Heat exchange at the boiling of ozone-safe refrigerants and their oil-freon mixtures

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Abstract. The object of research is the processes of heat and mass transfer during phase transitions of ozone-safe refrigerants and their oil-freon mixtures on smooth finned and capillary-porous heat-transfer surfaces of industrial heat exchange apparatuses.

The purpose and objectives of the research was theoretical and experimental research of processes of heat transfer in developed bubble boiling of ozone friendly refrigerant and oil-refrigerant mixtures on smooth and developed surfaces of heat exchange by establishing relationships to determine the coeffi-cients of heat transfer and influence of the various factors that determine the intensity of heat transfer at phase transitions in devices of refrigeration, heat pump systems and air conditioning systems; the estab-lishment of the mechanism of heat transfer processes during evaporation of oil-refrigerant mixtures. De-velopment of practical recommendations for the calculation and design of high-efficiency heat exchange equipment, reducing the material consumption and weight and size indicators of heat exchangers. Development and implementation of improved performance vaporizers and condensers for refrigeration, heat pump installations and air conditioning systems.

For the first time, experimental studies of heat exchange processes during the boiling of refriger-ants and their oil-freon mixtures on various surfaces in a wide range of thermal loads (2,9...100,8 kW / m2). Graphic dependences of the heat transfer intensity on the operating parameters of the boiling process and other characteristics are obtained.

The results of the work are implemented in the technological process of VESA LLC and in the educational process of Sukhoi state technical University for lectures on the disciplines "heat and mass Transfer" and "Industrial heat and mass transfer processes and installations".

The results obtained can be used in the development and creation of highly efficient evaporative heat ex-changers.

1. Introduction

Currently, more and more attention is paid to the search for the most efficient and safe Heat exchangers are widely used in energy, chemical, oil refining, aviation and space technology, food industry, in refrigeration and cryogenic technology, in heating and hot water supply, air conditioning, in various heat engines. With the growth of energy capacities and production volume, their mass and dimensions are increasing, which leads to the consumption of a large number of alloyed and non-ferrous metals. In this regard, reducing the overall dimensions of heat exchangers is an urgent problem. A significant contribution to solving this problem can be made by the introduction of scientifically based and experimentally tested methods of intensifying heat transfer during boiling. Therefore, the creation of heat and mass transfer apparatuses with developed heat transfer surfaces is one of the promising directions for organizing the heat transfer process during boiling of liquids [2].

Despite the large number of works on heat transfer during boiling, their results do not fully reflect the heat transfer processes on developed surfaces. For the conditions of "constraint" and the difficult removal of the vapor phase, literary data are practically absent. Therefore, the size and optimal parameters of the heat transfer surfaces of a number of heat exchangers used in power plants of various industries cannot be determined without sufficient knowledge in this area. There are also practically no studies of the processes of boiling of contaminated liquids (oils, etc.), where finned surfaces have an undeniable priority. When boiling liquids on fin surfaces with different types of finning, the specific features of heat transfer and hydrodynamics associated with the influence of the parameters and orientation of the ribs have not yet been fully studied. The available data are insufficient to determine the optimal geometric parameters of the rib and intercostal distance, which are largely determined by the properties of the working fluid and the pressure in the system [1].

Currently, newly manufactured equipment for refrigeration, heat pump systems and air conditioning systems should operate on ozone-safe refrigerants with low global warming potential (R134A, R404A, R407C, R410A). However, when they are used in plants, an oil-freon mixture is formed, which leads to a change not only in the intensity of heat transfer during boiling and condensation, but also in a change in the mechanism of these processes. Changing the composition of the refrigerant during operation of the installation also complicates the regulation of operational parameters and leads to a change in heat transfer coefficients in the evaporator and condenser. This, in turn, affects the efficiency of the processes occurring in them. In this regard, it becomes relevant to study the processes of boiling and condensation of oil-freon mixtures in refrigeration and heat pump units in order to increase the intensity of boiling and condensation processes on heat transfer surfaces and to increase the overall dimensions of apparatus units. In this regard, it becomes relevant to carry out theoretical and experimental studies of heat transfer processes during phase transitions of pure refrigerants and their oil-freon mixtures on smooth and developed surfaces of various types, as well as obtaining generalized dependences for calculating the heat transfer intensity of boiling and condensation processes. This is possible only on the basis of theoretical and experimental studies with their subsequent application for the calculation and development of heat exchangers for refrigeration, heat pump units and air conditioning systems [3].

