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EFFECT OF OIL ON THE HEAT TRANSFER OF MIXED REFRIGERANT BOILING IN EVAPORATOR TUBES

Akif BAKHSHIEV[1*], Asif GULIYEV[1], N. A. BAKHSHIEV[2]

[1]Baku Engineering University, Khirdalan, Azerbaijan

[2]Ministry of Economy, Baku, Azerbaijan

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ABSTRACT

The paper presents the results of an experimental study of the effect of oil on the heat transfer rate at boiling of mixed refrigerant R406A. Since the air conditioning system is not a pure refrigerant, but a mixture of oil with a concentration of up to 8%, such an amount of oil affects both hydrodynamics and heat exchange in the evaporators. The experimental work covers the entire range of regime parameters typical for these systems. There is shown the process of changing oil concentration in the pipe, as the working fluid boils, proving that most of the oil pipe does not im- pair the heat exchange in the course of two-phase flow boiling. Different modes of refrigerant R406A boiling dynamics have been defined, and each mode is given a quantitative assessment in terms of the effects of the oil and explaining of this effect on the fluid flow and heat transfer based on visual observations and the experiment results. The main factor of the effect is the freon-oil foam, which increases the proportion of the wetted surface in the wave and stratified modes and the heat transfer rate to 30%.

1. Introduction

After the cessation of the use of popular freons, which were pure substances, in air conditioning systems due to environmental requirements, multicomponent refrigerants were proposed instead, for example R406A, which is a zeotropic mixture with significant non-isothermality during phase transitions. This refrigerant boils in the pipes of evaporators or air coolers. Evaporators with in-tube boiling have a lower charge of the working fluid, but also a lower heat transfer coefficient during boiling, which leads to the need to increase the heat exchange surface.

The boiling of the refrigerant in the pipe determines the complex hydrodynamics of the two-phase flow as the vapor content changes, which largely determines the intensity of heat transfer [1,3]. All this speaks to the ambiguity and complexity of the heat transfer process during in-tube boiling, which is aggravated by the presence of oil soluble in freon. At some operating concentrations, oil foams and distorts the hydrodynamics of the flow and the intensity of heat transfer during boiling. In addition, the presence of oil up to 8% significantly changes such properties of the working fluid as viscosity, thermal conductivity, which will also affect heat transfer.

* Corresponding author.
E-mail addresses: abaxsiyev@beu.edu.az (Bakhshiev Akif Bayram).

To lubricate compressor parts, synthetic oil BSE 32 is used, which is highly soluble with freon and circulates with it in the system. As confirmed by special studies [1], oil carryover from the compressor is 0.4÷1.2% of the working fluid and taking into account the separation of approximately 50% in the oil separator, carryover to the condenser and then to the evaporator will be 0.2÷0.6 %. During in-tube boiling in the evaporator, as the refrigerant moves, the oil concentration ξm increases. Since no liquid should enter the compressor, it boiling off in the evaporator should be almost complete, up to 90–95%. The remaining liquid refrigerant evaporates in the heat exchanger and suction pipe, and clean oil enters the compressor in small, non-hazardous portions.

2. Materials and results of the study

The experiments were carried out on a special stand with R406A refrigerant in a pipe 3.3 m long, 13 mm in diameter, with a wall thickness of 0.5 mm, made of 1X18HT steel. Range of changes in operating parameters: mass velocity ωϙ = 30÷150 kg/(m2·s); boiling temperature t_0 = 5÷–20 °C; heat flux density q = 1÷10 kW/m2. Oil concentration at the pipe inlet ξm = 0÷4%. For visual observations, glass tubes are installed at the inlet and outlet of the pipe.

In Fig.1 shows the change in oil concentration along the length of the pipe in an evaporator with in-tube boiling.

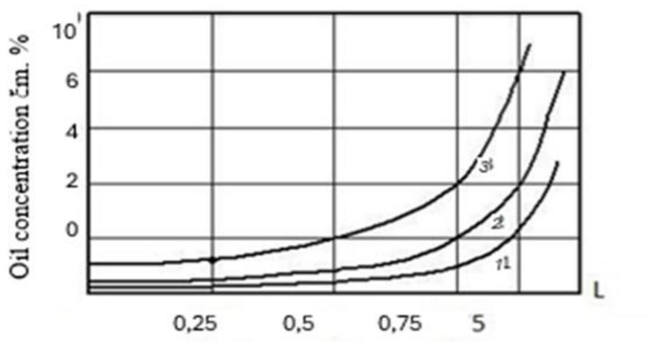

Fig.1. Dependence ξм = f(L) for complete boiling of the R406A refrigerant in an evaporator with in-tube boiling at the initial oil concen 1 – ξm = 0.25%; 2 – ξm = 0.5%; 3 – ξm = 1%

According to Fig.1 at the outlet of the evaporator pipe, the oil concentration ξm does not exceed 5–6%, and in most of its part ξm – 3%.

