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Experimental Research of Temperature Distribution on the Surface of the Front Plate, of a Flat Plate Heat Exchanger

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1. Introduction

Convective research, both experimental and numerical, arouses considerable interest among scientists. It is necessary to carry out tests of heating systems and devices with new constructions in construction: multi-storey buildings, glass walls, ventilation and air-conditioning ducts. During operation, operational problems arise, e.g. horizontal unevenness of the temperature (large office room dimensions, multi-use, new wall constructions, humidity problems, etc. Therefore, new research on these issues is needed. Particularly valuable are works that help support the intensity of natural convection.

In the work (Kalendar et al. 2019, Kalendar et al. 2016) the influence of the complexity of surface shapes on the convective heat exchange process was investigated. The scientific article concerned hexagonal and octagonal isothermal polygons of various shape proportions. Differences in temperature cause differences in fluid density and buoyancy force depends on them, other fluid properties are assumed to be constant. A numerical solution was obtained for the full three-dimensional form of the ruling equations, while these equations were written in a dimensionless form. The influence of Pr and Ra number in the examined range and their influence on Nusselt number were shown. Empirical correlation equations for the average speed in the studied area were obtained.

The study (Han-TawChen et al. 2016) investigated free convection on various models from the obtained experimental data, which was introduced into the three-dimensional computing package. Fluid flows in single-tube vertical plate heat exchangers with fins and tubes were investigated for different fin spacing values and tube diameters. On the basis of the obtained calculations, correlations between the Nusselt number and the Rayleigh number were created.

On the subject of convection, apart from experimental or numerical works, there are also works of an analytical nature. An example of this is the work (Schaub et al. 2019) where the obtained calculation procedure allows to predict heat transfer by unstable natural convection. Earlier studies collected data on laminar, transient and turbulent flow, the Grashoff number for a surface with a constant temperature in a given range, or a constant heat flux in a given range. The physical model assumes a variable proportion of the potential and kinetic energy of fluid molecules for the unstable case.

Earlier research on identifying issues was conducted in an experimental but also numerical way. Experimental research of this work concerns checking the temperature distribution on the front panel of a flat plate heat exchanger. Panels are a very popular type of heaters used in our home. First of all, simple construction, light construction, low thermal inertia, moderate cost, the ability to choose the color, a wide range of sizes determine their choice.

The article is a continuation of the author's research on the convective heat exchange with radiators (Orłowska & Czapp 2012, Orłowska 2019, Orłowska et al. 2019).

2. Research methodology

The theoretical description of the phenomenon boundary layer of heat exchange during free convection with a vertical plate, omitting the pressure drop along the plate, includes equations: continuity, motion and energy. The equations indicate that in free convection, the velocity values depend on the temperature field and do not fall under the uniqueness conditions. If so, the Reynolds number is part of the Grashof number

$$Gr = \frac{\beta g l^3}{v^2} \Delta T \tag{1}$$

where:
β – coefficient of fluid volume expansion,
g – gravitational acceleration,
v – velocity component in the direction of y,
l – linear dimension,
ΔT – temperature difference.

The radiator chosen for experimental research is: Purmo Plan Ventil Compact M, FCVM, dimension: height 90 cm, width 100 cm, thickness 10 cm, type 22, power 2301 W PN-EN 442-2 for parameters 75/65/20°C, middle and bottom connection, maximum working pressure 10 bar, color – white, weight

58.8 kg, Water temperature in the storage tank: 45°C, Installation water flow rate: 180, 280, 380 l/h, System water pressure: Pump gear: third.

The radiator is made of deep-pressed DC01 cold-rolled low-carbon steel sheet in accordance with PN-EN 10130 (https://www.purmo.com/pl/produkty/grzejniki-plytowe/purmo-plan-ventil-compact-m.htm).

The research stand Fig. 1 is located at the Koszalin University of Technology, the Faculty of Civil Engineering, Environmental and Geodetic Studies, in the Department of Building Networks and Installations.

Fig. 1. Testing stand (own photo)

The front panel of the radiator is divided into 12 elements with dimensions of 25x30 cm – Fig. 2. The individual fields in the upper, middle and lower parts of the hob have been given the numbering – Fig. 3. From the side of the wall, the radiator is insulated, only the end surface of the heat exchanger was dealt with by examining heat exchange to the environment.

