Numerical analysis of gas-dynamic efficiency of the flow part of compact air heat exchangers and filters for mobile compressor units

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Abstract. The technique of numerical analysis of filters and heat exchangers used for air purification and cooling at mobile compressor units is presented. The proposed method is verified by comparing the results of numerical and experimental studies on similar objects in geometry and under similar operating conditions. The numerical parametric analysis of filters and heat exchangers with different options of the flow part is carried out. The efficiency of these devices has been improved by replacing the flat partition with a short diffuser with guides.

1. Introduction
Mobile compressor units are widely used in various branches of technology and production. Known requirements to limit the overall dimensions and weight of such units lead to the need of ensuring the minimum dimensions of their technological components while maintaining the operation efficiency. Such components include air-cooled heat exchangers and filters. Air filters are used to clean the intake air from mechanical impurities; air heat exchangers are used for interstage and end cooling of compressed air, as well as lubricating and cooling liquids. The analysis of the currently known designs of air heat exchangers and filters from the point of view of the gas-dynamic efficiency criteria (flow pressure loss and non-uniformity of the velocity field [1]) showed that they have an imperfect design of the flow part, since in most cases the air flow is irrationally distributed over the flow part of these devices [2]. This is largely due to the large transverse dimensions of the filters and heat exchangers in comparison with the cross section of the pipeline or the diameter of the fan [3]. In its turn, the unevenness of the flow distribution leads to an increase in local velocities in the flow part of the apparatus [4], which can significantly exceed the calculated average velocities taken in the design of the apparatus. Providing the required technical characteristics leads to the fact that the area of the heat exchange surface or the filter layer thickness is calculated with a large margin, which leads to an increase in the size and weight of the apparatus, and an increase in flow pressure loss.

One of the ways to solve this problem is the use of so-called short diffusers in the design of air filters and heat exchangers. As shown by the studies, there are a number of ways to improve the operation of short diffusers [5-7], the greatest efficiency is achieved when installing additional guides in their flow part [8-10], and the required configuration and location of these guides for filters and heat exchangers are markedly different. That is why, to determine the optimal geometry of the guides in each case it is required to develop a calculation method that will take into account the gas-dynamic processes in the operation of the devices under consideration.
2. Methods of numerical analysis and experimental research

Nowadays, in studying working processes in the flow part of filters [11] and heat exchangers [12, 13] software products are widely used, based on the numerical simulation and calculation of the designed objects by the finite element method. One of such products is the software package ANSYS CFX [14], which is in the case under consideration the basis for developing a method of numerical heat and gas dynamic analysis of the flow part of compact air heat exchangers and filters with a short diffuser.

According to this method, the computational model of the flow part of the filter or heat exchanger is imported into the ANSYS CFX environment, where it is divided into a grid of finite elements with dimensions located within the specified limits. Next, the boundary conditions and calculation conditions are set, and the program performs the necessary calculations. The final stage is the visualization and analysis of the results.

The method of numerical calculation involves gas-dynamic analysis of the flow part of the air filter with an air duct [1] and heat-gas-dynamic [15] analysis of the air heat exchanger with a fan running on the airflow (fig. 1 and fig. 2 respectively).

![Figure 1](image1.jpg)

**Figure 1.** Computational model of the air filter flow part:
1 - inlet air duct; 2 - short diffuser; 3 - housing; 4 - equivalent partition; 5 - outlet air duct

![Figure 2](image2.jpg)

**Figure 2.** Computational model of the air heat exchanger flow part: 1 - fan ring; 2 - short diffuser; 3 - housing; 4 - heat exchange section

To verify the reliability of the calculated results according to the proposed methods, experimental research methods were developed on the basis of an air filter with an air duct [1] and an air-cooled heat exchanger [9], and experimental stands were created for their implementation.
3. Verification of numerical analysis methods
Two design modifications of the air filter and the air heat exchanger were considered for verification of the numerical analysis method: with a flat partition and a short diffuser.

