Heat pump and orc as part of an energy technology complex of water desalination

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Abstract. The article considers the processes of modeling the flow of a refrigerant and presents the results of numerical simulation of freon evaporation in a tubular evaporator. The results show the effect of convective heat transfer and bubble formation on the heat transfer coefficient. It is assumed that this technology can be used, among other things, as an element for water desalination. The possibility of using heat pumps and the organic Rankine cycle in the scheme of water desalination is considered. The authors propose to design such energy-technological complexes, starting from the stage of numerical simulation. The modeling results and the developed schemes presented to the attention of readers are part of a unified methodology for heat pumps and desalination systems.

1 Introduction

The heat pump can be included in the technological setup for the purpose of heating water, such as a desalination or water treatment system. The principle of operation of a heat pump is based on a closed system with a circulating refrigerant (Freon), whose boiling point is only about 4°C. Chemical water treatment and other water treatment processes, as well as steam production chains, solar testing and other work to meet energy needs can be loaded into the energy technology complex to achieve the best quality results and implement chemical water treatment and other processes as efficiently as possible [1, 2]. Chemical water treatment in some conditions is part of the energy technology complex, as an additional layer to control and maintain the protection of the ecosystem from pollution. It can be part of the energy technology complex, depending on its nature. The utilization of chemicals in water treatment is a critical factor within the energy sector, as it enables water to be utilized in a wide array of applications, from energy production to waste management. By treating the water with specific chemicals, it can be made suitable for use in any number of processes [3, 4]. It helps improve water quality, prevent corrosion, improve heat transfer efficiency and reduce pollution. Evaporators are divided into types depending on the type of medium to be cooled: air, liquid and solids [5, 6]. The shell and tube evaporator consists of steel cylinders with copper tubes pressed into steel grids through which water flows. Plate evaporators consist of rows of steel plates arranged in a herringbone pattern. Evaporators for air cooling consist of thin copper tubes with a diameter of 8-13 mm and aluminum fins, between which air passes.

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The size and total cooling capacity of the evaporator are determined by the volume of the cooled air, as well as the evaporation temperatures of the refrigerant and the incoming air. The power range of these devices ranges from 7 to 200-250kW. Evaporator pressure loss depends on the diameter of the evaporator tubes, fan configuration, airflow rate and the amount of condensate leaving [9, 10]. At the moment, seawater desalination schemes are on an industrial scale in countries with a hot climate and in the absence of fresh water sources. But, it should be emphasized that in such areas it is necessary to develop industry. Production processes at enterprises in most industries are accompanied by the consumption of water. At the same time, enterprises of some industries and energy facilities consume an amount of water that often exceeds the water consumption of residential complexes. Having access to high quality water is imperative for industrial businesses as it significantly impacts their product cost and quality. An appropriate and superior water supply for these companies is key for their smooth operations and thus has a substantial economic effect.

2 Materials and methods. Scientific novelty

In practice, researchers are faced with the problem of determining the heat transfer coefficient when solving the problem of heat transfer and fluid motion together. This statement is valid both for water and water vapor, and for a mixture of freon in the liquid and vapor phase. At the moment, a lot of research on this topic has been carried out, mainly by numerical simulation methods. In particular, the movement of water and its evaporation in a static state, as well as in motion, have been studied in detail. For example, such problems often occur during heating in heat exchangers. Often such devices are boiler units and heat exchangers of a recuperative type with a change in the phase of steam and liquid. For the process of designing and assembling technical complexes, it is first necessary to develop in detail a model that describes one or another thermophysical process. The Freon is circulated, allowing it to transfer heat and cool the air. This process of Freon's movement is essential for the heat exchanger to function properly. It is best to use numerical simulation methods, in particular computer models based on material data and boundary conditions. Numerical simulation helps to avoid unnecessary physical experiments if these experiments are expensive. Computer simulation should be considered as the most inexpensive and accurate design method. At present, there is no single approach for calculating the heat transfer coefficient or for describing the thermophysical picture of boiling in a liquid flow [11, 12]. However, numerous empirical methods have been developed to calculate heat transfer on various refrigerants under conditions of low pressure (up to 2-4 atm) and mass flow, as well as special formulas for calculating heat transfer to small channels, for example, 1 mm in diameter, at certain values pressure [13, 14].

Bubble boiling is a heat transfer process in which heat is transferred from a liquid to the boiling surface by evaporation of the liquid. According to standard calculation methods, the heat transfer coefficient shows the intensity of heat transfer from the liquid to the surface at a known temperature difference [15, 16, 17]. Freon evaporation process was simulated by the finite element method in the ANSYS. Modeling of freon boiling is necessary for a visual representation of the process of the phase separation as steam bubbles form in a pipe that has a diameter of 25mm and a length of 1m. Modeling of freon boiling during the flow in the evaporator tube showed satisfactory convergence with the k-ω SST turbulence model.