2. Description of the experimental stand

To study the heat transfer during boiling of liquids, ozone-safe refrigerants and their oil-freon mixtures on heat-transferring surfaces at the Department of Industrial Heat and Power Engineering and Ecology of the Educational Establishment of Gomel State Technical University named after P.O. Sukhoi, a comprehensive experimental installation was developed, shown in Figure 1. The operation of the installation is regulated in a wide range of thermal (up to 100,8 kW/m^2).

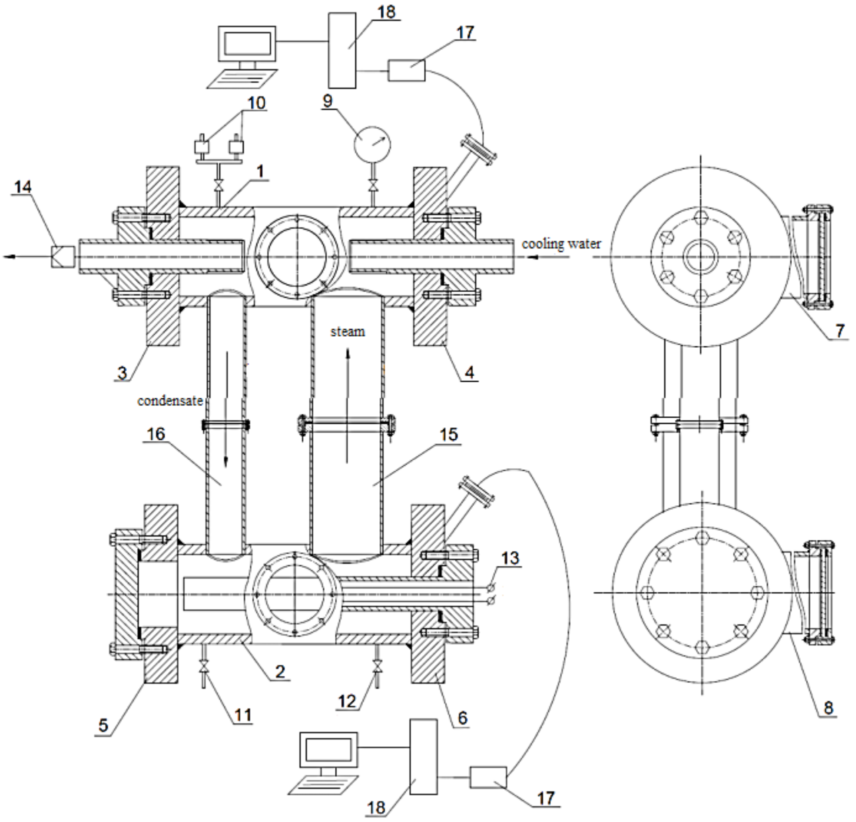

Figure 1. Comprehensive experimental bench: 1, 2 - working chambers; 3, 4, 5, 6 - flanges; 7, 8 - viewing windows; 9 - pressure gauge; 10 - safety valve; 11, 12 - valve; 13 - heater; 14 - flow meter; 15 - steam channel; 16 - liquid channel; 17 - analog-to-digital Converter; 18 is a computer.

The working chambers of installation 1 and 2 are made of stainless steel 1X18H9T and are cylinders with a diameter of 150 mm and a length of 310 mm. The axes of the working chamber are located horizontally. The side walls of the cylinder have viewing windows through which visual observations of the processes of boiling and condensation are carried out.

The working chambers 1 and 2 are closed by flanges 3, 4 and 5, 6. Connectors for supplying thermocouples are mounted on flanges 4 and 6. In the middle of the cameras, viewing windows 7 and 8 are provided for visual observation of the processes of boiling and condensation on the surface of the samples. A pressure gauge 9 and safety valves 10 are installed on the working chamber 1 (condensation chamber), and valves 11 and 12 are installed on the working chamber 2 for boiling gas when checking for leaks, when changing samples, discharging working fluid and evacuating the working chamber 2 (boiling chamber).

The necessary pressure in the chambers is created and maintained by adjusting the load supplied to the heater 13 of the boiling chamber 2 and changing the flow of cooling water in the condenser 1. The flow of water is controlled by the flow meter 14. Pressure is controlled by a pressure gauge and two thermocouples located in the liquid volume and steam space. The experimental samples are installed using a threaded connection in chamber 1 and a flange connection in chamber 2. Heat flow to the sample is supplied by an electric heater 13. The steam and liquid circulation in the installation is provided by steam 15 and liquid 16 channels.

The experimental samples are horizontal pipes made of D16 duralumin, on the outer surface of which thermocouples are installed in the required places.

