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EFFECT OF THE INCLINATION ANGLE OF THE CONDENSER ON THE HEAT TRANSFER COEFFICIENT VALUE – EXPERIMENTAL STUDY

Considering problem of the condensation of the refrigerant in a flow inside channel, the attention should be paid to the shape of its cross-section, the hydraulic diameter, the channel length as well as the orientation of the channel axis in space (horizontal, vertical, inclined). This paper presents an experimental study concerning the effect of the inclination angle of the condenser with a single coil pipe on the heat transfer coefficient value. In the laboratory test the air-cooled condenser with R410A refrigerant has been investigated. The results of test have proved that during the condensation in a single inclined pipe channel there is a specific value of the inclination angle at which the highest value of the heat transfer coefficient is obtained.

Keywords: condensation, condensers, heat transfer, heat transfer coefficient

1. Introduction

High-performance heat exchangers (e.g., evaporators and condensers), that have high heat efficiency, are currently used in compressor-based refrigeration installations. The phenomenon of condensation in heat exchangers can occur on a flat surface (in plate condensers), on the external surface of the channels (e.g., in shell and tube condensers) or during the flow of the refrigerant inside the channels (e.g., in air-cooled condensers with external enhancement) [1, 9, 16]. When refining the problem to the condensation of the refrige-

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rant in a flow inside channels, one needs to pay attention to the shape of the cross-section [3, 6, 7] (in the majority of cases, pipe channels with a circular cross-section are used), the hydraulic diameter [5, 8, 14] and the channel length (i.e. a straight segment or a coil pipe), and the orientation of the channel axis in space (horizontal, vertical, inclined) [7, 8, 10, 13]. To increase the efficiency of heat transfer in a condenser an inclination of the condenser may be introduced [2, 4-7, 10-12, 15]. Next sections present the results of an experiment concerning the effect of inclination angle of a condenser on the value of the heat transfer coefficient.

2. Laboratory test bench

An air-cooled lamelled condenser with a single coil pipe, fed with the R410A refrigerant was the object of the experimental study conducted by the authors. In the structure of the coil pipe, segments of a straight horizontal copper pipe with an internal diameter $d = 6.7$ mm and an external diameter of 7.5 mm were used, with each segment length of 750 mm and connected with pipe elbows. The number of straight pipe segments that formed the coil pipe was 16. The total length of the coil pipe was $L_T = 12\,500$ mm (the design index of the coil pipe was $L_T/d = 1866$). From the outside (i.e. from the air side), the coil pipe was lamelled (with the aluminum lamellas 0.15 mm thick and the division of the lamellas 1.3 mm). The computational external heat exchange area of the condenser with a single coil pipe was $A_z = 4.54$ m^2. An axial fan generated air movement through the lamelled coil pipe block, and the lamelled block was placed on the suction side of this fan. The average air velocity in the inlet cross-section to the condenser was determined experimentally and it was equal to 1.45 m/s.

Figure 1 presents a schematic diagram of the air-cooled condenser, which was fed with the R410A refrigerant. The experiment was conducted with two different settings of the condenser. In the first setting, in which the segments of straight connection pipes were parallel to the horizontal plane; in the second setting, the segments were inclined in relation to this plane. The experiment was conducted at a specially designed and constructed test bench (Fig. 2). The air-cooled condenser was placed in an isolated chamber. Superheated vapour of the R410A refrigerant was fed to the condenser while leaving the discharge port of the compressor. The temperature and pressure of the refrigerant were measured on its inlet and outlet from the condenser and on its flow path in the coil pipe.

On the basis of these measurements, it was possible to prepare a distribution of these parameters in the flow path of the refrigerant within the coil pipe. The temperature was measured using K-type thermocouples with a thermocouple wire diameter of $\Phi = 0.2$ mm. Prior to use, the thermocouples were calibrated and their individual characteristics were established. As main