Figures 3-4 show the results of numerical calculations and experimental studies for the air filter. Comparing the results obtained, we can note their rather similar nature: the profiles of the velocity field in the output section of the diffuser (flat partition) and the flow pressure loss of the filter as a whole have a qualitative coincidence, while the quantitative values have differences within 10-15%. At the same time, for a flat partition the velocity field profile (fig. 3) has a strong uneven character. It is well noticeable when comparing it with the profile of the velocity field built for the air filter with a short diffuser. So, we observe higher flow pressure loss (fig. 4), which is higher than that for a short diffuser by up to 30%.

Figure 3. Velocity field profiles built for the air filter (average flow rate in the outlet section is 3 m/s):
1 - flat partition; 2 - short diffuser. Solid line - calculation, dotted line - experiment.

Figure 4. Flow pressure loss depending on the average flow velocity for the air filter:
1 - flat partition; 2 - short diffuser. Solid line - calculation, dotted line - experiment.

A similar conclusion is made by comparing the results of calculations and experiment for the air heat exchanger (fig. 5-7).
Figure 5. Velocity field profiles of the heat exchanger (average flow rate in the outlet section is 3 m/s: 1 - flat partition; 2 - short diffuser. Solid line - calculation, dotted line - experiment.

Figure 6. Flow pressure loss depending on the average flow velocity of the heat exchanger: 1 - flat partition; 2 - short diffuser. Solid line - calculation, dotted line - experiment.
Figure 7. Temperature of the cooled air at the outlet of the heat exchange section:
1 - flat partition; 2 - short diffuser. Solid line - calculation, dotted line - experiment.

The velocity field profile obtained at the outlet of a short diffuser has lower velocity values than the profile at the outlet of a flat partition (fig. 5). This effect, like in the case of the filter, can be explained by a better flow opening in the flow part of the diffuser. In its turn, this leads to a decrease in the flow pressure loss (up to 21 %) of the heat exchanger (fig. 6) and a more efficient decrease in the temperature (up to 3 °C) of the cooled air (fig. 7).

Thus, the comparison of the experimental results with the results of numerical calculations showed their sufficient convergence, which makes it possible to use the developed technique to perform parametric analysis.

4. Parametric analysis and its results
The purpose of the parametric analysis was a comparative evaluation of the gas-dynamic efficiency of air filters and heat exchangers with different modifications of the flow part. The following options were considered:

1. Air filter (fig. 8):
   - with a flat partition,
   - with a short diffuser and flat guides installed at the same distance from each other in both the inlet and outlet sections of the diffuser (flat evenly installed guides),
   - with a short diffuser and concentric guides installed at the same distance from each other in both the inlet and outlet sections of the diffuser (evenly installed concentric guides),
   - with a short diffuser and concentric guides installed at the same distance from each other only in the outlet section of the diffuser (unevenly installed concentric guides).

Flat evenly installed guides (fig. 8, b) are plates oriented in a horizontal plane and installed in the flow part of a short diffuser at the same distance from each other both at the inlet and at the outlet from the diffuser. Evenly installed concentric guides (fig. 8, c) are a set of diffusers also installed in the flow part of a short diffuser with the same distance. Unevenly installed concentric guides (fig. 8, d) [16] have different gaps in the input section of the short diffuser, which is designed to provide a uniform velocity field in the output section of the diffuser.

2. Air heat exchanger (fig. 9)
   - with a flat partition,
   - with short diffuser and guides installed at the same distance from each other in both the inlet and outlet sections of the diffuser (evenly installed guides),
• with a short diffuser and guides installed at different distances from each other in the inlet and outlet sections of the diffuser (unevenly installed guides).