The temperature difference between the heating surface and the liquid in chamber 2 and the vapor temperature and the surface in chamber 1 are measured directly by differential thermocouples, one junction of which is located in the sample, and the second in the liquid or vapor. Thermocouple wires are checked for uniformity. To convert the values of thermo-EMF into degrees, calibration tables are used. To take into account the error that occurs during manufacture, assuming that the thermo-EMF varies linearly with temperature in the operating range, thermocouples are calibrated using a V7-16A electric millivoltmeter and a TSP-1 reference platinum resistance thermometer against reference points for ice melting and boiling water. For measurements, thermocouples are used, in which the deviation of the experimental values of thermo-EMF from the table does not exceed 1.5%.

The liquid level above the upper generatrix of the sample of chamber 2 is ~ 50 mm, which ensures independence of the heat transfer rate during boiling relative to the liquid column above the heating surface. Before conducting experiments to remove bubbles of non-condensable gases, the samples are boiled for several hours. After disconnecting the heat load, stopping boiling on the surface of the samples and establishing the experimental conditions, the heater is turned on to supply the heat flux to the surface of the test sample. The saturation conditions in the experimental chamber 2 are supported by controlling the flow of coolant through the condenser 1. The saturation temperature is determined by two thermocouples placed in the liquid and the vapor space. Saturation pressure was monitored using an exemplary pressure gauge 9.

The measuring system is a complex consisting of an analog-to-digital converter 17 and computer 18. The measurement process is controlled by a data processing program. The exchange of control and feedback signals between the computer and the measuring devices takes place via the measuring buses.

Thermocouples are automatically interrogated using an analog-to-digital converter, and then the measured temperature value in the form of thermo-EMF is sent to a computer, where the data processing program translates the thermo-EMF values into degrees. Cold junctions of thermocouples, which maintain the saturation temperature inside the experimental chamber, are placed in a thermostat, where the temperature is maintained at 0 ^{0}C. The heater is connected to a 220V network through a laboratory autotransformer. To determine the input power, the current is measured with an ammeter, and the voltage with a voltmeter. The power supplied to the heater is controlled by a laboratory autotransformer. The measuring system operates in a cyclic mode of polling thermocouples after a certain period of time. The polling rate is 10 measurements per second. The duration of the exit of the temperature of the heating surface to the stationary mode is 15 ... 60 minutes. After reaching the established heat transfer mode, determined by the displayed data on the display, the thermocouple readings are recorded. Before installing the sample, the inner walls of the experimental chambers and the heat exchange surface are thoroughly cleaned and wiped with ethyl alcohol. After sealing, air is removed from the chamber using a vacuum pump, then the test liquid is poured into the volume of the working chamber 2. Then, the amount of heat input is changed and the procedure is repeated for the next experimental point. Research is carried out with a gradual increase in heat load until its maximum value is reached, then the heat flux decreases. The error in determining the heat transfer coefficient does not exceed 15%. The measuring system for the condensation chamber 1 is made similarly to the measuring system of the boiling chamber 2.

The measuring system for the boiling (Figure 2) chamber is a complex consisting of the SOSNA-002 analog-to-digital converter and an acer laptop.