sensors for the pressure measurements, elastic pressure gauges (calibrated) were used. Strain gauges were also used, but only as auxiliary sensors (without temperature compensation). The flow rate of the refrigerant was measured on the side of the liquid with the aid of an electronic Massflow flowmeter manufactured by Danfoss. The liquid flow was monitored with the use of a typical speculum. Changes of the heat load of the condenser were measured as a change in the heat load of the evaporator (an air fan cooler), which was fed with a thermostatic expansion valve TZR that was placed in an isolated chamber. Adjusting elements were used in the chamber (electric heaters). All of the measured signal values were processed using computer measuring cards and were supplied to the computer data acquisition system.
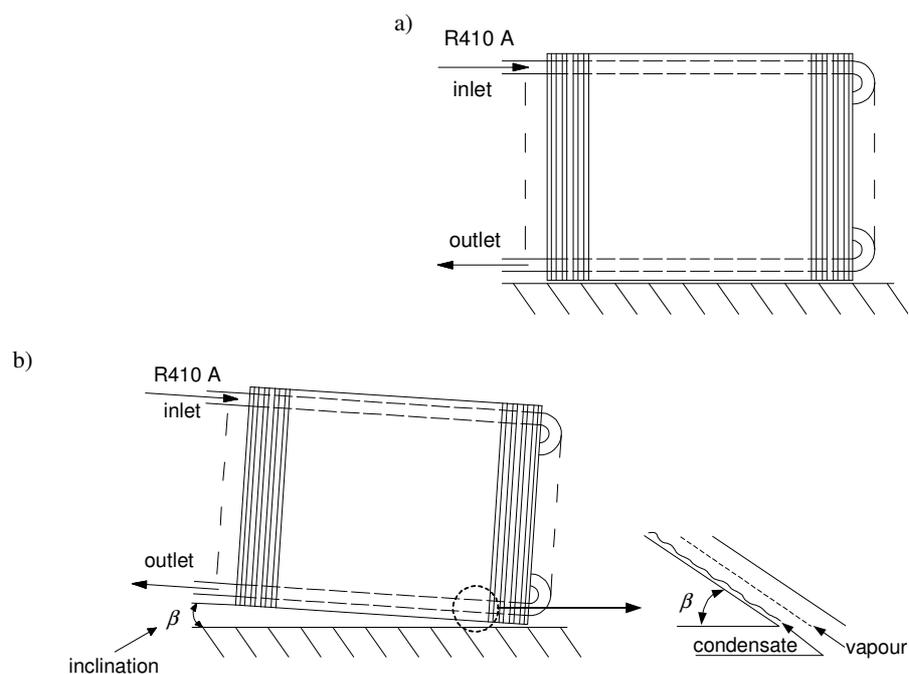
Fig. 1. Diagram of the analysed condenser with the R410A refrigerant; the condenser is situated: a) in parallel to the horizontal plane, and b) at an angle β

The mean heat transfer coefficient value was calculated according to the following expression:

$$\alpha = \frac{k_{in}}{1 - \dfrac{k_{in}}{\varphi \cdot \alpha_{out}}} \tag{1}$$

where: k_{in} - mean heat transfer coefficient through the pipe (determined experimentally), α_{out} - mean heat transfer coefficient at the outside of the pipe (determined according to Gogolin's correlation), φ - degree of the enhancement of the condenser's external surface.
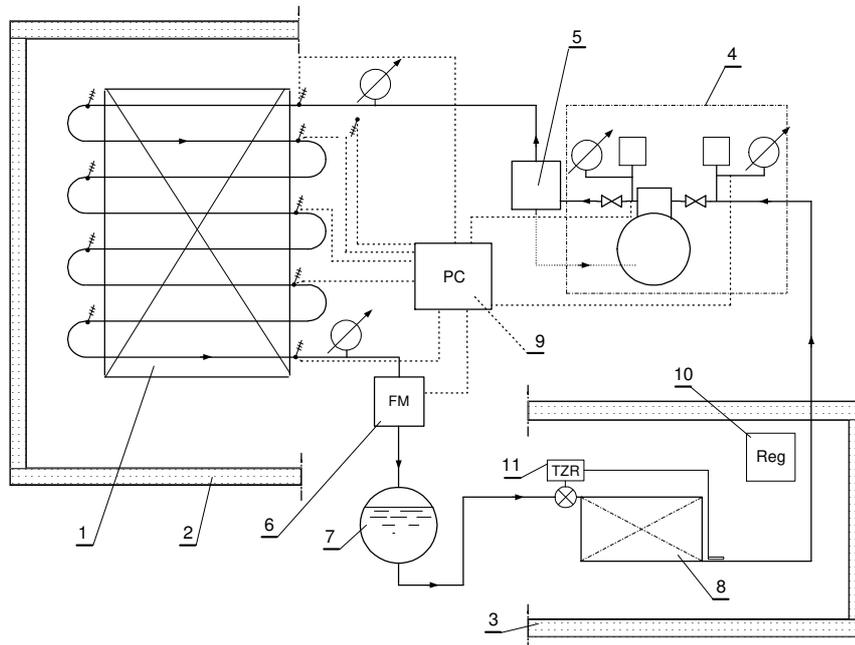
Fig. 2. Diagram of the laboratory test bench: 1 - tested condenser, 2 - isolated condenser chamber, 3 - isolated refrigeration chamber, 4 - compressor installation, 5 - oil separator, 6 - refrigerant flow meter, 7 - liquid refrigerant tank, 8 - evaporator, 9 - measuring personal computer, 10 - heat load adjusting system, 11 - thermostatic expansion valve

