INVESTIGATION THE HEAT TRANSFER COEFFICIENT OF WATER-AIR CONVECTOR

Zhivko Kolev
"Angel Kanchev" University of Ruse, Bulgaria

The purpose of this work is to investigate the heat transfer coefficient of a convector's heat exchange apparatus. For this purpose a methodology for determination the coefficients of heat convection and the heat transfer coefficient have been presented. Using the presented methodology the heat exchange parameters of the convector have been investigated in cooling regime of the installation. The laboratory installation simulates the work of heat pump system for heating and cooling buildings by the heat pump works with a heat source - water from an underground water source (well or river). In the convector's tubes running water, which is heated or cooled by the heat pump, depending on the installation regime of work. The pipe bundle is wrapped cross by airflow, generated by an axial fan. Because such tubes and rabes of the convector's heat exchange apparatus are made of copper alloy and have very small thickness, their thermal resistance is ignored, that is neglected and the temperature difference between the water in the tubes and the temperature of the outside surface of the heat exchanger. It gives the impression the unstable work of the heat pump due to: the lack of buffer vessel in the inner installation circle and the low heat power of the convector compared to the power of the heat pump. The determination of the momentary values (every second) of the investigated parameters and the presentation of their change over time, making it possible to analyze more clearly the de-pendence between them in the particular investigation. Heat pump systems offer economic alternatives for extracting heat from various sources and use it for various industrial, commercial and residential applications. Because, as the price of energy continues to grow, it is imperative to reduce energy consumption and improve overall energy efficiency. Heat pump systems offer one of the best solutions to reduce the amount of harmful emissions into the atmosphere.

Keywords: *methodology, water-air convector, coefficients of heat convection, heat transfer coefficient.*

ИССЛЕДОВАНИЕ КОЭФФИЦИЕНТА ТЕПЛОПЕРЕДАЧИ КОНВЕКТОР «ВОДА–ВОЗДУХ»

Живко Димитров Колев
Русенский университет им. А. Кынчева, г. Русе, Болгария

Цель данной работы является исследование коэффициента теплопередачи в конвектор теплообменника аппарата. Для этого была представлена методология для определения коэффициента тепловой конвекции и теплопередачи. С помощью этой методики теплообменные параметры конвектора были исследованы в режим установки – „охлаждение". Лабораторная установка имитирует работу системы теплового насоса для отопления и охлаждения здания, когда тепловой насос работает с источником тепла - водой из подземного колодца (реки). В трубы конвектора течет вода, которая нагревается или охлаждается тепловым насосом в зависимости от режима работы установки. Трубный пучок проходит через воздушный поток, образуемый осевым вентилятором. Так, как трубы и ребра выполнены из меди и имеют очень небольшую толщину, их тепловое сопротивление игнорируется, как пренебрегается и разность температур между водой в трубах и внешней поверхностью теплообменника. Стоит отметить, нестабильная работа теплового насоса из-за отсутствия буфера во внутреннем круге установки и низкая тепловая мощность конвектора, по сравнению с мощностью теплового насоса. Определение мгновенных значений (каждый второй) из изученных параметров и их изменений во времени, это делает возможным анализировать более четко взаимосвязь между ними в данном конкретном исследовании. Системы тепловых насосов предлагают экономически альтернативные решения для извлечения тепла из различных источников и использования его для различных промышленных, коммерческих и жилых помещений. Потому как цены на энергоносители продолжают расти, крайне важно снизить энергопотребление и повысить общую энергоэффективность. Системы тепловых насосов предлагают один из лучших решений, чтобы уменьшить количество вредных выбросов в атмосферу.

Ключевые слова: *методология, конвектор «вода-воздух», коэффициент тепловой конвекции, коэффициент теплопередачи.*

Introduction

In this article the heat transfer coefficient of water-air convector in laboratory reversible heat pump installation, working in "cooling" regime, has been investigated. The laboratory installation type water-water works without a buffer vessel in the inner circle. The heat consumer (the convector) has low heat power, compared with the power of heat pump, which is a prerequisite for investigations of strong non stable processes. The heat pump aggregate works with compressor without possibility for regulations of the rotation speed. The water-air convector is brand BUMYANG, model FVC20MLL2. The convector's heat exchange apparatus has been made as a two-pipe staggered ribbed tube sheaf. The tubes and ribs have been produced from a copper alloy.