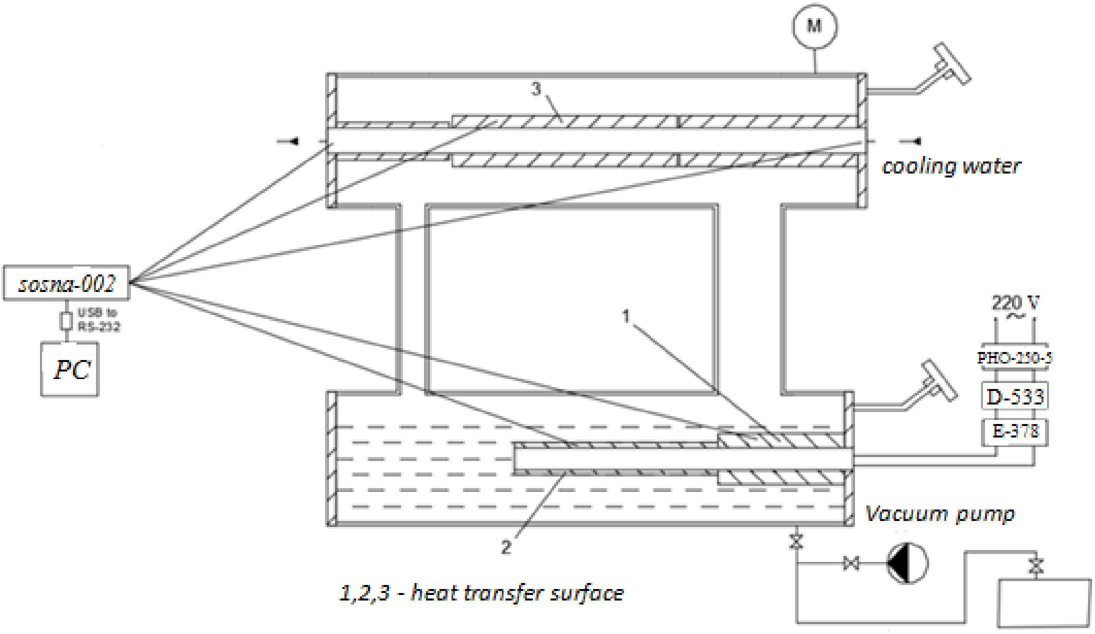

Figure 2. Measurement scheme of the experimental setup

The measuring system for the boiling chamber is a complex consisting of the SOSNA-002 analog-to-digital converter and an acer laptop. The measurement process is controlled by the SysView2 data processing program. The exchange of control signals and feedback signals between the laptop and measuring instruments takes place using the USB-RS232 adapter. Thermocouples are automatically interrogated using the COSNA 002 analog-to-digital converter, then the measured temperature value in the form of thermo-EMF is sent to a computer, where the SysView2 data processing program converts the thermo-EMF into degrees. The heater of the working section is connected to the 220 V network through the laboratory autotransformer RNO-250-5. To determine the input power, the current is measured with a D553 type ammeter, voltage is measured with an E-378 type voltmeter. The power supplied to the heater is controlled by the laboratory autotransformer RNO-250-5. The measuring system operates in a cyclic mode of polling thermocouples after a certain period of time. The duration of the temperature of the heating surface to reach the stationary mode ranges from 15 to 60 minutes. After reaching the established heat transfer mode, determined by the displayed data on the display, the thermocouple readings are recorded.

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The measuring system for the condensation chamber is made similarly to the measuring system of the boiling chamber.

3. Experimental studies of heat exchange at boiling of pure r404a, r407c, r410a on heat-surface surfaces

The study was carried out on samples smooth and with longitudinal finning at heat flux densities in the range of 2.9-100.8 kW / m2, saturation pressures from 0.74 to 1.62 MPa (saturation temperatures t_c = 9.5-35 °C). Figure 3 shows the location of thermocouples on the samples under study.

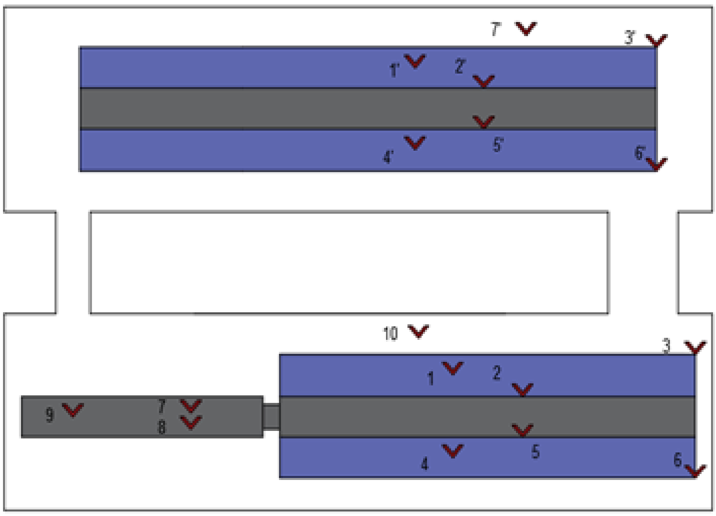

Figure 3. Schematic layout of thermocouples on installation samples: 1, 2, 3, 4, 5, 6, 7, 8, 9.10 - the location of thermocouples in the evaporator; 1 ’, 2’, 3 ’, 4’, 5 ’, 6’– location of thermocouples in the capacitor.