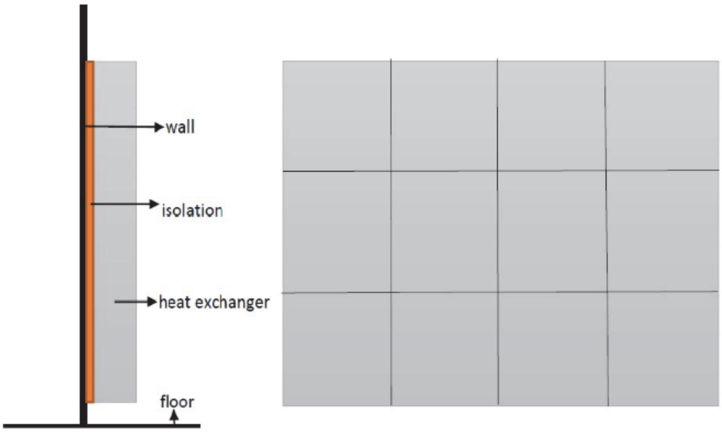

Fig. 2. Heat exchanger – testing stand (side view and front view of heat plate)

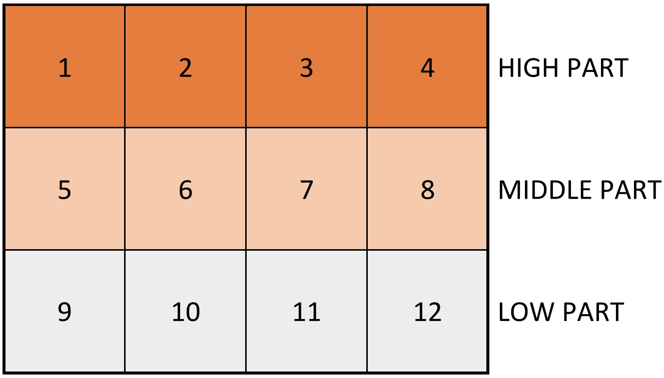

Fig. 3. Division of the plate into measuring elements

In each of the 12 designated fields, the temperature was measured with a FLIR E6 wifi infrared camera. The camera gives the possibility of spot measurement and has the function of multi-spectral imaging. It is possible to apply thermal and digital photos. Thanks to this, the measurement is more precise and the analyzed object is examined more accurately (https://www.conrad.pl/p/kamera-termowizyjna-flir-e6-wifi-20-do-250-c-160-x-120-px-9-hz-1545476). Specifications of camera: „IR resolution 160×120 pixels, Thermal sensitivity/NETD <0.06°C (0.11°F) / <60 mK, Field of view (FOV) 45×34°, Minimum focus distance 0.5 m (1.6 ft.), Image frequency 9 Hz, Detector type: Uncooled microbolometer, Object temperature range -20°C to +250°C (-4°F to +482°F), Accuracy ±2°C (±3.6°F) or ±2% of reading, for ambient temperature 10°C to 35°C (+50°F to 95°F) and object temperature above +0°C (+32°F), Emissivity table of predefined materials/variable from 0.1 to 1.0" (https://www.atel.com.pl/doc/03084_DS.pdf). The emissivity of the tested object, based on the manufacturer's data. Possible reflection of radiation from surrounding objects due to the glossy surface radiator were not included.

3. The results of experimental analyzes

The graphs in the figures 4-7 show the temperature fields of the flat heat exchanger heating plate, which have a huge impact on the process of free convection. Measurements were made in several measurement series. The flow rate of the medium was changed Q = 380 l/h, Q = 280 l/h, Q = 180 l/h. The results of experminatal analyzes were given by Fig. 4-7.

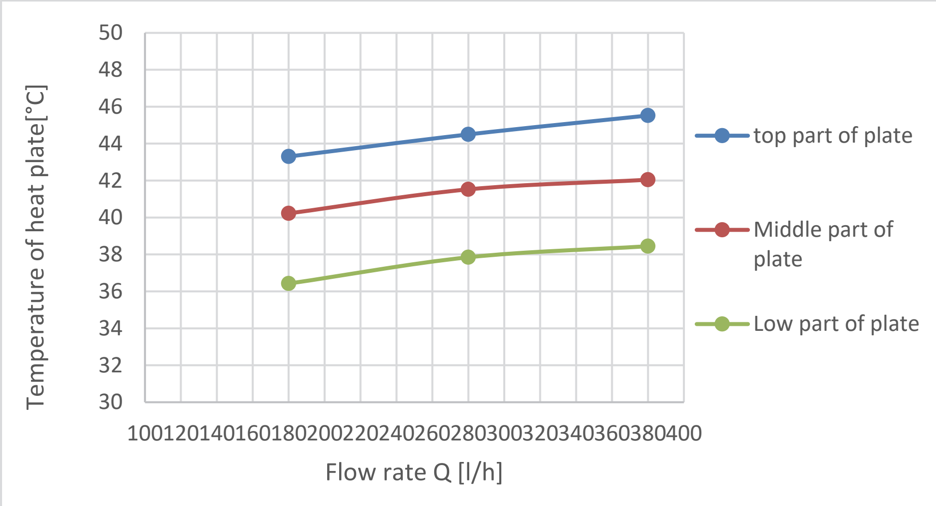

Fig. 4. The fields of temperatures a heating plate temperature T [°C] as a function of flow rate Q [l/h] depending on the height od heat plate (top, middle, bottom)