Objectives

The purpose of this work is to investigate the heat transfer of the convector's heat exchange apparatus by determination the heat convection coefficient between the water in tubes and the inner tubes surface, and the heat convection coefficient between the outer surface of the heat exchanger and the airflow.

Procedure

1. Principal scheme and description of the laboratory heat pump installation [1, 5, 6]

The principal scheme of the laboratory installation is shown on Figure 1.

The laboratory installation allows carry out a number of laboratory and investigation activities. The installation simulates the work of heat pump system for heating and cooling buildings by the heat pump works with a heat source - water from an underground water source (well or river) [1, 2, 3, 7]. For measure the water temperatures (input and output of the convector) and the ambient temperature, a digital thermoelectric thermometer "Thermologger K204" has been used. For continuous monitoring of the measured temperatures in a certain interval of time, graphical and tabular visualization of obtained results, a computer program "TestLink SE-309" has been used. The velocity of the airflow, created by the convector's fan, has been measured by a digital anemometer "Mastech" [5].

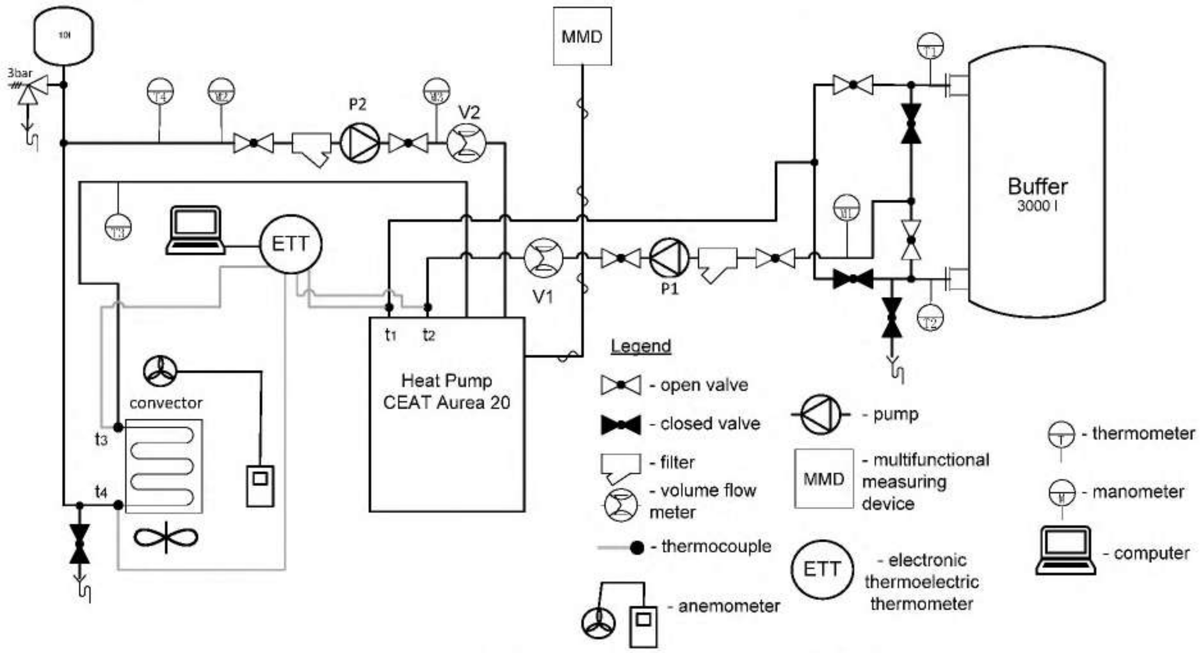

Fig. 1. Principal scheme of the laboratory installation

2. Methodology fot determination the heat convection coefficients and the heat transfer coefficient of the convector [5, 6]

2.1. Principal scheme of the heat exchange apparatus

The principal scheme of the convector's heat exchange apparatus is shown on Figure 2.