3. Results of the experiment

Experimental studies of the condensation of the R410A refrigerant are focused on the interpretation of the impact of the angle β on the effectiveness of the condensation, especially on value of the heat transfer coefficient α. Figure 3 presents mean heat transfer coefficient α values in the area of the two-phase condensation of the R410A refrigerant as a function of the mass flux density wρ, for constant values of the angle β. The characteristics presenting dependence between the heat transfer coefficient α and heat flow density q in a two-phase condensation area of the R410A refrigerant, are shown in figure 4. Figure 5 presents the dependence between the coefficient α and the angle β, when the mass flux density wρ is constant.

The characteristics (Figs. 3-5) of the heat transfer coefficient α allow to determine the effect of the inclination angle β on the condenser efficiency.

Experimental studies were carried out in the range of low values of the angle β (i.e. 0÷13.9°), which can be treated as the most often applied.
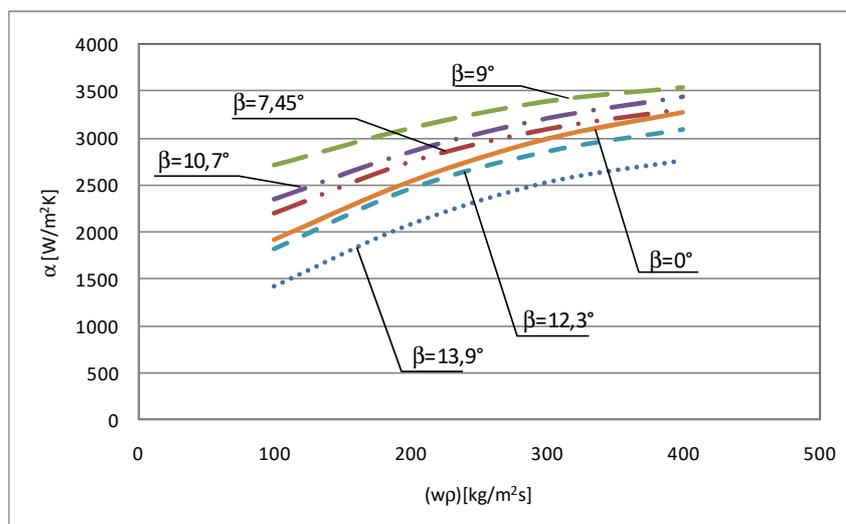
Fig. 3. Mean heat transfer coefficient α in the area of the two-phase condensation of the R410A refrigerant as a function of the mass flux density wρ, for selected values of the angle β
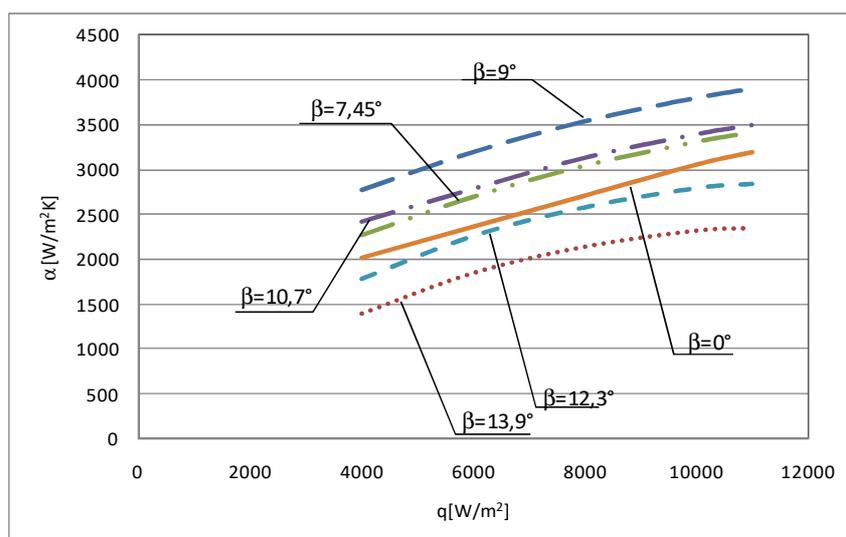
Fig. 4. Mean heat transfer coefficient α in the area of the two-phase condensation of the R410A refrigerant as a function of the heat flux density q, for selected values of the angle β