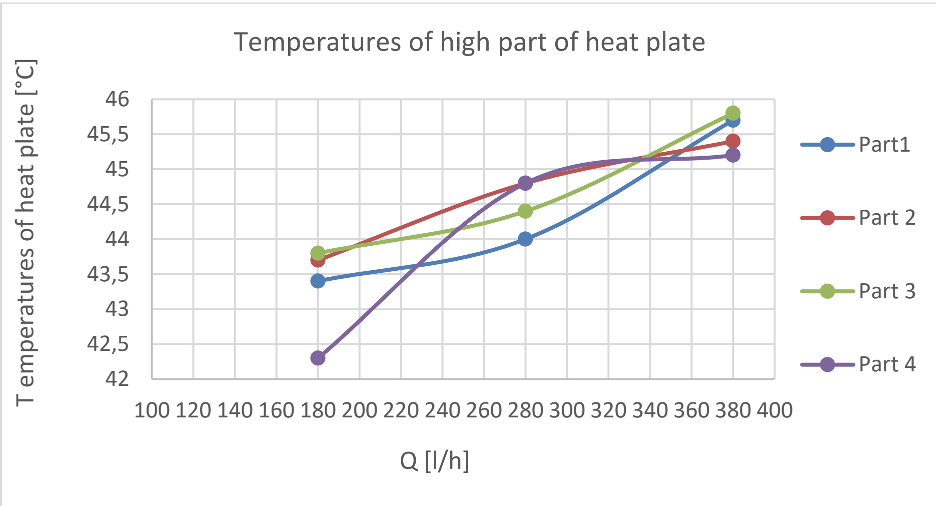

Fig. 5. The fields of temperatures at the high of the heat plate T [°C] in individual elements of the plate (legend) as a function of flow rate Q [l/h]

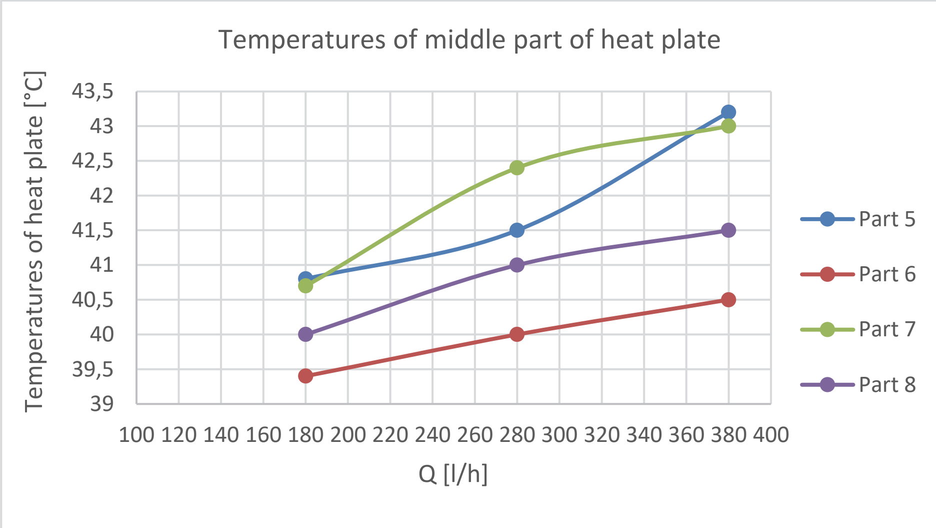

Fig. 6. The fields of temperatures at the middle of the heat plate T [°C] in individual elements of the plate (legend) as a function of flow rate Q [l/h]