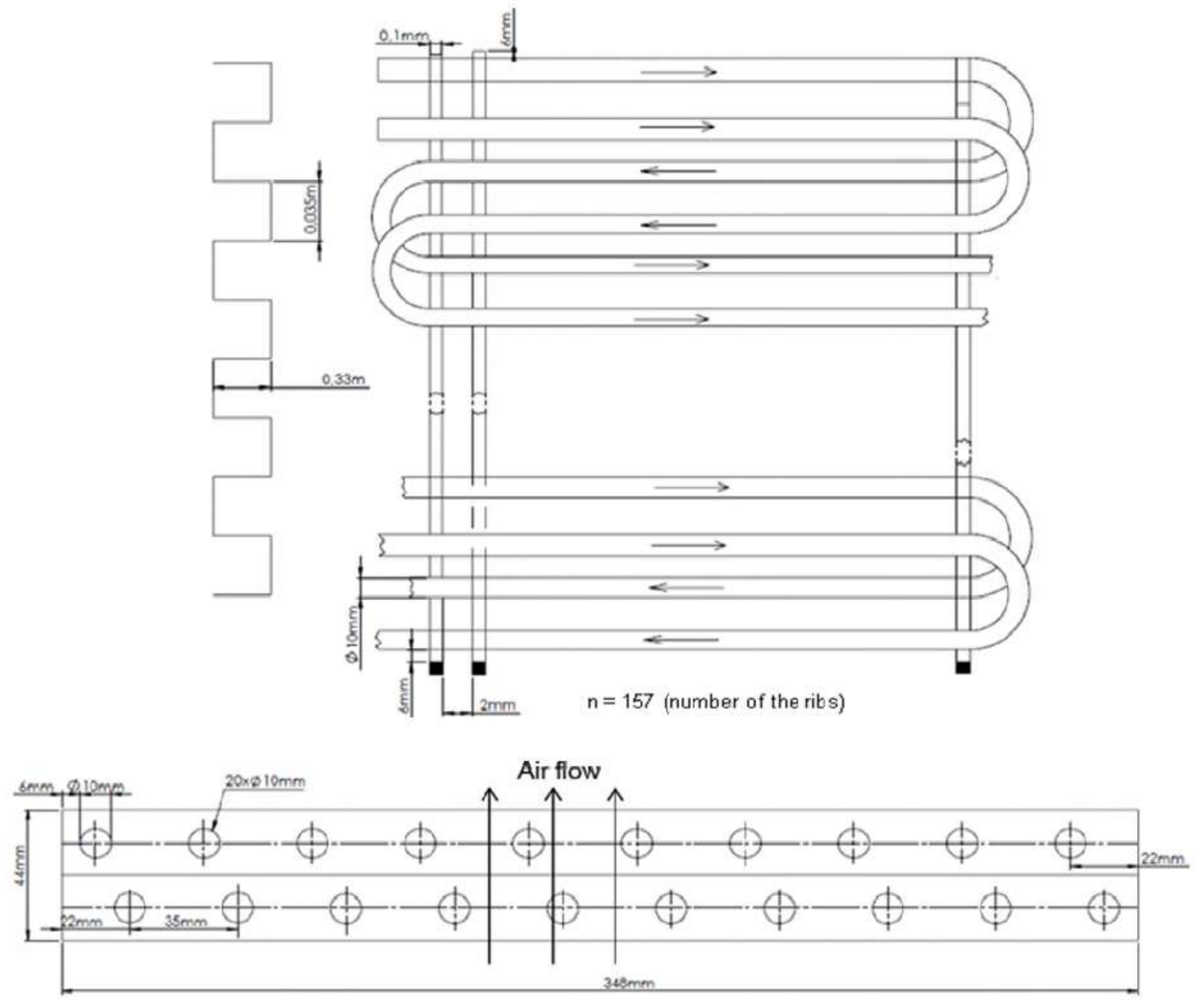

Fig. 2. Principal scheme of the convector's heat exchange apparatus

In the convector's tubes running water, which is heated or cooled by the heat pump, depending on the installation regime of work. The pipe bundle is wrapped cross by an airflow, generated by an axial fan.

<u>2.2. Methodology fot determination the heat convection coefficient between the water in tubes and the inner tubes surface (α_1) [5, 6]</u>

2.2.1. Determination the water volume flow in the inner installation circle (through convector's tubes) $\dot{V}_1\,[m^3/s]$ by the volume flow meter.

2.2.2. Calculation the water velocity trough the convector:

$$w_1 = \frac{\dot{V}_1}{2}.S_{tube1} = \frac{\dot{V}_1}{2}.\frac{\pi.d_{tube1}^2}{4}, m/s \tag{1}$$

where $d_{tube1} = 8\,mm$ is the inner tubes diameter.

