MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

Rocznik Ochrona Środowiska

Volume 21. Year 2019 ISSN 1506-218X 728-737

Numerical Analysis of the Influence of the Angle of Inclination of the Screen on the Intensity of Heat Exchange from a Flat Heat Exchanger in a Partially Limited Space

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1. Introduction

Panel radiators appeared in the 1920s and they were originally made of steel. The automation of production, the development of welding technology in the middle of the last century, caused a significant increase in the production of such heaters. In recent years they have been quite popular and their share exceeds 90% of all types of radiators used (Nantka 2006).

The common use of plate heat exchangers has undoubtedly been the advantages resulting from the design itself or the principle of operation, related to, among others with heat exchange conditions (co-or counter-current), performance range, service activities, etc.

In order to properly match the radiator's power to the room, we should take into account primarily the heat demand of this room and the operating parameters of the installation, additional heat sources such as: human heat, lighting, cooking, etc. Also changing factors, such as: wind, sunshine, outside temperature. All these factors affect the amount of heat supplied by the installation, through appropriate regulation (Szpakowska 2010).

When deciding to buy a heater, check whether it has the required marketing authorizations in accordance with PN-EN 442 (Polish Standards, items in literature 17, 18) or the Declaration of Conformity with Technical Approval, which came into force before the creation of the above-mentioned standards (Dąbrowska 2008).

The standard refers to the measurement of thermal power of radiators and informs, among others, about the causes of differences in the power of radiators of the same dimensions. These are, for example, different side surfaces of the radiators, the shape of the pressed plate, the efficiency regulated by the top cover. More interesting requirements and guidelines regarding the features and parameters of heaters according to standards are, for example:

- varnishing and lacquer coating, (paint coat: guilty-protected against corrosion, resistant to damage),
- material properties, (the sheet used to build the wet surfaces of the radiator should be made of low-alloy steel, free from milling defects and corrosion),
- tightness testing, (each radiator should undergo a leak test at a pressure 1.3 times higher than the maximum working pressure, the minimum test pressure should not be lower than 520 kPa),
- strength testing, (the radiator is subjected to a test at a pressure of 1.3 times greater than in case of tightness test) (Guzik 2000).

Other standards for radiators are given in the literature (Polish norms, references in literature 16:29).

Free convection compared to other methods of heat transfer is characterized by relatively low intensity,

- intensified process of free convection affects the economics of the heat exchange process,
- currently, new methods for compensating free convection are sought for and developed.

The intensity of convective heat exchange depends on:

a) field of the fluid temperature and the wall,
b) fluid velocity fields.

The methods for intensifying heat exchange are generally broken down as follows:

- passive - not requiring energy,
- active - requiring the drive with special devices,
- combined - a combination of 2 passive or passive and active methods.

Examples of intensification:

- setting shell-and-tube exchangers with inter-walled interceptors and small cross-sectional areas of the tube bundles (in order to increase the medium flow rate),
- using agitators (intensifying the movement), e.g. in the food industry,

- placing the so-called sieve baffles in the inter-wall spaces of shell-and-tube heat exchangers, which also serve to organize the fluid flow and thus to wash hard-to-reach places,
- application of the electric field in convective heat exchange. This method consists in "bombardment" of the boundary layer with electric charges. There are also known acoustic methods of intensification (Szpakowska 2010).

2. Research methodology

The intensification of convective heat exchange can be followed by the modification of the parameters and flow properties of the convective agent, using properly shaped and positioned elements that influence the convective movements of the fluid.

Modifying the space that exchanges heat allows to shape both temperature fields and fluid velocity in these spaces, affecting the mechanisms that determine the convective heat exchange. The article is a continuation of the author's research on the convective heat exchange (Czapp et al. 2016, Orłowska and Czapp 2012, Orłowska et al. 2017, Orłowska 2017, Orłowska 2018). Natural convection research is a broad field of research for many other researchers (Azzous et al. 2019, Bagai et al. 2019, Kogawa et al. 2019, Oh et al. 2019).

The system proposed for numerical research is a model with a plate heat exchanger, which was supplied in a variable distance x screen-partition Figure 1 (screen-partition) (Fig. 1).

After setting the input parameters for the given geometry and the input conditions, the program proceeds to calculations according to the desired number of iterations.

Boundary conditions:

- T_{sc} – wall temperature (exchanger plates) = const = 55°C
- w_{sc} – velocity on the wall = 0 m/s
- T_{wl} – air inlet temperature = const = 20°C

Assumptions:

- fixed system layout,
- axis x is directed horizontally, perpendicular to the surface of the plate,
- something is directed vertically,
- the heating plate, the front part of the exchanger is isothermal,
- the back plate of the exchanger is insulated,
- T_{sc} – wall temperature (exchanger plates) = const = 55°C, 328 K, (±0,1°C),
- T_{ekr} – temperature of screen.