**Figure 8.** Air filter options selected for the parametric analysis: a – with a flat partition; b – with a short diffuser and evenly installed flat guides; c – with a short diffuser and evenly installed concentric guides; d – with a short diffuser and unevenly installed concentric guides; 1 – inlet air duct; 2 – flat partition; 3 – housing; 4 – equivalent partition; 5 – outlet air duct; 6 – short diffuser; 7 – guides

Evenly installed guides (fig. 9, b), like in the case with the filter, are plates oriented in the horizontal plane and installed in the flow part of the short diffuser at the same distance from each other both at the inlet and outlet of the diffuser, which should improve the operation of the latter. Unevenly installed guides (fig. 9, c) are installed in a way to direct most of the cooling air flow to the upper more heated area of the heat exchange section, where the cooled air with the highest temperature comes.

**Figure 9.** Air heat exchangers modifications selected for parametric analysis: a - with a flat partition; b - with a short diffuser and evenly installed guides; c - with a short diffuser and unevenly installed guides; 1 - fan ring; 2 - flat partition; 3 - housing; 4 - heat exchange section; 5 - short diffuser; 6 - guides
Comparative results of parametric analysis are presented in fig. 10-14. Parametric analysis of air heat exchangers and filters with different options of the flow part and at different flow velocities showed that the use of guides allows to optimally distribute the air flow on the heat exchange and filter surface and improve the efficiency of the devices upgraded in a described way compared to the basic designs.

**Figure 10.** Velocity field profiles constructed for the air filter: 1 - partition; 2 – with a short diffuser and evenly installed flat guides; 3 – short diffuser and evenly installed concentric guides; 4 – with a short diffuser and unevenly installed concentric guides.

**Figure 11.** Air filter aerodynamic drag: 1 - partition; 2 – with a short diffuser and evenly installed flat guides; 3 – short diffuser and evenly installed concentric guides; 4 – with a short diffuser and unevenly installed concentric guides.
At the same time, air filters require uniform blowing of the filter surface at a speed close to the average flow velocity, and from the guides a uniform velocity field is required at the outlet regardless of what velocity field is available at the inlet to the guides. In this case, unevenly installed concentric guides (fig. 10) have proved to be most effective in achieving this effect. The use of such guides makes it possible to reduce the flow pressure loss of the air filter flow part (by up to 70 %) relatively to the basic version with a flat partition (fig. 11).
Figure 13. Flow pressure loss of the air heat exchanger: 1 - with a flat partition; 2 - with a short diffuser and evenly installed guides; 3 - with a short diffuser and unevenly installed guides

Figure 14. Temperature of the cooled air at the outlet of the heat exchange section for the air heat exchanger: 1 - with a flat partition; 2 - with a short diffuser and evenly installed guides; 3 - with a short diffuser and unevenly installed guides

For heat exchangers, on the contrary, uneven blowing (fig. 12 and 14) of the heat exchange surface (increase in the cooling depth up to 18 °C) is more efficient, which means that uneven installation of guides is required, the number and angle of installation of which depends on the layout of the specific heat exchanger. In this case, there is a slight increase in the flow pressure loss of the flow part of the heat exchanger (fig. 13).

5. Conclusion
According to the results of the theoretical and experimental research, the following conclusion can be made:

- It was found out that the replacement of a flat partition with a short diffuser with unevenly installed concentric guides can improve the efficiency of air filters in terms of reducing flow pressure loss and more uniform airflow of the filter surface. In turn, a more uniform airflow will effectively use
the entire filter surface, rather than any part of it, which will extend its service life, and in the absence of high local speeds will reduce the thickness of the filter material.

- It was found that the replacement of a flat partition with a short diffuser with unevenly installed guides allows to improve the cooling of compressed gas in heat exchangers (up to 18 °C).

Summing up, the achieved improvement of the flow part by the method of numerical analysis with an increase in the efficiency of air heat exchangers and filters will reduce the excess area of the heat exchange and filter surface and provide compactness of the design when used in mobile compressor units in a limited space.

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