2.2.3. Calculation the average temperature of the water, circulating in the inner circle of the installation:

$$\bar{t}_{water} = \frac{t_3 + t_4}{2}, \ ^\circ C \tag{2}$$

where t_3 and t_4 are respectively the temperatures of the water inlet and outlet of the convector, $^\circ C$. These temperatures have been measured on the outer surface of the tubes. Because such tubes and rabes are made of copper alloy and have a very small thickness, their thermal resistance is ignored, that is neglected and the temperature difference between the water in the tubes and the temperature of the outside surface of the heat exchanger.

2.2.4. Defination the tabular values of the following water parameters (according $\bar{t}_{water}$): kinematic viscosity ($\nu_1, m^2/s$), thermal conductivity coefficient ($\lambda_1, W/m.K$) and criterion of Prandtl (Pr_1).

2.2.5. Calculation of the criterion of Reynolds:

$$Re_1 = \frac{w_1.d_{tube1}}{\nu_1}. \tag{3}$$

2.2.6. Selection of a criterion equation for calculation the criterion of Nuselt (Nu_1), according to the obtained values of Re_1 and Pr_1.

2.2.7. Calculation the heat convection coefficient α_1:

$$\alpha_1 = \frac{Nu_1.\lambda_1}{d_{tube1}}, W/(m^2.K). \tag{4}$$

2.3. Methodology fot determination the heat convection coefficient between the outer surface of the heat exchanger and the airflow (α_2) [5, 6]

2.3.1. Measurement the airflow velocity $w_{measured-2}[m/s]$ generated by the convector's fan, at the convector output.

2.3.2. Calculation the average actual velocity of the airflow in the narrowest section of the outer surface of the heat exchange apparatus:

$$w_2 = w_{measured-2}.\frac{S_2}{S_{nerrowest\,section-2}}, m/s \tag{5}$$

where: $S_2 = 0{,}115 m^2$ is the cross-sectional area of the heat exchanger, wrapped by the airflow;

$S_{narrowest\,section-2} = 0{,}041\ m^2$ is the cross-sectional area of the air gap between the tubes and rabes.

2.3.3. Calculation the average temperature of the airflow, wrapping the outer surface of the heat exchanger:

$$\bar{t}_{air\,flow} = \frac{\bar{t}_{water} + t_{ambient\,air}}{2},\ {}^oC \tag{6}$$

where: $t_{ambient\,air}$ is the determinant temperature of the ambient air (measured at an enough distance from the convector), ^oC;

$\bar{t}_{water}[^oC]$ is assumed to be the average temperature of the outer surface of the heat exchange apparatus.

2.3.4. Defination the tabular values of the following air parameters (according $\bar{t}_{air\,flow}$): kinematic viscosity ($\nu_2, m^2/s$), thermal conductivity coefficient ($\lambda_2, W/m.K$) and criterion of Prandtl (Pr_2).

2.3.5. Calculation of the criterion of Reynolds:

$$Re_2 = \frac{w_2.d_{tube2}}{\nu_2}, \tag{7}$$

where $d_{tube2} = 10mm$ is the outer tubes diameter.

2.2.6. Selection of a criterion equation for calculation the criterion of Nuselt (Nu_2), according to the obtained values of Re_2 and Pr_2.

2.2.7. Calculation the heat convection coefficient α_2:

$$\alpha_2 = \frac{Nu_2.\lambda_2}{d_{tube2}}, W/(m^2.K). \quad (8)$$

2.4. Methodology fot determination the heat transfer coefficient between the water in tubes and the air flow (U) [5, 6]

For determination the heat transfer coefficient the equation for single-layer flat wall has been used, neglecting the thermal resistance ($\delta_{wall}/\lambda_{wall}$) of tubes and ribs:

$$U = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{wall}}{\lambda_{wall}} + \frac{1}{\alpha_2}}, \text{ but } \frac{\delta_{wall}}{\lambda_{wall}} \approx 0 \Rightarrow U \approx \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}}, W/(m^2.K).$$

(9)

Results and discussion

1. Set operating parameters of the installation:

► heat pump settings – temperature of heat pump switch t_4 = 10,7 °C (the temperature of the output convector water), temperature of heat pump shutdown t_4 = 7,2 °C;

► convector's fan setting - maximum air flow rate (degree „HIGH");

► setting of the circulation pump in the inner circle of the installation $\dot{V}_1 = 0{,}000148\ m^3/s$.