The prediction of temperatures, velocities or pressures is main parameter that affects the design features. In particular, in the case under consideration, the freon temperature at the outlet of the tube is decisive for designing the length of this tube, and, consequently, for the amount of material used.

The results of the studies presented in Figure 1 turned out to be quite interesting. The authors would like to note that the appearance of freon bubbles in the movement area indicates the beginning of the boiling process. For example, at the initial stage, the number of such bubbles is insignificant and depends on the intensity of heat supply in the area. Subsequently, the number of bubbles will increase, and the intensity of heat supply at some point in time will reach the limit. Once the heat transfer has begun, the temperature will become more consistent across the length of the tube over time.

Numerical simulation data showed that the heat transfer coefficient increased to the area of intense evaporation at a distance of 0.9 pipe length from the inlet. Behind this section, a decrease in heat transfer is observed along the way to the outlet section.

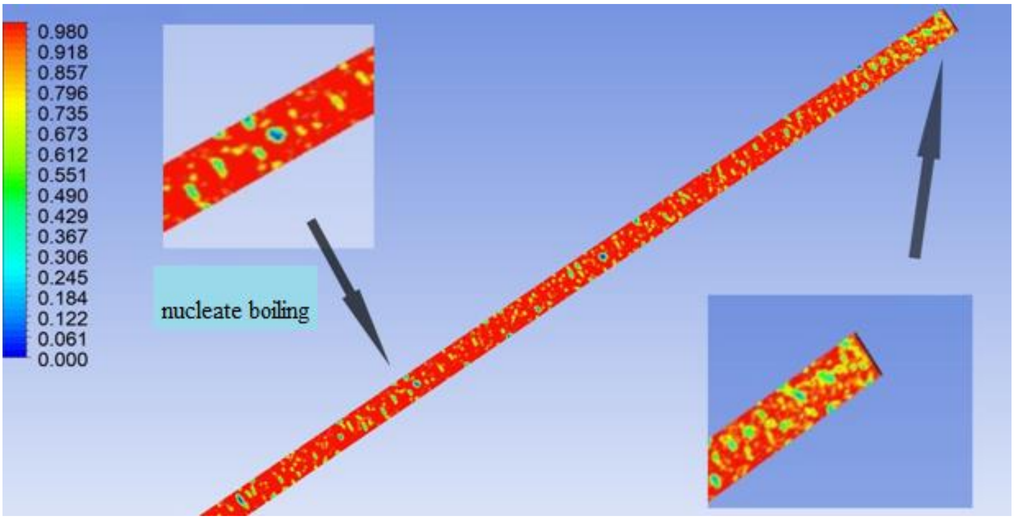

Fig. 1. The ratio of steam and liquid in the evaporation process.

3 Results. Practical significance

At many thermal power plants, the temperature of incoming raw water in summer and winter is approximately from 15℃ to 5 °C. In figure 2 TPP- thermal power plant, CTW- chemical treatment of water, HP- heat pump shows the opportunity of using heat pumps. To accurately simulate the movement of freon, it is necessary to develop theoretical and practical models of thermodynamic and heat and energy content. The entropy of the system must be maximized in order to reach a state of equilibrium. However, external factors can interfere with this process, bringing the system to a stationary nonequilibrium state, which is characterized by a minimum value of the entropy index. In addition, additional effects must be taken into account when implementing new methods of numerical simulation.

During the operation of heat pumps using freon, the temperature ranges are shown, for which the values of pressure in the evaporator and condenser are selected. The upper pressure limit is achieved by the operation of a compressor that compresses freon vapor. The minimum temperature is achieved through the use of an expansion valve or a turboexpander in an organic Rankine cycle. The outcomes of the simulation concerning freon temperature are novel. These results can be implemented in the development of energy technology complexes. For instance, it is possible to set the temperature at the outlet of the evaporator to achieve a freon boiling model, and then determine how far from the start of the heat exchange tube the boiling stops and vapor phase takes over.

In addition, the authors would like to note the possibility of using the obtained results in enterprises with high water consumption and sanitation. In particular, waste water from the enterprise can be used as a low-potential heat source, and the heat pump condenser can be used to heat water in a water treatment system or in a desalination system. Thus, it is possible to obtain a closed cycle of operation of an industrial enterprise using water sources.

4 Discussion

The heat pump is an integral part of the energy technology complex. Modeling in this work was carried out for freon R-113. Bubble boiling of this refrigerant is described in the work. Empirical data have shown the influence of both the convective heat transfer process and the boiling process on the heat transfer efficiency. This fact can correlate with the effect of reduced heat transfer at the exit from the evaporator tube in the model. Thus, if acceleration contributes to the detachment of bubbles from the surface, it is possible to use a formula to describe heat transfer under the conditions created.