Previous studies have confirmed that when the oil concentration is less than 3%, the boiling intensity of the refrigerant becomes greater than when the pure working substance boils [2]. It is also noted that at ξm < 0.4% the hydrodynamics of the refrigerant flow will not change, and at high concentrations during boiling in the pipes foaming is observed, so the influence of oil on the hydrodynamics of boiling R406A in the evaporator will certainly be affected.

The degree of influence of oil on heat transfer depends on the flow mode. The refrigerant enters the evaporator after the throttling valve at a vapor content X = 0.1÷0.15 kg/kg. This corresponds to projectile or wave motion of the flow. The emulsion flow can be pumped.

In an emulsion flow, the addition of oil has virtually no effect on heat transfer, since heat transfer α is determined mainly by the speed of fluid movement, and at such an oil concentration ξm the properties of the working substance practically do not change and there is no foaming.

The heat transfer coefficient can be calculated using the formula

$$Nu = 0{,}021 \cdot Re^{0{,}8} \cdot Pr^{0{,}43} \quad (1)$$

In the slug flow mode, the presence of oil also does not affect heat transfer, since the oil foam is located inside the bubble and does not come into contact with the heat transfer surface [4]. And in this mode, heat transfer αcon is determined by the speed of the flow, and boiling αboil intensifies heat transfer little.

When processing experimental data in slug mode, the dependence was obtained

$$\alpha = \alpha_{con} \sqrt[3]{1 + \alpha_{con} \cdot \alpha_{con}^{3}} \quad (2)$$

In equation (2), the heat transfer coefficient during forced convection of liquid α_{con} is calculated according to (1) based on the true fluid velocity, and αboil - according to the dependence

$$Nu = 2{,}38 \cdot K_p^{0{,}25} \cdot (Pe \cdot K_t^{0{,}63} \cdot K_G^{0{,}5})^{0{,}75} \quad (3)$$

Where $K_G = {}^{\tau}/_{q} \cdot \sqrt{{}^{\delta}/_{q} \cdot (p' - p'')}$ – characterizes the relationship between the heat of evaporation and free-free energy of the surface layer.

In the wave mode, the presence of oil foam significantly increases the wetted surface. Under conditions that corresponded to the wave regime for a pure refrigerant, in the presence of oil, the entire heat transfer surface turned out to be wetted by a wave or oil foam.

In Fig.2 shows a graph of the temperature distribution along the pipe wall in one section in relation to t_0 in the wave mode with and without oil.

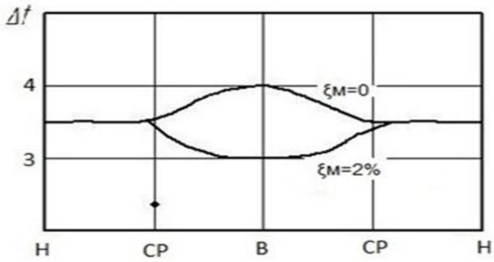

Fig.2. Temperature distribution along the pipe wall in wave mode with and without oil at $\omega\varrho$ = 100 kg/(m2 s); q = 2 kW/m2; P = 0.539 MPa

At $\xi_M = 0$, the temperature in the upper part of the pipe is higher than in the lower part, which is explained by the presence of a dry wall.

The intensity of heat transfer associated with boiling is not yet high, since in these regimes undeveloped boiling is observed.

Intensification of heat transfer in the presence of oil occurs mainly due to an increase in the proportion of the wetted surface in the upper part of the pipe. The effect of oil on α in this mode is ambiguous. As visual observations confirmed, at ξm < 0.4% this influence does not exist, since there is no foaming and the oil concentration practically does not change the properties of the working fluid. An increase in ξm > 3% leads to a decrease in heat transfer.

In Fig.3 and 4 show the increase in heat transfer coefficient in the presence of oil compared to α of pure R406A refrigerant.

