary conditions of heat transfer to establish heat transfer parameters.

SIMULATION OF THE HEAT EXCHANGE PROCESS IN THE NEAR AIR COOLING HEAT EXCHANGE PIPES

The geometry of heat exchange elements is a very important factor that significantly affects the parameters of convective heat transfer. Selection of optimal and rational geometric parameters of finning is carried out, as a rule, experimentally. As a result of the conducted experimental researches on a prototype the coefficients of criterion equations of Nusselt are defined. The methodology described above is a rather complex, time-consuming and costly process. An alternative may be modeling in computer aid design (CAD) system. The use of such systems reduces the cost of resources for the production and conduct of pilot studies. This study evaluates the effectiveness of finning based on the results of computer simulations in the ANSYS. This can be done by evaluating the original plots of the simulated process, the technique is described in detail in the list of articles cited in the literature [2–4].

ANSYS CFX module is used to perform computer simulations of air flow around heat exchanger tube. For the adequacy of the model to real processes it is necessary to set explicit conditions.

GEOMETRIC CONDITIONS

Before modeling the process, we build the geometry of a rectangular channel in the SolidWorks environment, which forms a volume in which hot air moves and in which there is a heat exchange tube of a certain geometry (Fig. 2). The tube without fins has the characteristic size $d = 0{,}025$ m, the tube with spiral and sector fins have two characteristic sizes accordingly: diameter of a tube – $d = 0{,}025$ m, diameter of fins – $D = 0{,}055$ m.

PHYSICAL CONDITIONS

Domains must be broken down into finite elements before physical conditions can be set. For this purpose the Mesh module is used with the default settings. The formation of the mesh is performed using the shape of tetrahedrons, as the use of this type of partition, although it increases the required modeling time, but allows for a more accurate calculation. The medium that flows around finning is air with thermophysical parameters at operating temperature, the heat exchange tube is a solid.

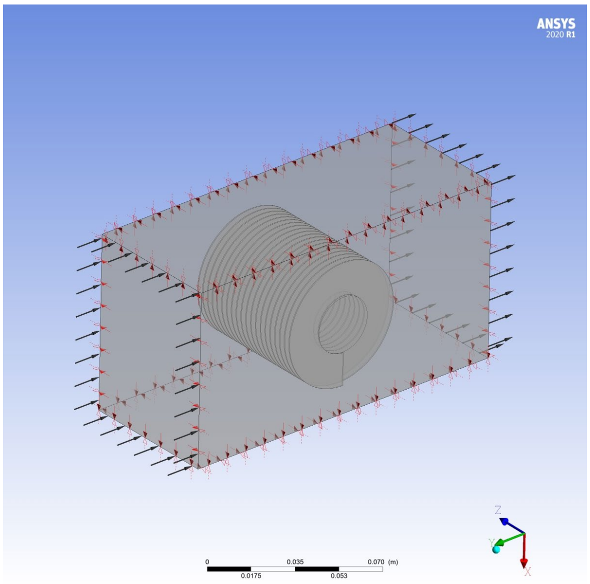


Fig. 2. Geometry of the calculated model of the heat exchange tube

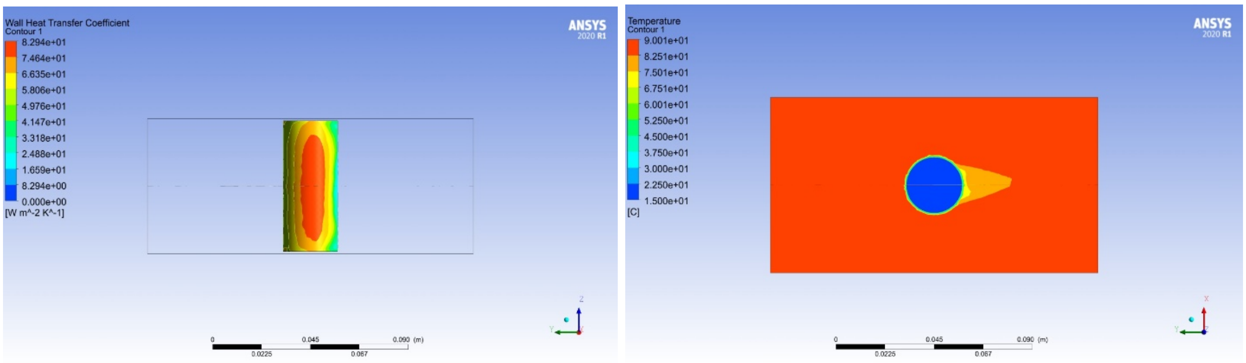
BOUNDARY CONDITIONS

On the left side of the volume we set the air velocity w = 5 m / s, and on the right the air outlet without additional hydraulic resistance P. The outer surfaces of the channel are defined as symmetry. The stationary temperature on the surface of the heat exchange tube is set to 15 °C, while the air flow temperature at the inlet is – 90 °C.

Comparative analysis was performed for three types of heat exchange tubes: smooth tube, tube with spiral finning and tube with sector finning.