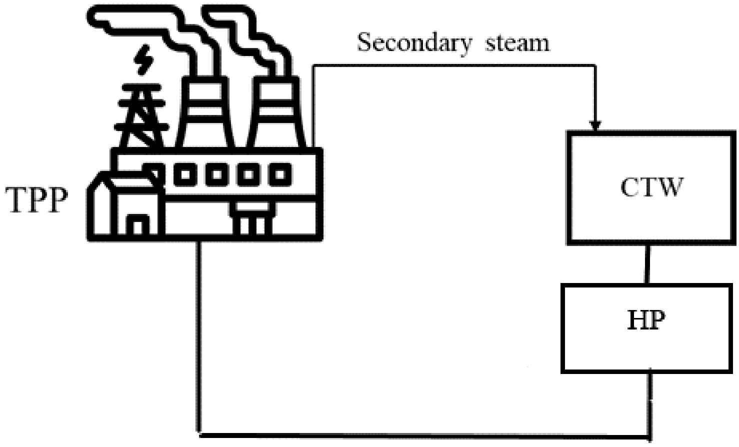

Fig. 2. Energy-technological complex of using a heat pump.

Let's imagine a description of the scheme of operation of a heat pump in water treatment or desalination systems, since the principle of operation will be similar. A sufficiently large amount of steam is generated at a thermal power plant, including flash steam. This steam is used in a water treatment or desalination system. Any water treatment or desalination system has waste water at relatively low temperatures. However, small, but constantly discharged volumes of water are sufficient for the operation of the heat pump. Thus, the authors propose to use waste (waste) water from water treatment or desalination systems for the operation of a heat pump in which freon is the main coolant. It was necessary to conduct a numerical simulation of the freon boiling process due to its low boiling point. The purpose of the study was to measure the amount of heat that is exchanged at the surface. The quality of water from natural sources and water for industrial enterprises is assessed in terms of the standards applicable to water consumers. Water quality assessment makes it possible to use it at an industrial facility. By analyzing the water, its compliance with the physical and chemical properties required by the enterprise is determined. It is essential to assess the quality of the water source in order to decide the type and degree of water treatment required. To examine the water for hardness, sodium cationization is done as a means of evaluating the water quality at any given business. Calcium and magnesium hardness salts are responsible for carbonate hardness.

Relatively hard water is used for drinking, since the presence of hardness salts in water is not harmful to health. To ensure that the water quality in technological systems is up to standard, the guidelines for the prevention of scale buildup must be adhered to. Additionally, oxygen, carbon dioxide, and hydrogen sulfide, which are all aggressive gases, must be taken out of the supplied water as they have the potential to activate corrosion of the pipes. The corrosion process increases with increasing water temperature, as well as with the movement of water along the metal walls. With a significant content of carbon dioxide, concrete pipes are susceptible to corrosion. Obviously, the presence of dissolved oxygen in water is not suitable for steam boilers. Therefore, the use of the system shown in Figure 2 will lead to more efficient use of the cycle and increase the reliability of the equipment. It should be recognized that the information obtained as a result of conventional physical and chemical tests is insufficient for the design of large-scale energy systems. The water under study requires a special technological analysis, which will provide additional information for deciding on the most reliable and economical method of purification or desalination. The complexity of the phenomena occurring in a moving medium and the impossibility of studying only theoretically and experimentally lead to the use of numerical simulation methods in projects. A rise in the effectiveness of computations and engineering is the primary cause for this. The technique used to examine the boiling process in a flowing stream is not only founded on experimentation, but also involves using computer systems to simulate the motion, heat exchange, and boiling.

The properties of freons are different, therefore the presented solution of the problem can only give an unambiguous answer in a particular case. If it is necessary to consider another type of freon, the algorithm passed as a result of numerical simulation of the boiling process should be repeated. This is necessary because the properties of the refrigerant have changed, which can lead to a shift in the area where the boiling process begins.

5 Conclusion

In order to understand the calculations in high-tech innovation technology, we should use the following methods should be used. This includes both the analysis of current data and the study of recently proposed calculations. The development of such a model will make it possible to predict the dynamics of energy exchange processes and optimize their control parameters. The main provisions of the study can be reduced to a proposal. Researchers utilize a computer program to analyze models of refrigerant. The data obtained from the calculation of the refrigerant's representation is then used to determine the amount of heat released from the heat exchanger. The data obtained from the calculation of the results of the studies determine the heat transfer coefficient, which was practically impossible to conduct studies for the refrigerant in motion. Using a heat pump or an organic Rankine cycle as part of a desalination plant is a possible solution. The design of the energy-technological system includes the numerical examination of the processes related to the refrigerant. Modern technologies based on renewable energy sources owe their development to the development of such applications as Ansys, Matlab, etc. The use of computer simulations can streamline the design process and enhance the dependability of structures. Additionally, the authors believe that computer modeling is a necessary part of the modern scientific development of energy technology complexes.

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