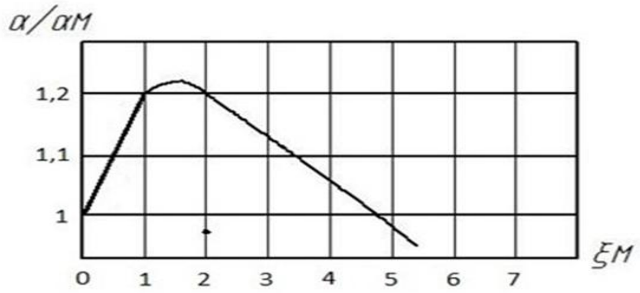

Fig.3. Ratio of coefficients α oil / α pure refrigerant in wave mode:
$\omega\varrho$ = 50 kg/(m2 s); q = 2 kW/m2; t = –10 °C

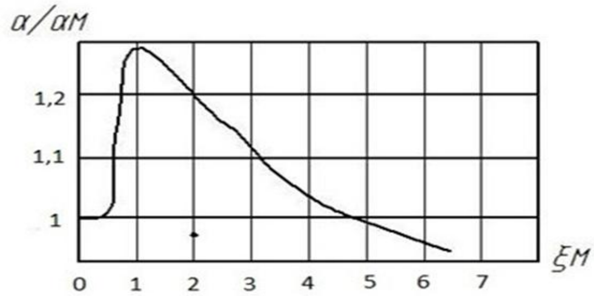

Fig.4. Ratio of coefficients α oil / α pure refrigerant in stratified mode:
$\omega\varrho$ = 100 kg/(m2 s); q = 2 kW/m2; t = –20 °C

At the beginning of the regime, which corresponds to stratification during boiling of a pure refrigerant, the upper part of the pipe remains wetted with oil plugs, which move in large volumes along the surface of the liquid or fly in small portions in the vapor volume. In Fig.5 shows the temperature distribution in the pipe section at the parameters that determine the stratified flow regime of pure refrigerant.

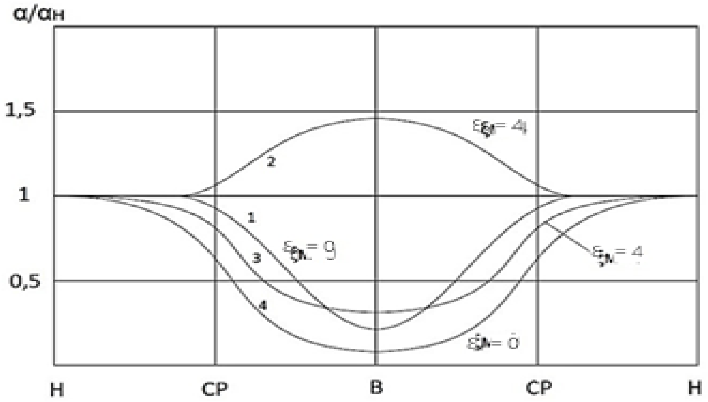

Fig.5. Ratio α/α_H in the pipe section in stratified mode: $\omega\varrho$ = 50 kg/(m2 s); q = 2 kW/m2;
t = –10 °C; 1, 2 – at the beginning of the mode, 3, 4 – at the end of the pipe

The maximum heat transfer at the beginning of the mode is noted in the upper part, since it is wetted by foam. At the end of the pipe with a vapor content of X = 0.90÷0.95 kg/kg, the presence of a low-boiling stream at the lower generatrix of the pipe with a small cap of foam was visually noted. There is no foam in the steam area. Here, heat transfer determines the speed of steam movement and the boiling point of a freon-oil solution with a high oil content.

To determine the average heat transfer coefficient in a stratified mode of movement of a two-phase flow, W/(m2 K), we can propose the dependence

$$\alpha = \alpha_j \cdot \frac{F_w}{F} + \alpha_n \cdot (1 - \frac{F_w}{F}) \quad (4)$$

where, α_j is the heat transfer coefficient of the boiling liquid; αn is the heat transfer coefficient of moving steam; F_w – wetted surface of the pipe section, m^2; F – pipe cross-sectional perimeter, m^2.

3. Conclusion

Calculation using formula (4) confirmed good agreement with the experimental results.

As a result of studying the effect of oil on the hydrodynamics and heat transfer of a two-phase boiling flow of refrigerant R406A:

– calculation formulas and criterion dependencies were obtained that make it possible to calculate the heat transfer coefficient during boiling of the R406A refrigerant with oil in the pipes of the evaporators of cooling systems;

– the influence of oil on the hydrodynamics of a two-phase flow was assessed;

– the influence of oil on heat transfer during boiling was determined both over the cross-section of the pipe and along its length.

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