RESULTS

In Fig.3. contours of the gradient of heat transfer coefficient and air temperature near the heat exchange pipe without finning are presented. The range of values of the heat transfer coefficient is from 8,29 to 82,94 W / m^2*K, while the average value on the surface is 59 W / m^2*K. The air temperature in the active contact zone varies in the range from 90 to 67 °C. However, it should be noted that the active zone of temperature change is local in nature, so the average temperature in the zone is 78,5 °C. If you analyze the entire area around the pipe space, the average value at the outlet is only 89 °C, i.e. the temperature difference does not exceed 1 °C. The average value of the hydraulic resistance of the air flow is 3,96 Pa.



a ***b***

Fig. 3. Temperature gradient for the tubular heat exchange element: a - heat transfer coefficient on the surface, W / m^2*K; b – air temperature, °C

In Fig.4. plots of the gradient of heat transfer coefficient and air temperature near the heat exchange pipe with spiral finning are presented. The range of values of the heat transfer coefficient is from 9,57 to 95,7 W/ m^2*K, while the average value on the surface is 47 W/ m^2*K. The air temperature in the active contact zone varies in the range from 90 to 45 °C. In the case of using a heat exchange element with a spiral fin, the active temperature change zone is long. If you analyze the entire area around the pipe space, the average value at the outlet is 82 °C, ie the temperature difference does not exceed 8 °C. The average value of the hydraulic resistance of the air flow is 13,16 Pa.

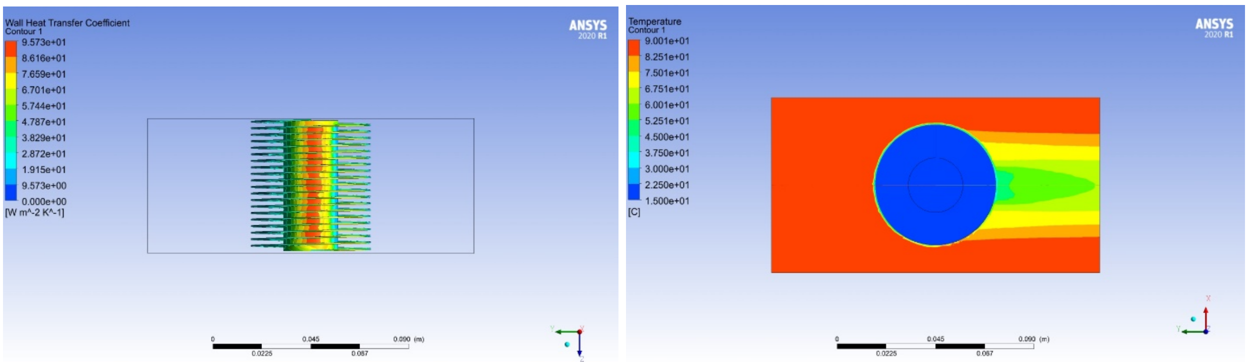


Fig.4. Temperature gradient for tubular heat exchange element with spiral finning: a – heat transfer coefficient on the surface, W/ m^2*K; b – air temperature, °C

In Fig. 5 the plots of the gradient of heat transfer coefficient and air temperature near the heat exchange pipe with sector finning are presented. The range of values of the heat transfer coefficient is from 10,1 to 100,1 W/ m^2*K, while the average value on the surface is 45 W/ m^2*K. The air temperature in the active contact zone varies in the range from 90 to 52,5 °C. In the case of using a heat exchange element with sector fins, the active temperature change zone is long. If you analyze the entire area around the pipe space, the average value at the outlet is 78 °C, in the temperature difference does not exceed 12 °C. The average value of the hydraulic resistance of the air flow is 10,19 Pa.

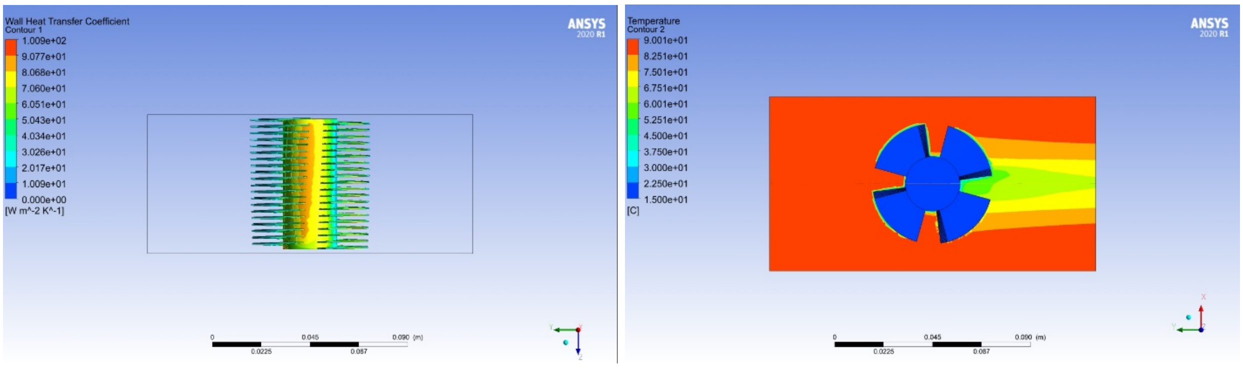


Fig.5. Temperature gradient for tubular heat exchange element with sectional finning: a – heat transfer coefficient on the surface, W/ m^2*K; b – air temperature, °C