2. Measured parameters:

► temperature of the ambient air $t_{ambient\ air} = 23{,}3\ ^\circ C$;

► average air flow velocity at the convector output $w_{measured-2} = 1{,}86\ m/s$.

3. Investigation the heat convection coefficient between the water in tubes and the inner tubes surface (α_1)

Calculation the velocity of the water in the convector tubes:

$$w_1 = \frac{\dot{V}_1}{2}.S_{tube1} = \frac{\dot{V}_1}{2}.\frac{\pi.d^2_{tube1}}{4} = \frac{0{,}000148}{2}.\frac{3{,}14.0{,}008^2}{4} = 1{,}472\ m/s.$$

(10)

On Figure 3 it is shown the change of the temperature of the water in the two circles of installation (the temperature measurements are in 1 s).

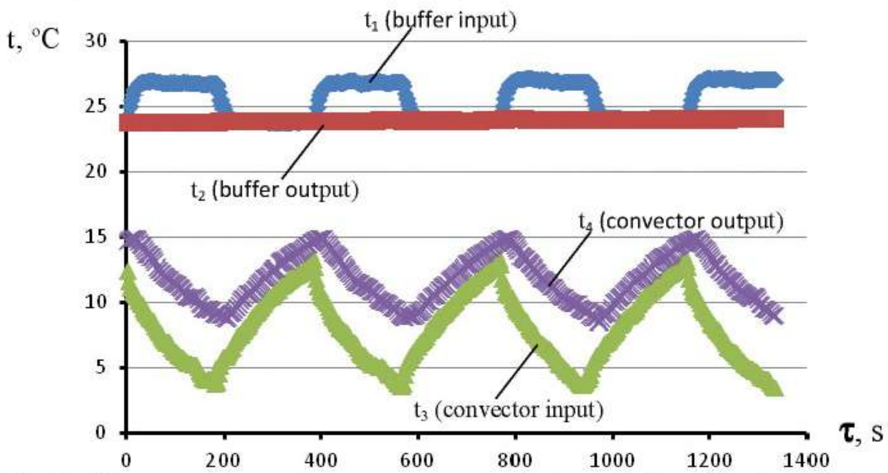

Fig. 3. Change of the water temperatures in the two circles of the installation

It gives the impression the unstable work of the heat pump due to: the lack of buffer vessel in the inner installation circle and the low heat power of the convector compared to the power of the heat pump. The differences between the values of t_4, regarding the heat pump settings (measured by the heat pump temperature sensor) and the measured values of this temperature by the thermoelectric thermometer on the convector, due to: the specifics of the temperature measurement by the heat pump temperature sensor and the thermoelectric thermometer on the convector, the distance between them, the inertia in changing the temperature during the heat pump switch and shutdown.

On Figure 4 it is shown the change of the average water temperature in the convector tubes $\bar{t}_{water}$.

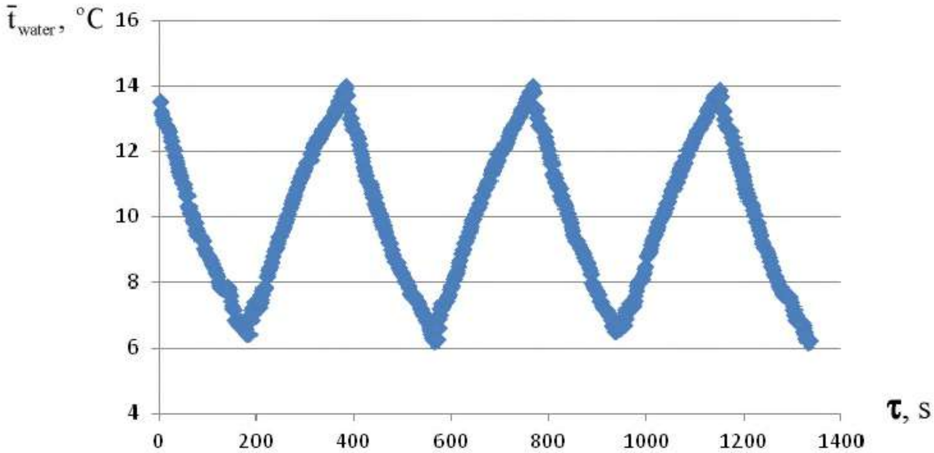

Fig. 4. Change of the average water temperature in the convector tubes

Based on the resulting limits of $\bar{t}_{water}$, using tabular data, equations for determination the momentary values of the water kinematic viscosity ($\nu_1, m^2/s$), coefficient of thermal conductivity ($\lambda_1, W/m.K$) and criterion of Prandtl (Pr_1), have been composed.