Relatively low values of the angle represent operation of a condenser in conditions when, due to installing limitations, a condenser cannot be parallel to the horizontal plane. The dependence $\alpha = f(\beta)$ presented in figure 5 enables to conclude that within the range of the values of the angle $\beta = 0 \div 9^{\circ}$ there is an increase of the heat transfer coefficient. Further, for higher angle β ($\beta > 9^{\circ}$) the value of the coefficient α is markedly reduced. Thus, there is the optimal inclination angle β which gives the maximal effectiveness of the condensation.
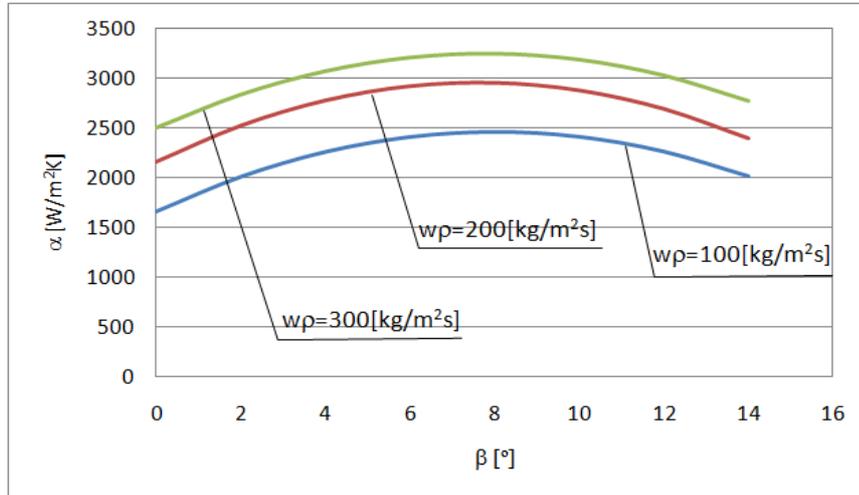
Fig. 5. Mean heat transfer coefficient α in the area of the two-phase condensation of the R410A refrigerant as a function of the angle β, for selected values of the mass flux density (wρ)

It should be noted that the condensation conditions of the refrigerant during a flow in a coil pipe are completely different from those in a straight pipe. In the case of a straight pipe, there is a free outflow of the condensate that is generated in the condensation process of the refrigerant. The inclination of the straight pipe facilitates the outflow of the condensate; however, this is limited, and for angles over 40º, this begins to hinder the outflow. For this reason, the course of the dependences of the heat transfer coefficient from the pipe inclination angle can be justified. For the analysed inclination angle, there were no problems with the free flow of the condensate.

4. Conclusions

The results of the experimental study makeit possible to determine the value of angle β for which the highest value of the mean heat transfer coefficient. This coefficient was obtained in the two-phase condensation area in the coil pipe of the air-cooled condenser that was inclined in relation to the horizontal plane. In the conditions of the experimental investigations of the con-

densation of the R401A refrigerant in the coil pipe, with a design index $L_T/d = 1866$ (L_T is the total length of the coil pipe and d is its internal diameter), the value of the optimal inclination angle of the channel was $\beta \approx 9°$. Higher value of the angle β limited the process of the condensation of the refrigerant. In consequence, it reduced the efficiency of the condensation.

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WPŁYW KĄTA NACHYLENIA SKRAPLACZA NA WARTOŚĆ WSPÓŁCZYNNIKA PRZEJMOWANIA CIEPŁA - BADANIA EXPERYMENTALNE

S t r e s z c z e n i e

Analizując skraplanie czynnika chłodniczego przepływającego wewnątrz kanału, trzeba zwrócić uwagę na kształt jego przekroju poprzecznego, średnicę hydrauliczną i długość kanału, a także usytuowanie przestrzenne osi kanału (poziome, pionowe, nachylone). W artykule przedstawiono wyniki badań eksperymentalnych wpływu kąta nachylenia skraplacza jednowężownicowego na wartość współczynnika przejmowania ciepła. Badano skraplacz z czynnikiem chłodniczym R410A, chłodzony powietrzem. Wyniki badań potwierdziły, że istnieje optymalny kąt nachylenia tego rodzaju skraplacza, dla którego osiąga się największą wartość współczynnika przejmowania ciepła.

Słowa kluczowe: skraplanie, skraplacze, wymiana ciepła, współczynnik przejmowania ciepła