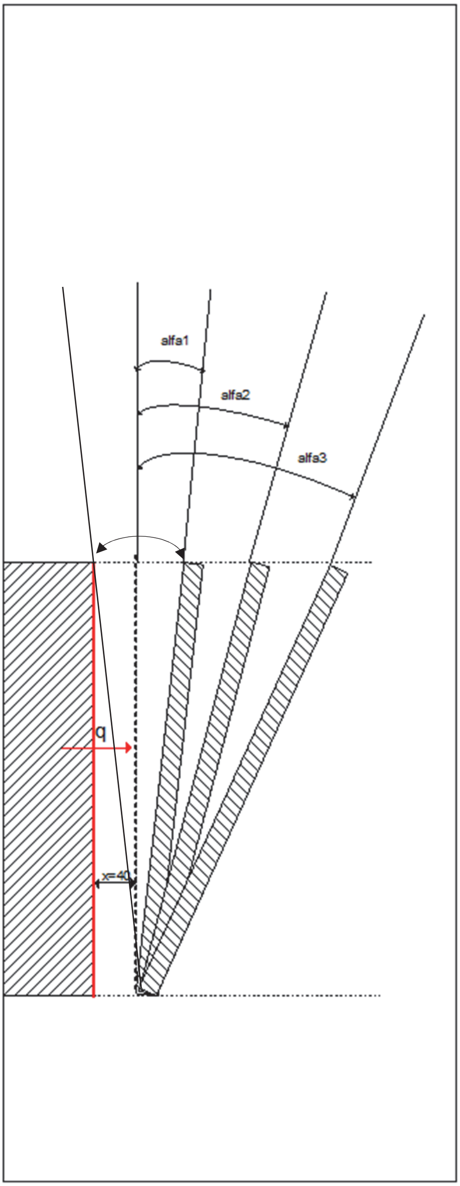

Fig. 1. Heat exchanger with a screen inclined to the various angles alfa

Air:

- compressible,
- fluid movement – turbulent (except for the case without a partition, where the movement is laminar),
- w_{sc} – speed on the wall and partition = 0 m/s,
- T_{wl} – air inlet temperature
- ambient temperature = const = 20°C, 295 K (±0,1°C),
- reference pressure at the outlet of the channel p = 0 Pa, (it is assumed that the pressure level in the outlet section = 0),
- the thermal properties of the working medium are constant except for changes of density in the equation of motion according to the Boussinesquian hypothesis: $\rho = \rho_\infty[1 - \beta \cdot \Delta T]$, gdzie: $\Delta T = T - T_\infty$; T_∞ – opening temperature (T_∞= 293 K, 20 °C); ρ_∞ – density of the medium at the reference temperature.

Simplifications:

- the pressure gradient in the equations of motion was neglected,
- the buoyancy force direction is consistent with the y axis,
- dissipation of energy and heat conduction in the fluid in the direction along the plate,
- pressure drop along the plate was neglected and brought to the wall layer flow.

The proposed model was solved using the method of numerical modeling in the Ansys commercial package. In this way, velocity and temperature distributions were obtained that allowed to calculate the thermal efficiency of the device. The theoretical description of the phenomenon of heat exchange during free convection with a vertical plate, omitting the pressure drop along the plate, includes equations: continuity, motion and energy.

These equations have the form:

− continuity

$$\frac{\partial w}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{2.1}$$

− movement

$$\varrho w \frac{\partial w}{\partial x} + \varrho v \frac{\partial w}{\partial y} = \nu \varrho \frac{\partial^2 w}{\partial y^2} + g(\varrho_0 - \varrho), \tag{2.2}$$

where:

$$g(\varrho_0 - \varrho) = g\varrho \frac{T - T_{ekr}}{\theta_\infty}, \tag{2.3}$$

$$g(\varrho_0 - \varrho) = g\varrho \frac{T - T_{ekr}}{\theta_\infty} = g\varrho \frac{T_w - T_{ekr}}{\theta_\infty} \frac{T - T_{ekr}}{T_w - T_{ekr}} = g\varrho \frac{T_w - T_{ekr}}{\theta_\infty} \vartheta, \tag{2.4}$$

− energy

$$w\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=a\frac{\partial^2 T}{\partial y^2}, \tag{2.5}$$

By entering a variable:

$$\vartheta=\frac{T-T_{ekr}}{T_w-T_{ekr}}, \tag{2.6}$$

we transform the energy equation into:

$$w\frac{\partial \vartheta}{\partial x}+v\frac{\partial \vartheta}{\partial y}=a\frac{\partial^2 \vartheta}{\partial y^2}, \tag{2.7}$$

Limit conditions:
$y=0$ $w=0$ $v=0$ and $\vartheta=1$,
$y\rightarrow\infty$, $w=0$ $\vartheta=0$ (Staniszewski 1979).

All computer simulations were carried out using the Ansys / Flotran (Ansys) computing code. This program is based on the solution of energy balance, momentum and mass equations used in Numeric Fluid Thermomechanics (CFD - Computational Fluid Dynamic). The standard version of the calculation code enables modeling based on traditional phenomena relationships and additional closing equations describing the previously mentioned turbulent momentum and energy streams. The studied system was modeled in two-dimensional space. Two-dimensional so-called the closing model was developed by Launder. At low flow rates, the turbulence model for low Reynolds numbers is often assumed. The presented model can be used both for solving free and forced convection issues. After selecting the desired motion type option (laminar, turbulent), the program takes into account the relevant elements in energy, momentum and mass conservation equations. The calculations were carried out on a computer with a processor with two cores, at 2.1 GHz each and 3 Gb of RAM. At the outset, an analysis was made of the heating plate flow system without a screen. For this purpose, a mesh size 0.0035 (mesh type – free mesh) was used.

