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Dynamics of propagation of the self-sustaining evaporation front in a mixture of Freons under the natural convection conditions

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Abstract. The results of experimental studies on dynamics of propagation of the self-sustaining evaporation front at nonstationary heat release are presented in the paper. The experiments were carried out in a large volume at liquid saturation temperature and subcooling on a horizontal cylindrical heat-releasing surface with the diameter of 3 mm under nonstationary heat release. Freons R21, R114 and their mixtures were used as the working liquid. The experiments carried out in the range of concentrations of high-volatile component $0 < C < 1$ showed that in the range of temperature heads corresponding to the loss of hydrodynamic stability of evaporation front interface, a higher evaporation front velocity corresponds to the higher content of volatile component R114. The temperature head corresponding to the initiation of the evaporation front has a minimal value at mixture concentration corresponding to the point of azeotrope (C = 0.62). At a fixed value of the temperature head in the range of high values of ΔT, liquid subcooling relative to saturation line leads to a decrease in the velocity of evaporation front propagation.

1 Introduction

Nonstationary heat release at the local section of the heat exchanger can cause significant overheating of liquid heat carrier contacting with a heated wall, and formation and propagation of a continuous vapor film. This effect can be observed in the systems of film and droplet irrigation and in a large volume. There are a number of models describing propagation of undisturbed self-sustaining evaporation front, as well as individual attempts to simulate the front dynamics taking into account small-scale perturbations of the interface at intense evaporation [1]. In recent years, there has been a tendency to use the mixtures instead of a one-component fluid as a working medium in the refrigeration machines, heat pumps and thermal transformers. The ozone-safe non-azeotropic mixture refrigerants R32/R134a and R32/R152a are considered in [2] as well as heat transfer at boiling in horizontal tubes.

The purpose of this work is the experimental study of evaporation front dynamics and development of hydrodynamic instability on the interface in freons R21, R114 and their mixtures.

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2 Experimental setup and methods

The experimental setup is a cylindrical vessel with the diameter and height of 250 mm with the built-in windows for visualization of transient processes. The mixtures of Freons R114 and R21 on the saturation line at the pressure of 0.27 - 0.28 MPa and under the subcooling conditions were used as the working liquid. A horizontally oriented cylindrical test section made of a stainless steel tube 3-mm in diameter and wall thickness of 0.5 mm was used in experiments. The roughness of the section with the diameter of 3 mm was presented by multidirectional grooves with the width of not more than 10 μm and separate smoothed cavities with the diameter of 30-50 μm. The temperature of the working section wall under the conditions of nonstationary heat release was determined from the current-voltage characteristic and calibration curve, and by numerical calculations using the equation of nonstationary heat conductivity. The accuracy of temperature determination was ± 1.5 K. To observe the evaporation front dynamics, a high-speed video camera was used. The shooting speed was 25000 frames per second with an exposure of 25 microseconds. Heat-releasing surface was heated by a rectangular current pulse of given duration and amplitude. To illuminate the object in transmitted and reflected light, the LED assemblies with a light flux of 9000 lm were used, their switching-on time was synchronized with the point in time corresponding to begining of heat release. The detailed description of setup and experimental procedure is given in [3].

3 Discussion

The experiments were carried out with Freons R21 and R114 and their mixtures, including the azeotropic mixture of 62% R114. Dependences of evaporation front velocity V_{fr} on temperature head relative to saturation temperature ΔT are shown in *Fig*. 1 for different molar concentrations C of high-volatile component R114. As seen from the diagram, $V_{fr}(\Delta T)$ dependence has two characteristic regions – the region of a weaker dependence (*region* 1) and region of a stronger dependence (*region* 2). In [1, 3], the presence of *region* 2 is associated with development of Landau's hydrodynamic instability of. For all series of experiments carried out in *region* 1, there is no significant difference in the front propagation velocity. In *region* 2, the experimental data are stratified depending on concentration of R114 component in the mixture. At the same values of temperature head ΔT, the propagation velocity of evaporation front is larger in the mixture with higher concentration of component R114, and for pure Freon R114, the front velocity is maximal.

The temperature head with respect to saturation temperature (ΔT_0), corresponding to initiation of evaporation front for the mixtures with different concentrations, varies from 34 to 41 K (*Fig*. 2). The dependence has a nonmonotonic character with minimal values of ΔT_0 at concentrations C = 0.35 - 0.62.

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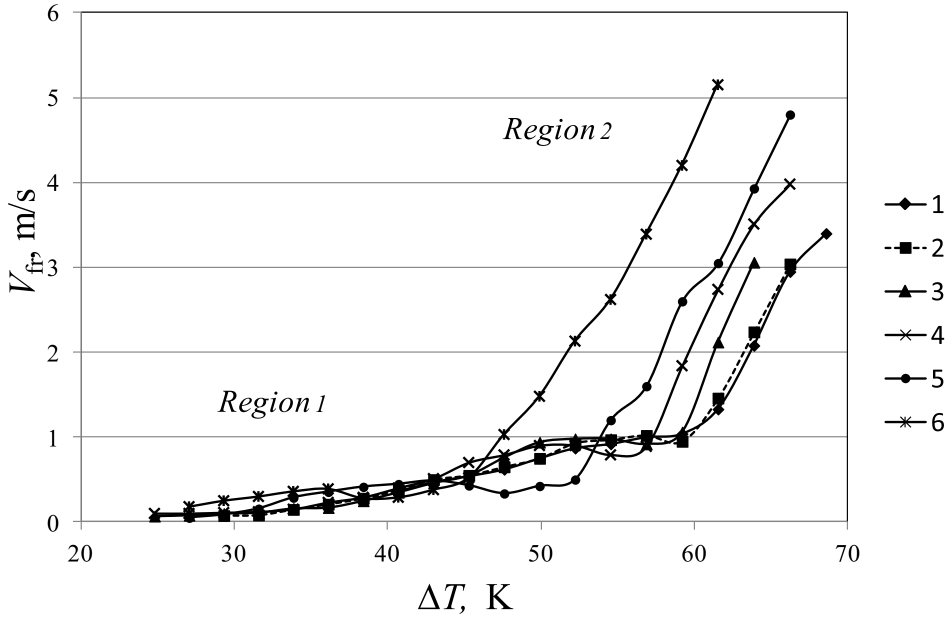

