Research on Heat Exchange Process in Aircraft Air Conditioning System

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Abstract. Using of heat-exchanger-condenser in the air conditioning system of the airplane Tu-204 (Boeing, Airbus, Superjet 100, MS-21, etc.) for cooling the compressed air by the cold air with negative temperature exiting the turbine results in a number of operational problems. Mainly it's frosting of the heat exchange surface, which is the cause of live-section channels frosting, resistance increasing and airflow in the system decreasing. The purpose of this work is to analyse the known freeze-up-fighting methods for heat-exchanger-condenser, description of the features of anti-icing protection and offering solutions to this problem. For the problem of optimizing the design of heat exchangers in this work used generalized criterion that describes the ratio of thermal resistances of cold and hot sections, which include: the ratio of the initial values of heat transfer agents flow state; heat exchange surface finning coefficients; factors which describes the ratio of operating parameters and finning area. By controlling the ratio of the thermal resistances can be obtained the desired temperature of the heat exchange surface, which would prevent freezing. The work presents the results of a numerical study of the effect of different combinations of regime and geometrical factors changes on reduction of the heat-exchanger-condenser freezing surface area, including using of variable ratio of thermal resistances.

1. Introduction
The main operational problem of the heat-exchanger-condenser is the cooling heat carrier has to have the negative temperature in operating duty. In this case, process of heat-mass transfer becomes complicated. The overcooled aerosol and particles of snow and ice appear in air behind the turbine. Nonstationary processes of frosting melting of ice happen on entrance edges of heat exchange section. In a hot path there are conditions in order that the condensed moisture froze (fig. 1). Thus, at projection of the heat exchanger condenser it is necessary to provide anti-icing measures: to exclude frosting in a hot path and icing of snow on leading edges of heat exchange section in a cold path.

2. Anti-icing systems of the condenser
Anderson's condenser (the patent of the USA No. 1246963) gained distribution by planes of firms the Boeing, Airbus. The essence of this heat exchanger and its following modifications consists in design change of the heat exchanger. In particular, in Anderson's option it is offered to warm directly entrance edges of plates in a cold path. When maintaining temperature at these edges the higher than 0 °C surface works in the mode of "a thermal knife". The snow weight which is formed on this surface melts and taken to channels of a cold path. Thus are prevented formation of snow on the entrance front.
and all negative consequences. It is offered to warm entrance edges by the principle of air and thermal anti-icing system (AIS). More perfect option requires creation of the express bypass canal for cold air.

![Image](image_url)

**Figure 1.** The connection scheme of the turbo-cooler and heat exchanger-condenser: 1 – compact heat exchanger, 2 – turbo-cooler turbine, 3 – turbo-cooler compressor, 4 – aerosol mist, 5 – moisture separator

3. Optimization of the condenser design

For the problem of optimizing the design of heat exchangers in this work used generalized criterion which describes the ratio of thermal resistances of cold and hot section. This criterion includes the ratio of initial values of heat transfer agents flow states; heat exchange surface finning coefficients; factor which describe the ratio of operating parameters and finning area. By controlling the ratio of the thermal resistance can be obtained the desired temperature of the heat exchange surface, which would prevent freezing. The work presents the results of a numerical study of the effect of different combinations of regime and geometrical factors changes on reduction of the heat-exchanger-condenser freezing surface area, including using of variable-ratio of thermal resistance. The following design options of heat-exchanger-condenser are studied: single-pass with common to the surface by operational and geometric factors; multipass; single-pass with variable geometry, including the use of regime factors for surface.

\[ RR = \frac{R_2}{R_1} = \frac{Re_1 \phi_1}{Re_2 \phi_2} = \frac{Re_1}{Re_2} \cdot \frac{\phi_1}{\phi_2} = A_{Re} \cdot A_\phi \]

where: \( Re_1, Re_2 \) – characteristics of the initial values of heat transfer agents flow state; \( \phi_1, \phi_2 \) – heat exchange surface finning coefficients, \( A_{Re} \) – factor which describe the ratio of operating parameters; \( A_\phi \) – factor which describe the ratio of finning area surface areas values.

4. Influence of the heat exchanger configuration on a heat transfer

4.1. Single-pass heat exchanger

In the first series of experiments the relation change of the thermal resistance is set by means of configuration of heat exchange section. The main idea consists in change the ratio of the channels cross-sections with the fixed values of the finning areas and identical volume of the heat exchanger (\( A_{Re} \) parameter). The 40 types and sizes of configurations were considered at the invariable volume of the heat exchanger, invariable surface area of heat exchange and flow regime [1, 2, 4]. If to increase the section for pass of the cold air then temperature of a surface reaches the maximal value of 7 °C that leads 90% of a plate surface to temperature higher than 0 °C.