The following input data was adopted:

- fixed,
- turbulent or laminar motion depending on the system under consideration,
- the temperature of the heating surface 328 K,
- the ambient temperature 293 K,
- pressure at the outlet from channel 0,
- speed on the walls 0 m/s.

The program was solved by the Solver Tdma Ansys (Ansys) method.

It is worth mentioning that the selection of the appropriate number of iterations and the size of the grid significantly affects the calculation time. After the calculation, the program allows to read the results in the form of colored charts, among others:

- the temperature,
- speed,
- pressure decompositions,
- distribution of air density and related tables (Szpakowska 2010).

3. Results of numerical analyzes

Numerical analyzes were performed for systems with an inclination (screen) inclined by a certain angle of the same height as the heating plate of the heat exchanger, ie 1.15 m (Szpakowska 2010).

The baffle was moved away from the hob at a distance of: at the inlet (bottom) by 4 cm (x = 4 cm), at the outlet (top) at -2 cm (-1°), 5 cm (0.5°), 6 cm (1°), 7 cm (1.5°), 8 cm (2.3°). For comparison, a thermal efficiency value of Q = 448 W, which was obtained in a parallel installation with a plate placed at a distance of x = 4 cm (0°) from the heat exchanger, was also inserted in the collective chart.

Fig. 2 shows the obtained thermal efficiency of the exchanger at different angles of inclination of the partition.

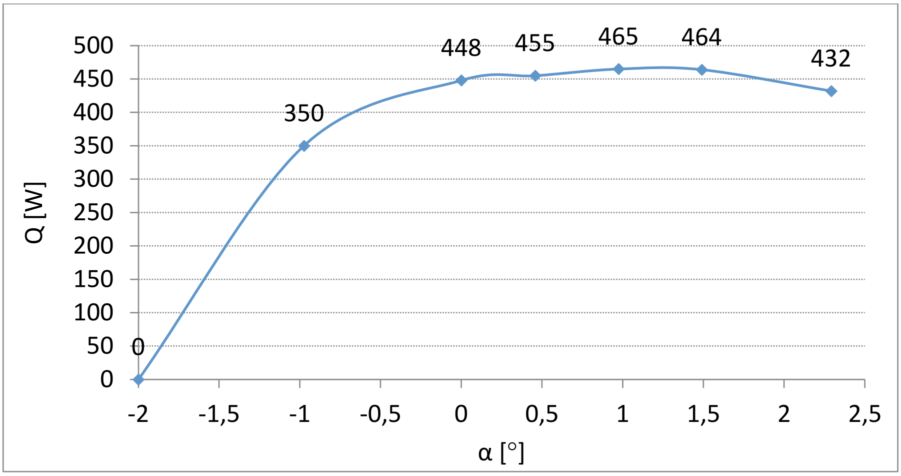

Fig. 2. Thermal efficiency Q [W] of the exchanger as a function of the inclination angle α [°] of the partition

4. Summary and conclusions

In the series of calculations made for the inclination of the screen (screens) – this inclination makes sense to the inclination angle α = 1° (deviation of the upper part of the screen to the distance x = 7 cm, bottom to x = 4 cm), thermal efficiency Q increases. Further tilting the screen reduces the thermal efficiency Q of the exchanger. Tilt of the screen by angle α = 0,5°; 1°, 1.5° makes the thermal efficiency Q of the exchanger higher than the efficiency with parallel geometry, where the screen was moved away to the distance x = 4 cm, Fig. 2. So this is another way to increase the efficiency of the device without the necessity of using energy inputs, i.e. non-mechanical.

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Abstract

The purpose of the work was to perform a numerical analysis enabling to learn the influence of the angle of inclination of a flat partition placed at the plate heat exchanger on the thermal efficiency of the device. It turns out that the inclination of the partition affects this efficiency. Selected systems allowed to capture these changes in the studied range and to visualize them graphically.

Keywords:
radiator**,** heat transfer coefficient α, convection, inclination

Analiza numeryczna wpływu kąta pochylenia ekranu na intensywność wymiany ciepła od płaskiego wymiennika ciepła w przestrzeni częściowo ograniczonej

Streszczenie

Celem pracy było wykonanie analizy numerycznej umożliwiającej poznanie wpływu kąta pochylenia przegrody płaskiej umieszczonej przy płytowym wymienniku ciepła na wydajność cieplną urządzenia. Okazuje się, że pochylenie przegrody ma wpływ na tą wydajność. Wybrane układy pozwoliły uchwycić te zmiany w badanym zakresie i zobrazować graficznie.

Słowa kluczowe:
grzejnik, współczynnik przejmowania ciepła α, konwekcja, pochylenie