Fig. 1. Dependence of evaporation front velocity V_{fr} on temperature head ΔT for Freons R21, R114 and their mixtures. Conditions of saturation: *1* – R21, P = 0.267 MPa; *2* – C = 0.1, P = 0.27 MPa; *3* – C = 0.2, P = 0.27 MPa; *4* – C = 0.35, P = 0.27 MPa; *5* – C = 0.62, P = 0.28 MPa; *6* – R114, P = 0.28 MPa.

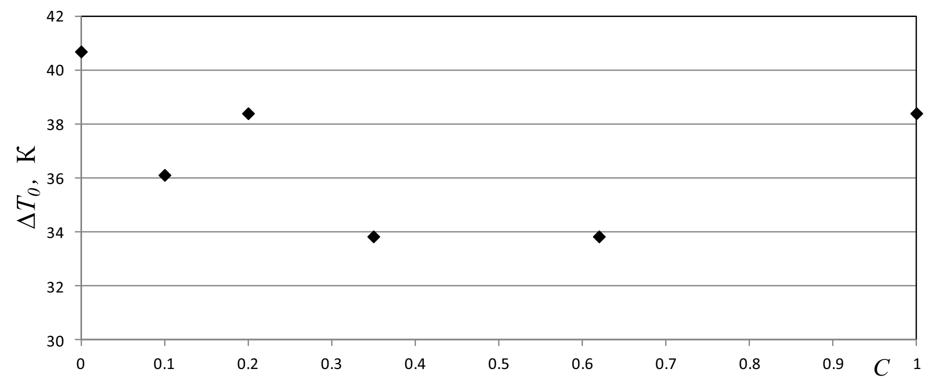

Fig. 2. Dependence of ΔT_0 on molar concentration of high-volatile component R114 in the mixture. P = 0.27 MPa

Data obtained in experiments with saturated liquid and liquid subcooled with respect to saturation temperature by η are shown in *Fig*. 3. Dependences of evaporation front velocity V_{fr} on the temperature head with respect to saturation temperature ΔT are given for molar concentration C = 0.22 for different subcoolings. As seen from the diagram, the pressure and subcooling of liquid affect the velocity of the self-sustaining evaporation front. Under the conditions of liquid being at the saturation line, an increase in pressure from 0.266 to 0.355 MPa led to a shift in V_{fr} (ΔT) dependence to the region of lower temperature heads by a value of about 3 K. Under the conditions of liquid subcooling relative to the saturation line, V_{fr} (ΔT) dependence shifts to the region of high values of the temperature head approximately by the same value. At a fixed temperature head in *region* 2, liquid subcooling leads to a decrease in the propagation velocity of evaporation front.

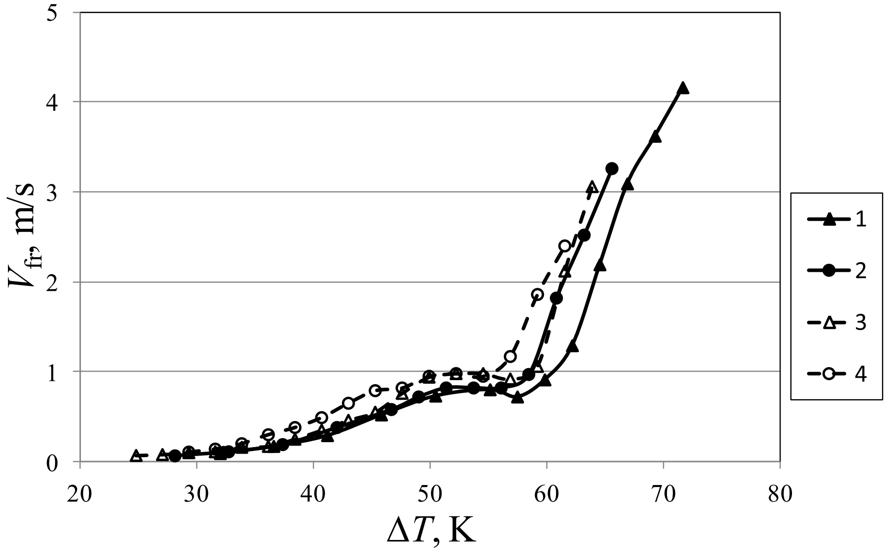

Fig. 3. Dependence of evaporation front velocity V_{fr} on temperature head ΔT for mixture with C = 0.22 : *1* – η = 6.4 K, P = 0.27 MPa; *2* – η = 14.9 K, P = 0.351 MPa; *3* – η = 0 K, P = 0.266 MPa; *4* – η = 0 K, P = 0.355 MPa.

4 Conclusions

The experiments carried out on the mixture of Freons R114 and R21 within the range of concentrations of high-volatile component $0 < C < 1$ showed that in the region of temperature heads corresponding to the loss of hydrodynamic stability of evaporation front interface, a higher content of volatile component R114 corresponds to a higher velocity of evaporation front. The temperature head corresponding to initiation of evaporation front at mixture concentration corresponding to the point of azeotrope has a minimal value. In the region of high ΔT at a fixed value of the temperature head, liquid subcooling below the saturation line leads to a decrease in propagation velocity of evaporation front.

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