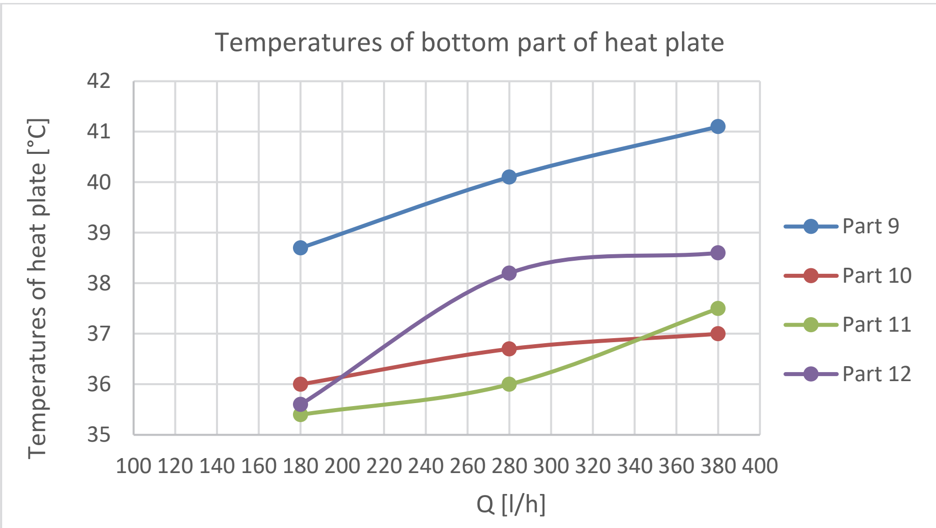

Fig. 7. The fields of temperatures at the bottom of the heat plate T [°C] in individual elements of the plate (legend) as a function of flow rate Q [l/h]

An example view of the heating plate from a thermal imaging camera is given by Fig. 8. The figure shows a pictorial photo of how the temperature fields are shaped. The video camera uses colors to determine the temperature scales. The use of the camera is simple and very convenient.

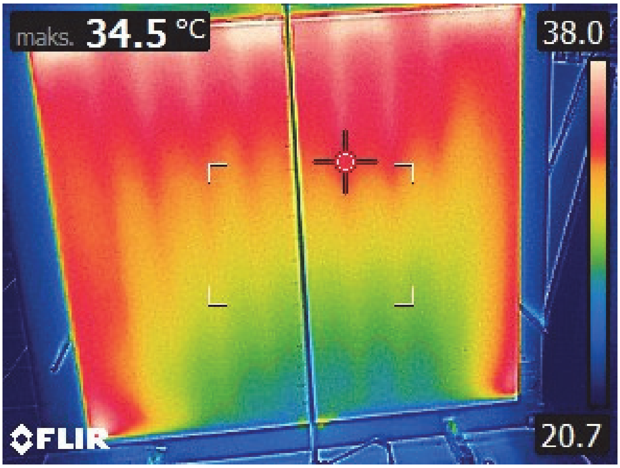

Fig. 8. An example view of the heating plate from a thermal imaging camera

4. Discussion of results, conclusions

The conducted experiment shows that the upper part of the exchanger's hob (fields marked with numbers 1,2,3,4) has the highest temperature, its average is 42°C, slightly lower value of the central part (fields 5,6,7,8) with an average temperature of 41.29°C and the lowest temperature was recorded in the lower part of the plate (fields numbered 9,10,11,12), the average temperature was 39.98°C. The surface, despite the approximate three given average temperature values in each of the tested heights (upper, middle and lower) of the heating plate is not isothermal. Despite the set flow conditions for the three tested different flow rates, the situation is analogous. The way the heater is connected can affect the temperature distribution. In this case, the connection was bottom, middle. The water in the tank is heated by a heater located in the storage heater. During the measurements, the value was observed, but even slight fluctuations certainly affect the result. In addition, the distance between the thermal imaging camera and the hob also plays a role. It was ensured that the measurement was spot-on, it is possible after the correct calibration of the device. The average room temperature, the temperature of other heaters in the room, the air temperature outside the room, additional air vents controlled by the building's air conditioning are also factors that affect the measurements. The work can be related to room heaters which are very popular heat exchangers in our homes. It turns out that many factors influence the proper operation of the heater in the room. Different temperature of the front surface of the radiator does not always mean there is air in the radiator. Temperature differences on the examined surface indicate the intensity of heat transfer, and thus the efficiency along the path of the water stream in the radiator.

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Abstract

The purpose of the work was to perform experimental tests on a plate heat exchanger. For this purpose, a laboratory test stand located in the hall of the Koszalin University of Technology was used. The experiment concerned checking the isothermal face of a flat panel radiator. Temperature distributions were checked at three board heights and in twelve finite elements. Temperature distribution fields were obtained depending on the flow rates tested.

Keywords:
radiator, temperature, convection, isothermal

Badania eksperymentalne rozkładu temperatury na powierzchni płyty czołowej płaskiego, płytowego wymiennika ciepła

Streszczenie

Celem pracy było wykonanie badań eksperymentalnych na płytowym wymienniku ciepła. W tym celu wykorzystano laboratoryjne stanowisko badawcze zlokalizowane w sali Politechniki Koszalińskiej. Eksperyment dotyczył sprawdzenia izotermicznej powierzchni płaskiego grzejnika płytowego. Rozkłady temperatury sprawdzono na trzech wysokościach płyty i w dwunastu elementach skończonych. W zależności od badanych natężeń przepływu uzyskano pola rozkładu temperatury.

Słowa kluczowe:
grzejnik, temperatura, konwekcja, izotermiczność