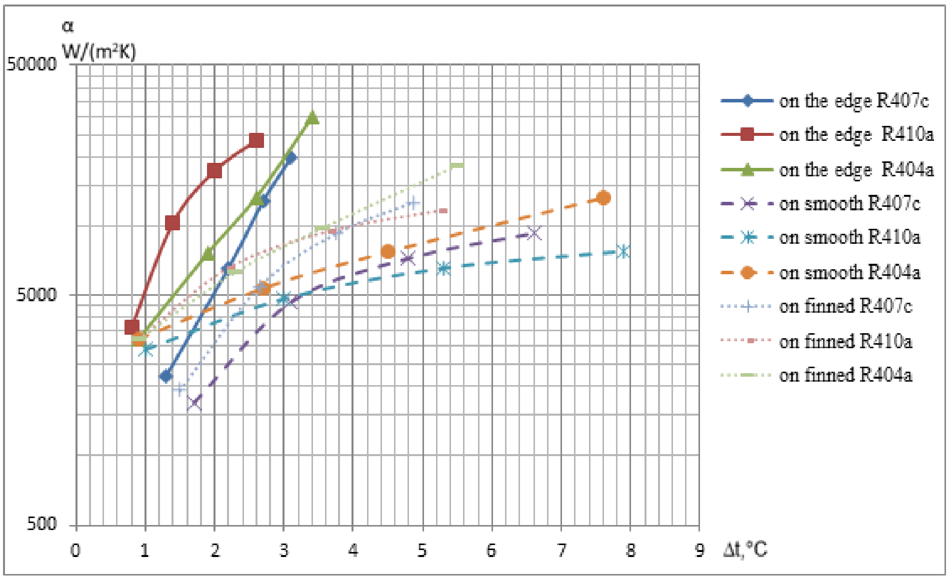

Figure 4. Graphical dependence α = f (Δt) established in the study of heat transfer at boiling R404a, R407c, R410a on a smooth, intercostal space and finned surfaces

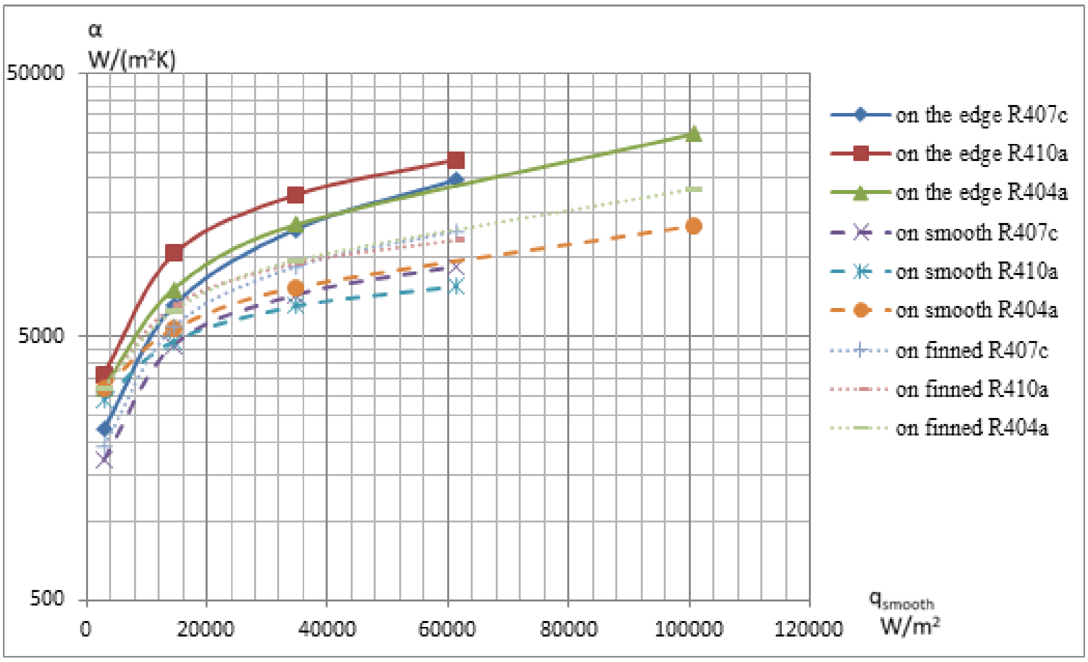

Figure 5. Graphical dependence $\alpha = f(q_{gl})$ established in the study of heat transfer during boiling of R404a, R407c, R410a on smooth and ribbed surfaces