On Figure 5 it is shown the change of the Reynolds criterion Re_1.

The change of Re_1 is due to the change of ν_1 when there is a change of $\bar{t}_{water}$. The figure shows that the maximum values of Re_1 have been about 1640 and the minimum - about 1300.

On Figure 6 it is shown the change of the Prandtl criterion Pr_1.

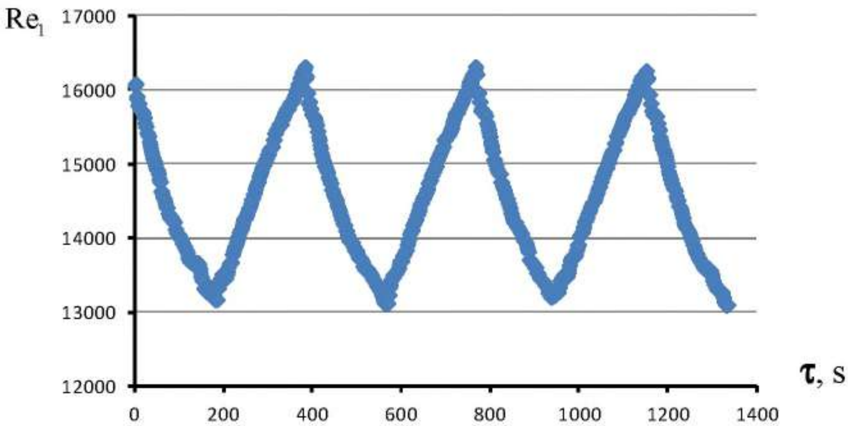

Fig. 5. Change of the Reynolds criterion of the water in the convector tubes

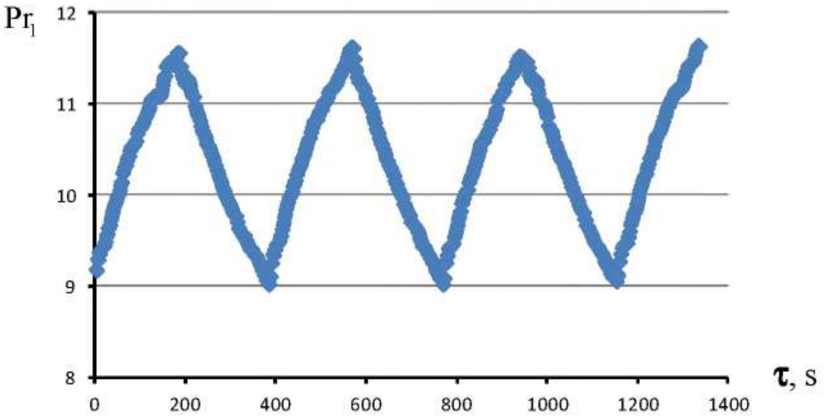

Fig. 6. Change of the Prandtl coefficient of the water in the convector tubes

It can be seen that the maximum values of Pr_1 have been about 11,7 and the minimum - about 8,9.

Based on the received results for Re_1 and Pr_1, it follows that it can be used the criterion equation (11) for determination the criterion of Nuselt [4]:

$$Nu_1 = 0{,}021 . Re_1^{0,8} . Pr_1^{0,43} . \qquad (11)$$

The next step is calculation the heat convection coefficient α_1.

On Figure 7 it is shown the change the coefficient α_1 in time.

