Problem of heat transfer in compact heat exchangers using variable thermal resistance

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Abstract. The paper presents the results of a complex of studies, analysis of the efficiency of the heat exchangers of aircraft ACS, as well as developed methods for protecting the heat transfer surface from freezing and thermal stresses. The basis of the work was the results of experimental studies of heat and mass transfer of a three-phase flow of “moist air - supercooled water aerosol” with a negative temperature in the CPFHE channels. As well as previously developed methods for modeling the processes of local heat transfer in compact heat exchangers with two-phase coolants (condenser) and in the presence of thermal stresses at high temperatures of hot air (preliminary heat exchanger). The proposed methods are based on the idea of obtaining a given surface temperature by changing the thermal resistances during the heat transfer process. The improvement of the models consists in taking into account the variable thermal resistances along the length of the hot and cold tract. In particular, the parameters of heat transfer processes defined by the geometry of the fins and flow regimes, as well as local heat and mass transfer processes during phase transitions.

1. Introduction

Currently, the widespread use in air conditioning systems (ACS) of Tu-204, Superjet 100, MS-21 aircraft and foreign Boeing, Airbus aircrafts has received compact plate-fin heat exchangers (CPFHE), due to the simplicity of design and maintenance, as well as high reliability of work [1-2]. However, some of them have specific operational problems that require solving a number of engineering problems. These include: the problem of freezing of the heat exchanger-condenser when operating in humid air with negative operating temperatures and the problem of the short life of the preliminary and primary heat exchangers due to fatigue failure as a result of thermal stresses when operating at high temperatures and their large swings [3-4]. Designing according to well-known methods does not fully take into account these operational features, therefore, at present, there is a need to develop more advanced methods for calculating and designing the CPFHE, allowing to obtain innovative ways to solve these technical problems.

In [3-4], a methodology for calculating heat transfer in a heat exchanger-condenser with constant finning in hot and cold heat exchanger paths is described. In [5], a method was proposed for controlling the temperature of the heat exchange surface of the primary heat exchanger using variable fins, which made it possible to solve the problem of reducing thermal stresses at high temperatures by 5–8 times. In [6], a similar technique was proposed for a heat exchanger-condenser, and an initial series of studies was carried out aimed at checking the reliability of the model.
2. Problem definition
The aim of this work is to carry out a series of studies on the effect of the variable ratio of thermal resistances on the temperature distribution of the heat-transfer surface of the CPFHE. For the task of optimizing the design of heat exchangers in our work, we use a generalized criterion, which includes the ratio of the initial coefficients of finning of the heat exchange surface. By controlling the ratio of thermal resistances, it is possible to obtain the necessary temperature of the heat-exchange surface, which prevents freezing.

3. Theory
In the present work, we modified a previously developed two-dimensional model for calculating heat transfer in a cross-precise compact plate-fin heat exchanger [5, 6].

At the same time, the total size of the grids was increased to the number of cells 100x100. As a result, each of the 16 “heat exchangers” accounted for a grid of 25x25 cells (Fig. 1). In each "heat exchanger" it is possible to set personal parameters for hot and cold fins: constant along both paths, variable along hot or cold paths, variable along both paths. The maximum error in determining temperatures was set at 0.0001 °C. As a result of the calculations, two-dimensional distributions of the temperatures of hot, cold coolants and surface temperatures on a grid of 100x100 cells were determined.

![Figure 1. Sectional separation of finning on the tracts](image)

4. Experimental results
The input parameters of the coolants were set the same (table. 1). In the work, the parameters of the fins were changed in series on the hot, cold or both paths. In total, calculations and analysis of more than 100 heat exchangers were performed. Below are the most typical options.

4.1. Initial data

| Parameter       | hot air       | cold air      |
|-----------------|---------------|---------------|
| Temperature     | 30 °C         | – 30 °C       |
| Pressure        | 400 kPa       | 100 kPa       |
| Coolant flow rate | 0.5 kg / s   | 0.5 kg / s   |
| Humidity        | 0 ... 30 g / kg | 0 ... 10 g / kg |

4.2. Constant fins in both paths
With constant fins in both paths (Fig. 2, standard calculation procedure), more than 50% of the surface area is at a negative temperature, that is, it freezes in a hot and cold path.

**Figure 2.** Change in temperature of the heat exchange surface with constant fins in both paths:

- X-axis: I-IV – cold path section, 1-100 – number of the cell;
- Y-axis: – I-IV - hot path section, 1-100 – number of the cell, temperature, °C.

4.3. **With alternating hot finning**

With alternating hot finning (Fig. 3), the surface area at negative temperatures decreases to 30%.

**Figure 3.** Change in temperature of the heat exchange surface with alternating hot finning:

- X-axis: I-IV – cold path section, 1-100 – number of the cell;
- Y-axis: – I-IV - hot path section, 1-100 – number of the cell, temperature, °C.

4.4. **With alternating cold finning**

With alternating finning in a cold tract (Fig. 4), the surface area at a negative temperature decreases to 15%.
4.5. With alternating finning in the hot and cold tracts

With alternating finning in the hot and cold tracts (Fig. 5), the surface area at negative temperature decreases to 0%, i.e. freezing is absent.

4.6. With alternating finning in the hot and cold tracts with heat and mass transfer in the hot (condensation) and cold (evaporation) paths

The last series presents the calculation of the CPFHE with alternating finning in the hot and cold paths (Fig. 6) in the presence of heat and mass transfer in the hot (condensation) and cold (evaporation) paths. As a result, an additional effect was discovered: inlet sections I-III along the cold path increased the surface temperature. In fact, they switched to the work of the “thermal knife” of the anti-icing system, i.e. supercooled moisture and snow are melted.
5. Discussion of results
As a result of studies, it was found that a change in the finning parameters significantly changes the temperature distribution of the heat-exchange surface. Changing the fins in one of the paths leads to a positive effect. Changing the fins on both paths can significantly increase the surface temperature and reduce the freezing area to 0%. Taking heat and mass transfer into account has shown that condensation and evaporation in the CPFHE provide an additional effect for increasing the surface temperature.

6. Conclusion
The paper presents the features of the proposed operational optimization of the heat exchanger-condenser, as well as the results of a numerical study and analysis of the production of the heat exchanger-condenser with a given temperature distribution of the heat-exchange surface, which prevents freezing of the heat-exchange surface. The developed modeling methods and the obtained results allow us to analyze the efficiency of applying variable thermal resistances in a wide range of changes in the operating and design parameters of the CPFHE in order to protect the heat transfer surface. This approach is the most promising, because it allows you to remove freezing zones in the condenser and reduce thermal stresses in the preliminary heat exchanger by 5-8 times with minimal energy and economic costs.

7. References
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