4. Heat exchange at the boiling of oil-freon mixtures r404a, r407c, r410a on smooth and ribbed heat-surface surfaces

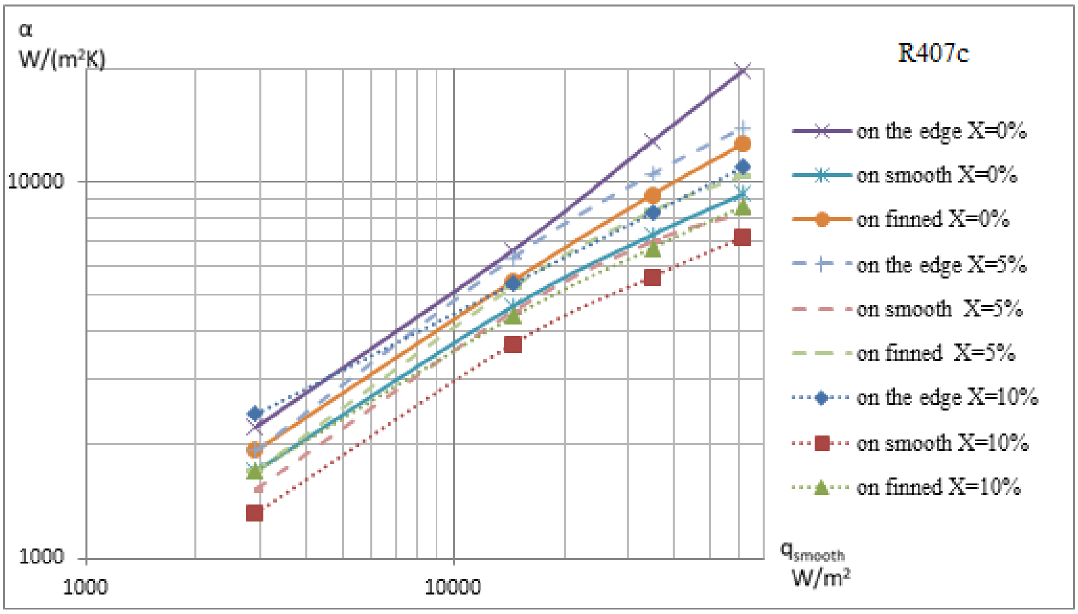

Figure 6. Graphical dependence $\alpha = f(q_{gl})$, established by boiling pure R407c and its oil-freon mixture on the rib, intercostal surface and finned surface

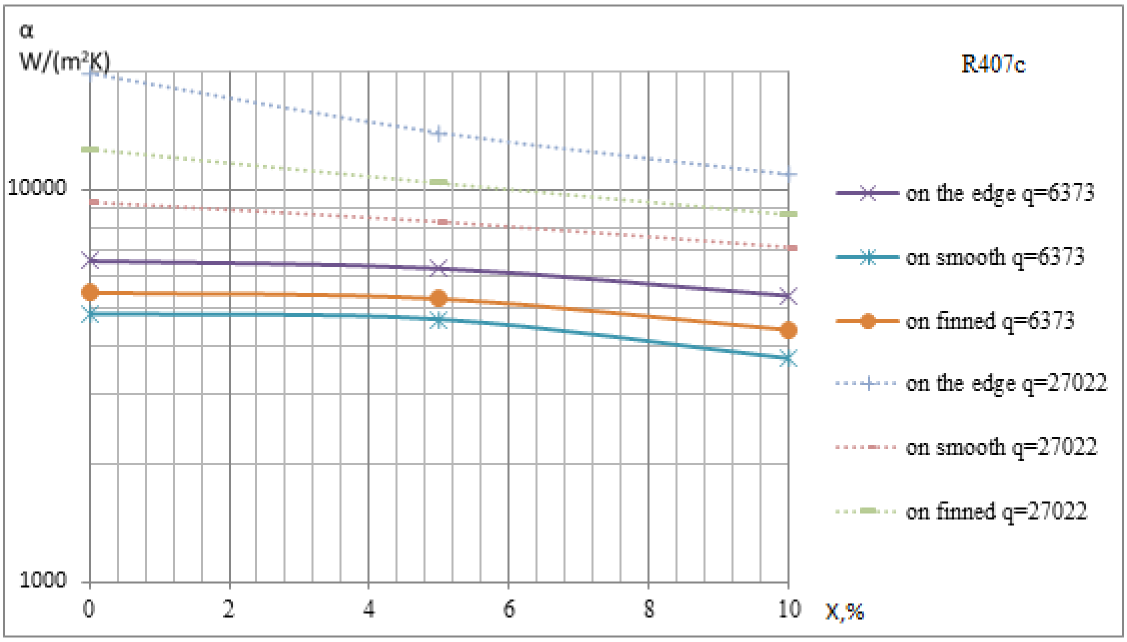

Figure 7. Graphical dependence α = f (X) established upon boiling of pure R407c and its oil-freon mixture on the rib, intercostal surface and finned surface