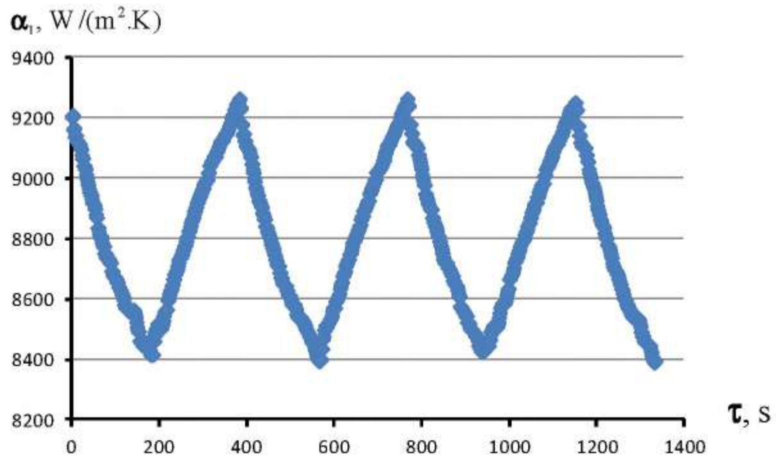

Fig. 7. Change of the heat convection coefficient α_1

The average value of the heat convection coefficient within the experiment is $\overline{\alpha}_1 = 8799\ W/(m^2.K)$.

<u>4. Investigation the heat convection coefficient between the outer surface of the heat exchanger and the airflow</u> (α_2)

The first step is calculation the average actual velocity of the airflow in the narrowest section of the outer surface of the heat exchange apparatus:

$$w_2 = w_{measured-2} \cdot \frac{S_2}{S_{nerrowest\,section-2}} = 1{,}86 . \frac{0{,}115}{0{,}041} = 5{,}06\ m/s .$$

(12)

Similarly to the determination of α_1, the second step is calculation the momentary values of the average temperature $\bar{t}_{air\,flow}$ of the air, wrapping the outer surface of the heat exchanger.

The next step is determination the momentary values of the air physical parameters ν_2, λ_2 and Pr_2.

The momentary values of Re_2 have been calculated. The resulting maximum values of Re_2 have been around 3420 and the minimum - around 3369.

Based on the results for Re_2 and the ratio (d/t), it follows that it can be used the criterion equation (13) for determination the criterion of Nuselt [4]:

$$Nu_2 = 0{,}25.\left(\frac{d}{t}\right)^{-0{,}54}.\left(\frac{D-d}{2.t}\right)^{-0{,}14}.Re_2^{0{,}65}.Pr_2^{0{,}4}, \quad (13)$$

where the geometric parameters of the ribbed tube sheaf are respectively: D = 22 mm, d = 10 mm and t = 2,1 mm (figures 2 and 8).

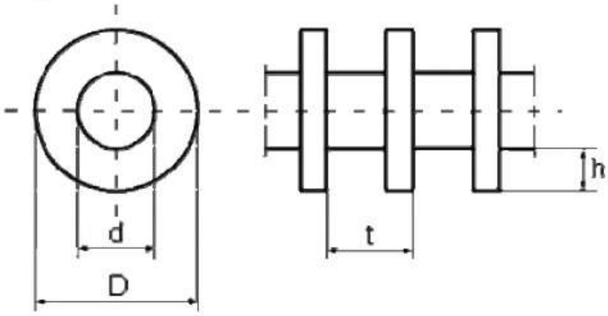

Fig. 8. Geometric parameters of ribbed tubes [4]

The next step is calculation the heat convection coefficient α_2, the change of which is shown on Figure 9.

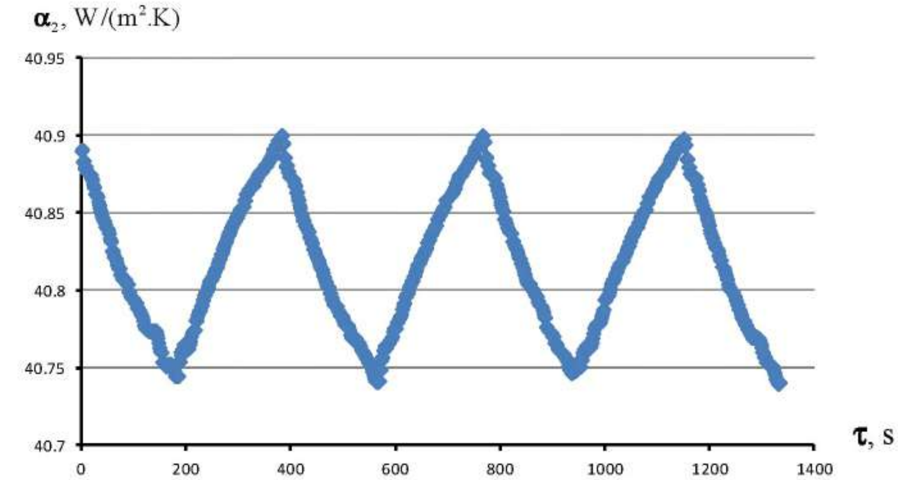

Fig. 9. Change of the heat convection coefficient α_2

The average value of the heat convection coefficient within the experiment is $\overline{\alpha}_2 = 40{,}82\ W/(m^2.K)$.