Based on the results obtained by data sets for three types of heat exchange elements, graphs of changes in air temperature from a distance as they move away from the heat exchange element were constructed (Fig. 6)

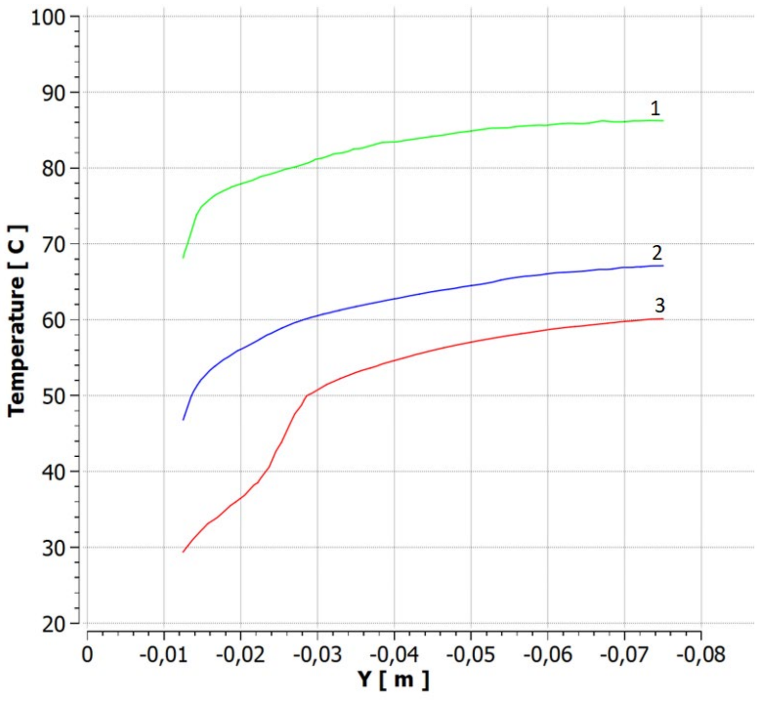


Fig.6. Graph of air temperature t, °C on the distance as it moves away from the heat exchange element Y, m:
1 – heat exchange element without finning;
2 – heat exchange element with spiral finning;
3 – heat exchange element with sector finning

Average values for all types of tubes are listed in table 1.

Table 1. Average values of experimental parameters

Type of heat exchange element	Average heat transfer coefficient, W/ m^2*K	Hydraulic resistance, *Pa*	Average outlet temperature, ^oC.	Area 10^{-6}, m^2
Smooth tube	59	3,96	89	4712
Tube with spiral coiled finning	47	13,16	82	81078
Tube with sector finning	45	10,19	78	56941

Analysis of the simulation results in ANSYS of three types of heat exchange elements gives grounds to assert that geometry has the greatest influence on the heat transfer intensity. Although the highest average heat transfer coefficient is observed in pipes without finning, it has the lowest heat removal efficiency. This fact can be explained by the fact that the hydraulic resistance is almost three times less than the heat exchange elements with finning, while the surface area of heat transfer is about 15 times smaller. Therefore, the use of heat exchange elements without finning for air cooling is inefficient and irrational. Similar parameters were obtained when comparing heat exchange elements with finning of different design. However, in this particular study, the use of a heat exchange element with sector finning proved to be more effective. This design shows the largest value of the difference in air temperatures at the inlet and outlet, which is due to almost the same values of the heat transfer coefficients with a smaller heat transfer surface and a lower value of hydraulic resistance.

CONCLUSIONS

1. The use of non-finned heat exchange elements for cooling systems of gaseous heat carriers, such as air, is inefficient and irrational.

2. When choosing the design of heat exchange elements, it is necessary to follow the rule of finding the optimal ratio between the surface area of heat transfer and the hydraulic resistance that this geometry will create in the channel.

REFERENCES

1 Ружинська Л. І. Апаратурні схеми фармацевтичних та біотехнологічних виробництв. Порядок складання та вимоги до оформлення. Посібник. Електронне видання. К.: НТУУ «КПІ», 2012 139 с.

2. Shybetskyi V., Kostyk S. Analysis of the special features of hydrodynamics in the boundary layer of the nozzle of the developed surface. *Technology audit and production reserves*, 2019. № 2.

3. Kostyk S., Shybetskyy V., Povodzinsy V., Fesenko S. Revealing special features of hydrodynamics in a rotor-disk film vaporizing plant. *Eastern-European Journal Of Enterprise Technologies*, 2019. 1/6 (97). P. 28–33.

4. Kostyk S. Plashykhin S., Shybetskyy V. Computer modeling of the laminar box ventilation system. *Комп'ютерне моделювання в хімії та технологіях і системах сталого розвитку – КМХТ-2020*, Київ, 2020. С. 352–356.