4.2. Multipass heat exchanger

In the second series of experiments the relation of thermal resistance is set by means of change of the passes number in a hot path for three options: two - three - and four-pass heat exchangers (\( A_{Re} \) parameter) [1, 2, 4]. Increase in number of the passes leads to the favourable redistribution of temperature of a plate surface. In particular, increase of the temperature at the most cold parts of a plate is observed. However average value of temperature changes slightly.
4.3. Variable relation of thermal resistance

In the third series of calculations modification of the developed earlier two-dimensional model of a heat transfer calculation in the compact cross-flow plate-fin heat exchanger is carried out (A_φ parameter) (fig. 2) [3].

![Two dimensional model for the local heat transfer calculation](image)

**Figure 2.** Two dimensional model for the local heat transfer calculation:

- a - calculated element, b - calculated scheme (100 cells), h_1 – fins package for the hot heat carrier, h_2 – fins package for the cold heat carrier, Δx_1Δx_2 – calculated heat-transmitting element, I – first calculated element, II – last calculated element

The collateral equations of the heat balance and heat transfer in grid (discrete) option for fig. 2. have an appearance

\[
\rho_{1i,j} w_{1i,j} c_{pf1i,j} (T_{1i-1,j} - T_{1i,j}) \Delta x_1 h_1 = \alpha_{1i,j} \varphi_{1i,j} \frac{c_{pf1i,j}}{c_{p1}} (\tilde{T}_{1i,j} - T_{3i,j}) \Delta x_1 \Delta x_2 ,
\]

\[
\rho_{2i,j} w_{2i,j} c_{pf2i,j} (T_{2i-1,j} - T_{2i,j-1}) \Delta x_2 h_2 = \alpha_{2i,j} \varphi_{2i,j} \frac{c_{pf2i,j}}{c_{p2}} (\tilde{T}_{3i,j} - \tilde{T}_{2i,j}) \Delta x_1 \Delta x_2 ,
\]

where: ρ – density, w – speed, c_φ – heat capacity at constant pressure, T – temperature, λ – the heat conductivity coefficient of heat carriers; Δx – the size between grid nodes, h – fins height, φ – finning coefficient; index: 1 – hot heat carrier, 2 – cold heat carrier, 3 – heat exchange surface; i, j – uniform grid nodes indexes for splitting from 0 to 100 cells, C_{pr} – accounting factor of the heat carrier phase transformations in a cell.

In this model the A_φ parameter can be changed only on a hot and cold path for the all calculated surface entirely.

For modernization of the presented model, splitting of the initial grid from 100 cells into four equal sectors I … IV longwise of a hot and cold path is added to an algorithm of the developed software (fig. 3). Each sector includes 25 cells of an initial grid. As a result the heat-transmitting surface breaks into 16 partial "heat exchangers", in each of which the geometrical parameters of fins are set independently of each other. An addition of two effects is observed with change of the finning coefficients on both paths (hot and cold): division of temperature distribution into four sites and decrease of a heat exchange surface thermal gradient. As a result there is a cooperative increase of a heat exchange surface temperature and sharp reduction of a thermal gradient. The analysis of a heat exchange surface temperature profiles allows to draw a conclusion: co-change of the thermal resistance relation is the most optimum reception because 100% of a plate surface have a temperature higher than 0 °C and the percent of a surface freezing is equal to 0 (fig. 4).
5. Conclusion

In this work the known ways of fight against freezing are presented. Features of the offered operational optimization of the heat exchanger condenser are described. Results of a numerical research of the heat exchanger condenser with the particular distribution of a heat exchange surface temperatures are presented. The analysis allows to pick up such distribution of temperatures which would prevent heat exchange surface freezing. The research on heat-exchanger-condenser's cold-path thermal protection allowed: 1) to establish the cause of heat-exchanger's construction frosting; 2) to develop the basic principles of condenser anti-icing protection; 3) to establish and offer the basic techniques of design changes, allowing to exclude negative temperatures of heat-exchange surface; 4) to analyses the effectiveness of proposed capacitor optimization options; 5) to solve an actual problem of creating a non-freezing design that allows to increase the reliability and durability of aircraft air conditioning system's heat-exchanger-condenser. The results are also of practical interest for the design of heat transfer equipment, which operates in moist air at negative temperatures.

**Figure 3.** Sectional separation of the surface along the paths

**Figure 4.** Temperature distribution at a variable ratio of thermal resistances in the cold and hot paths
6. References

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