Mathematical model of compressor-condenser unit

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Abstract. The article aims to consider a mathematical model of a compressor-condenser unit, based on the piston compressor with frequency control. The accepted initial data are temperatures and relative humidity of environment and a cooled room, geometrics of the main unit elements. CoolProp library was used for calculation of thermodynamic and thermophysical parameters. The flowchart of calculation of the compressor-condenser unit is provided in the article. The evaluation of the impact of change in environmental relative humidity on the heat transfer coefficient of the condenser has been made.

1. Introduction
Since the late 20th century the issue of working substances in refrigerating engineering and industry continues to be relevant. To control the distribution of substances that deplete the ozone layer, the Montreal Protocol was developed. It is an international treaty designed to protect the ozone layer. It was done to prohibit spread and exploitation of numerous chemical ozone-depleting working substances according to the plan of Montreal Protocol’s developers as represented in the document [1].

The Montreal Protocol was agreed on the 16th of September, 1987, and entered into force on January 1, 1989. It was a suggestion on the ozone layer recovery by 2050, subject to the conditions of the agreement, signed by all countries. Nowadays European Union countries start using ozone-safe equipment, the most of objects put into operation are protected against carbon dioxide that is an alternative refrigerant [2].

In January 2019 the Kigali amendment to the Montreal Protocol was accepted. There was information about future rejection of many groups of cooling agents that are applicable in refrigerating and low-potential engineering [3].

For this reason calculation and modelling of compressor refrigerating machine’s static characteristics are highly relevant. In the modelling there is a possibility to determine many properties of the refrigerating machine in different operating modes, as well as in changing the operating refrigerating machine to an alternative working substance [4].

The precise geometrical parameteres of components are needed in creating the mathematical model of the compressor-condenser unit. Authors [5] came to this conclusion; they found characteristics of the refrigerating machine working on the mixture of the cooling agent using mathematical modelling. Authors [5] concluded that the main affecting things for system’s characteristic are initial conditions, geometrical parameters of machines, the type of refrigerating machine’s components, such as a condenser and an evaporator.

Many researchers in the field of refrigeration and air conditioning seek to reduce energy consumption and focus on researching the capacity regulation methods for one of the main
refrigerating machine’s components, namely the compressor. Capacity regulation reduces cyclic losses of machines and increases reliability of the compressor by reducing pressure difference when working with partial capacity [3].

There are a lot of capacity regulation methods, namely: a bypass method, implementation of additional dead space, steam throttling on absorbing and smooth variation of shaft speed. The characteristics in using the above methods of regulation compressor’s capacity are described by authors Tassou S.A. and Qureshi T.Q. [8] and authors of [9-10].

2. Research methods
This paper considers the mathematical model of the compressor-condenser unit, based on the piston compressor with frequency control.

Data of calculating the characteristics of the one-step compressor-condenser unit based on a piston compressor obtained using implemented subprograms, namely characteristics of the compressor - subprogram XAR_CM and characteristics of the condenser - subprogram XAR_CD, which are consolidated into a single program – XAR_CMCD. The flowchart of the program XAR_CMCD is depicted in figure 1.

The known input signals are the temperature of the air in the room and the ambient temperature. Using these entry conditions and having the geometrical parameters of the compressor and the air condenser, there is a possibility to calculate all the parameters of the compressor-condenser unit at target temperatures both by the air and by the working substance.

The main thermodynamic and thermophysical properties of normal working substance are calculated using the CoolProp property library [12]. This library is supported by the majority of programs and programming languages used in the mathematical modelling. It has free distribution.

The main equations and algorithms of components of the compressor-condenser unit with the piston compressor implemented on ECM are based on material contained in paper [6].

There are some assumptions during modelling:
- overheating cooling agent on absorption is constant for all concerned operating modes of the compressor-condenser unit.
- all components of the compressor-condenser unit are connected in series, and mass flow through the components is unchanged.
- overcooling of the refrigerant lower than the condensing temperature for all operating modes is equal to zero.

It should be noted that for calculation of the heat-transfer coefficient for condensation inside horizontal tubes the model equation of Ackers and Rosson (1960) is used in the form [7]:

$$\text{Nu} = 0.1 \cdot \text{Pr}^{1/3} \left( \frac{r}{c_p \Delta T} \right)^{1/6} \text{Re}^{2/3} \left( \frac{\rho_l}{\rho_v} \right)^{1/3}, \quad (1)$$

where $\rho_l$, $\rho_v$ are the density of the liquid and vapor in kg/m$^3$; $c_p$ is heat capacity in kJ/(kg·K), $r$ – specific heat of vaporization in kJ/kg.

In considering the convective heat transfer in the flow around the tube stack on the side of the air, a universal formula is used. It takes into account the type of the tube stack, the initial data for the calculation are the same. Accordingly, by comparing the contacted computations with the calculations performed by the formula of D. M. Ioffe for staggered tube bank [11], the error of the calculations did not exceed 1 %:

$$\text{Nu} = c \cdot \text{Re}^n \left( \frac{L}{d_{eqv}} \right)^m, \quad (2)$$
where \( L \) is depth of heat exchanger in m, \( d_{eqv} \) is equivalent diameter in m.

**Figure 1.** The flow chart of the program, implementing calculation of characteristics of the compressor-condenser unit

### 3. The results of the study
When considering the obtained data as a result of the program according to the algorithm presented in figure 1, it is possible to make a conclusion about the influence of the size of difference in air...
temperatures on an input and an output from the condenser of air cooling and the average logarithmic of a pressure in the device. Regarding the influence of relative humidity at the input to the condenser, it was found that it was insignificant. The maximum discrepancy of the temperature difference at the inlet and outlet of the air condenser is manifested only at ambient temperatures of more than 45°C and it is about 3 %. These characteristics are presented in figure 2 as the dependencies $\theta_m = f(t_{amb}, t_c)$ and $\Delta t_a = f(t_{amb}, t_c)$.

Figure 2. The characteristics of the air condenser

4. Conclusions
The mathematical model of the compressor-condenser unit was created. With its help, it is possible to obtain the parameters of the unit when working on any working substance and in operating mode.

In calculating the heat-transfer coefficient, it is possible to ignore the influence of the relative humidity of the environment. According to the calculations, it was found that its impact is insignificant.

It is necessary to continue this investigation including in the mathematical model of the subprogram of the evaporator to analyse the operation of the entire refrigeration machine as a whole.

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