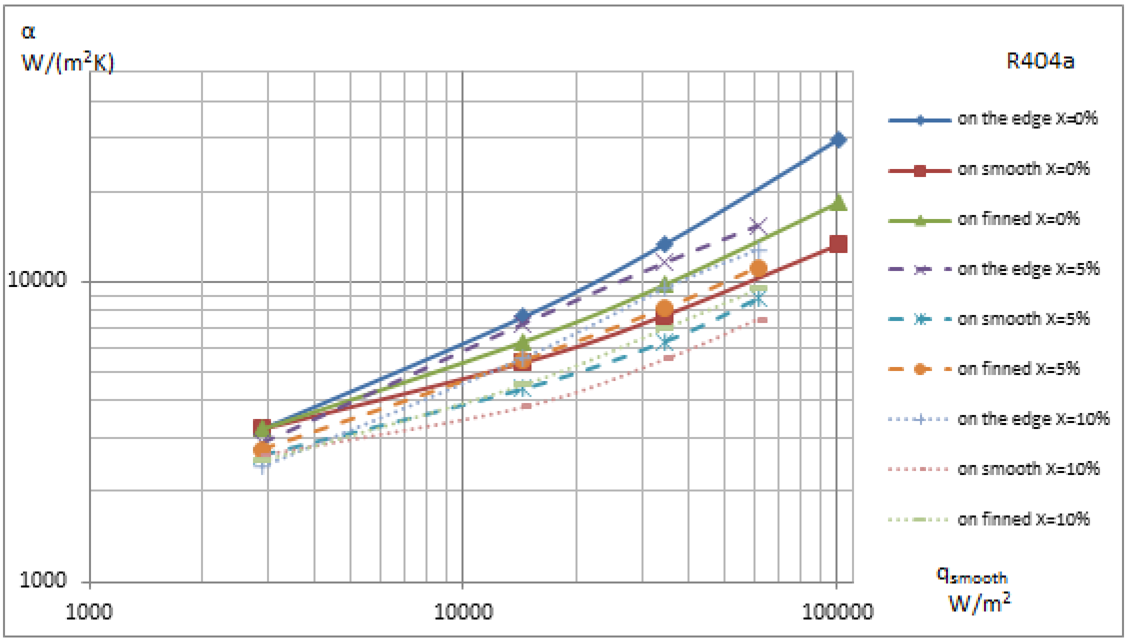

Figure 8. Graphical dependence α = f (q_{gl}) established by boiling pure R404a and its oil-freon mixture on smooth and ribbed surfaces

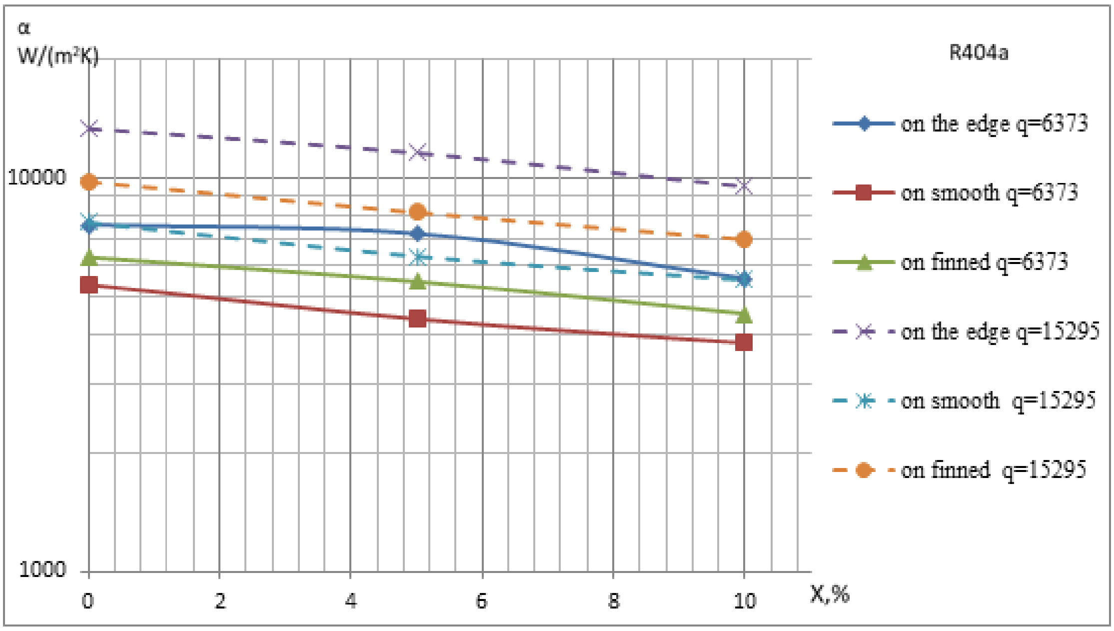

Figure 9. Graphical dependence α = f (X) established by boiling pure R404a and its oil-freon mixture on the rib, intercostal surface and finned surface

Figures 4−9 shows that the heat transfer coefficients during boiling of the studied refrigerants on the ribbed surface is much higher than on a smooth, i.e. Under the developed bubble boiling regime, heat transfer on finned surfaces is 2–3 times more intense than on a smooth surface.