5. Investigation the heat transfer coefficient between the water in tubes and the air flow (U)

For calculation the momentary values of the heat transfer coefficient, equation (9) has been used.

On Figure 10 it is shown the change the coefficient U in time.

The average value of the heat transfer coefficient within the experiment is $\overline{U} = 40{,}63\ W/(m^2.K)$.

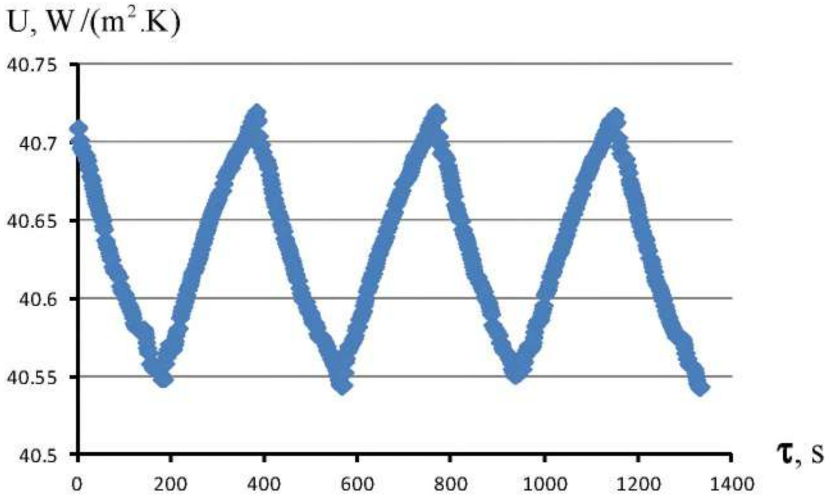

Fig. 10. Change of the heat transfer coefficient

Conclusion

The presented methodology allows investigation the momentary and average values of the coefficients of heat convection and the heat transfer coefficient of a convector's heat exchange apparatus in the laboratory installation work in different modes and setting various operating parameters.

The determination of the momentary values (every second) of the investigated parameters and the presentation of their change over time, making it possible to analyze more clearly the dependence between them in the particular investigation.

The internal heat convection coefficient α_1 has changed in larger percentages than the coefficient α_2, due to the larger range of variation of the average water temperature $\bar{t}_{water}$ than the average temperature of the air flow $\bar{t}_{air\,flow}$ and the larger range of variation of the water Nuselt criterion Nu_1 than the air flow Nuselt criterion Nu_2.

The heat transfer coefficient U depends in a much greater degree of the heat convection coefficient α_2 than of the coefficient α_1. Therefore an intensification of the heat exchange process should be performed with respect to the coefficient α_2.

References

1. Bobilov, V., G. Genchev, P. Mushakov, P. Zlatev, Z. Kolev. Methodology for investigation the coefficient of performance of reversible heat pump "water-water". Proceedings of University of Ruse, 2011, volume 50, series 1.2, p. 8-12.

2. Chua K. J. and others. Advances in heat pump systems: A review. Department of Mechanical Engineering, National University of Singapore, Singapore, 2010.

3. Eder, V., F. Mozer. Heat pumps. Techniques, Sofia, 1984.

4. Iliev, I., V. Bobilov, V. Kambourova, Z. Kolev, P. Zlatev, P. Mushakov. Collection of calculation examples for heat exchange processes and heat exchange apparatuses. Ruse, Engineering and researches in agriculture, 2015, ISBN 978-619-7135-07-7.

5. Kolev, Z., P. Zlatev, P. Mushakov, V. Bobilov. Investigation the heat exchange parameters of water-air convector in laboratory heat pump installation. Proceedings of University of Ruse, 2015.

6. Kolev, Z., P. Zlatev, P. Mushakov, V. Bobilov. Methodology for determination the heat exchange parameters of water-air convector in laboratory heat pump installation. Proceedings of University of Ruse, 2015.

7. Renedo C. J. and others. Optimum design for reversible water–water heat pumps. Department of Electrical and Energy Engineering, University of Cantabria, Spain, 2006.