The presence of fins leads to an intensification of heat transfer mainly due to the development of a heat transfer surface and an improvement in the conditions of nucleation and growth of vapor bubbles. The magnitude of the heat transfer coefficients when boiling a liquid depends on the pressure, the increase of which leads to the intensification of heat transfer, and the degree of influence of pressure manifests itself differently depending on the type of heat transfer surface and the thermophysical properties of the liquid.

The experimental results show that α continuously increases with increasing pressure. With increasing pressure, the critical radius of the vapor nucleus decreases, and steam generation begins on previously inactive microcavities of the outer surface of the ribs, which turn out to be quite overheated due to the high thermal conductivity of the material of the samples under study. As Rcr decreases with increasing pressure, the number of working centers of vaporization increases, as a result of which the heat transfer coefficient increases. However, at sufficiently high heat flux densities, the predominant part of the potential centers of vaporization is already included in the work on the generation of vapor bubbles and a further increase in pressure does not lead to intensification of heat transfer. Moreover, a gradual change in the thermophysical properties of a liquid, associated with an increase in pressure, leads to a weakening of other factors favorable for boiling, and there may be a tendency to a decrease in heat transfer coefficients.

In addition, an increase in the heat transfer intensity with increasing saturation pressure during boiling is caused by a decrease in the separation diameter of the vapor bubble and an increase in the density of the centers of vaporization. The intensity of heat transfer during boiling also depends on the thermophysical properties of the liquid, which change significantly with the pressure (and temperature) of saturation. With an increase in the thermal conductivity of a liquid, heat transfer increases, since the main heat flux from the wall is perceived by the liquid rather than the vapor phase. With an increase in viscosity, heat transfer, on the contrary, decreases, since the intensity of mixing of the liquid due to vaporization decreases.

The boiling heat transfer coefficient is a function of many arguments. Therefore, along with approximate expressions of a function that have sufficient physical justification, a number of variants of the expression of this function are possible, essentially weakly reflecting the physics of the process, but more or less satisfactorily corresponding to experimental data for some liquids, pressure ranges, thermal loads, etc. This explains the presence of insufficiently substantiated criteria systems and formulas that are based on the use of analogies, thermodynamic similarity, etc. and obtained as a result of formal mathematical operations or by random selection of criteria.

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5. Analysis of experimental data for r404a, r407c, r410a refrigerants on developed surfaces

As a result of a generalization of the results obtained at boiling R410a, R404a, R407c, it was possible to obtain a general empirical dependence for calculating the heat transfer coefficient on the rib, in the intercostal space and on the entire surface:

$$Nu_{\text{р}} = 0{,}45 \cdot Re^{0.65} \cdot {K_p}^{0{,}5} \cdot Pr^{-0{,}3};$$
$$Nu_{\text{мр}} = 1{,}8 \cdot Re^{0.59} \cdot {K_p}^{0{,}32} \cdot Pr^{-0{,}18};$$
$$Nu_{\text{о}} = 2{,}0 \cdot Re^{0.63} \cdot {K_p}^{0{,}32} \cdot Pr^{-0{,}18}.$$

6. Conclusions

Experimental studies of heat transfer during boiling of pure and mixed ozone-safe refrigerants R404a, R407c and R410a on finned and smooth surfaces with the following operating parameters: at saturation pressures ph = 0.74-1.62 MPa, heat flux densities q = 2.9-100, 8 kW / m^2.

The influence of various factors on the intensification of heat transfer during boiling of mixed ozone-safe refrigerants is revealed.

Criteria equations have been developed to describe the intensity of the heat transfer process during the boiling of ozone-safe refrigerants R404a, R407c and R410a on developed surfaces. The experimental data are satisfactorily described by the obtained equations with an error of $\delta = 20\%$.

The results can be used in the development of heat and mass transfer equipment of reduced material consumption and weight and size indicators of various power plants that use in the heat transfer processes a change in the phase state of a substance (refrigeration plants, heat pumps, coolers, etc.) of energy, chemical, food, refrigeration and electronic enterprises industry.

A comparison of pure and oil-freon mixtures R404a, R407c on smooth and ribbed samples was carried out.

7. References

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