Bladeless Air Cooler

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Abstract. Heat exchangers are designed to carry out heat exchange processes when it is necessary to heat or cool the process medium in order to process it or recover heat. Heat exchange equipment constitutes a very significant part of technological equipment in the chemical and related industries. The share of heat exchange equipment at chemical industry enterprises is on average (15–18)%, in the petrochemical and oil refining industries about 50%. A significant amount of heat exchange equipment at chemical plants is explained by the fact that almost all the main processes of chemical technology (evaporation, rectification, drying, etc.) are associated with the need to supply or remove heat. In the chemical and especially petrochemical industry, most of the heat exchangers are condensers and refrigerators. The use of water coolers for these purposes, for example, shell-and-tube or irrigation units, is associated with significant water consumption and, therefore, with high operating costs. For these purposes, special heat exchangers are used—air coolers (AVO). Air coolers are mainly used where the use of other cooling systems is technically impossible or not economically feasible. Typically, air coolers are more expensive than water cooled heat exchangers. However, with air cooling, there are no corrosion and fouling problems associated with the use of cooling water, and there is no possibility of mixing water with the cooled process fluid.

Keywords: Air cooler · Heat exchange · Air flow · Diffuser

1 Introduction

Air coolers (AVO) are widely used and are used in almost all industries. Due to their versatility and economy, they have a fairly wide range of applications. Due to the simplicity of design, reliability of operation, as well as the potential for modernization, these devices rank first among the heat exchange equipment of the petrochemical complex [1]. The specific weight at the enterprises of the chemical industry, of the total volume of heat exchange equipment of the AVO, is on average 15–18%. More than 40% in the petrochemical and oil refining industries. The experience of AVO operation confirms the high efficiency and reliability of such devices [2, 3].

2 Experiment Techniques and Materials

Along with the advantages, there are also significant disadvantages: a decrease in the efficiency of the ACU operation in the summer; when using water sprinkler airflow,

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problems with corrosion and pollution are possible; the presence of rapidly rotating mechanisms, as well as the fact that the efficiency of heat transfer in ACU strongly depends on the ambient temperature [2]. The design of the apparatus itself does not meet the modern requirements for compactness and modularity of petrochemical equipment, has a low modernization potential and is unable to regulate the volume of air pumped through the heat exchange sections in a wide range [1, 3].

The main structural elements that affect the performance of the ACU are the heat exchange sections and the axial fan itself, which creates the air flow necessary for cooling the ribbed tubes. The efficiency of this heat exchanger is achieved by creating an air flow passing through the heat exchange sections. At the same time, high turbulence of the air flow at the inlet to the heat exchange sections is achieved and, as a result, more efficient heat transfer at the air inlet and a significant decrease in efficiency at the outlet [1–3], which is mainly due to insufficient volumes of cold air [4]. The design feature of the heat exchange section, namely the compact arrangement of the ribbed tubes in the tube bundle, reduces the air flow rate. As a consequence, there is an increase in the probability of warm air recirculation and a decrease in the productivity of the equipment [3].

The solution to this problem lies either in choosing a more powerful fan, which is associated with higher energy consumption, or in increasing the heat exchange area, which is also not profitable due to the increase in the mass of the apparatus and its dimensions. It is quite clear that the traditional ways of increasing the performance of ACU within the framework of the classical design of the apparatus have substantially exhausted themselves [5].

The air flow behind the impeller of an axial fan is swirling in the direction of the rotor rotation, and as a result, a decrease in kinetic energy at the outlet of the impeller does not lead to an increase in the potential pressure energy, but only compensates for friction losses caused by the rotation of the flow, and part of the energy is wasted uselessly.

As a result of the use of axial fans, the speed of the cooling air is in the range (5–15 m/s), which, in combination with poor thermophysical properties of the air, leads to a low value of the heat transfer coefficient ($\alpha = 30\text{–}90\ \mathrm{W/(m^2 \times K)}$ [2, 3] and, as a consequence, an increase in the overall dimensions of the heat exchange sections.

The main requirements for the modernization of existing equipment are compact design, modularity, and high efficiency combined with minimal costs. We propose modernization of ACU, which is compact, modular, and more efficient.

The essence of the ACU modernization is to change the design of the air duct (diffuser), as well as to replace the traditional axial fan with an air turbine with a smaller size and weight.

Turbine (Fig. 1) will allow you to form a sufficiently large and fast air flow. Another advantage of using an air turbine is that the turbine is driven behind the air flow, which improves the efficiency of the turbine, eliminates overheating, and simplifies mounting and maintenance.

The concept of the new design is based on the principle of increasing the air flow with a directed high-speed flow (such a design has proven itself well in everyday life) [6]. The turbine creates an air jet that flows around the diffuser housing from the inside of its rim. The air masses cover the rim and, moving along the streamlined surface, create negative pressure in front of the heat exchange section (according to the antiwing

Fig. 1 Air turbine example

principle) (Fig. 2). As a result, this leads to the fact that air masses located next to the diffuser begin to be drawn into the area of reduced pressure. As a result, a powerful flow is created in front of the heat exchange section, which can be amplified up to 15–20 times (Fig. 3) [6]. Thus, a large air mass is involved in the process of heat exchange, much larger than a blade fan can create [5–10]. This creates a dense flow of air masses. The large air volume reduces the effect of natural convection within the heat exchange section, so recirculation is unlikely.

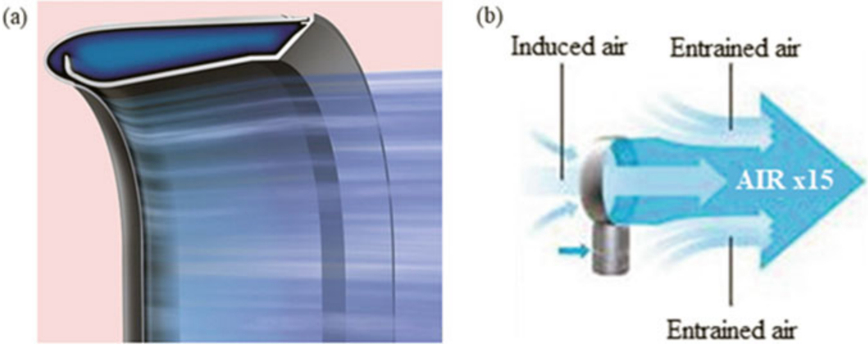

Fig. 2 Diffuser **a** section, **b** operation diagram

The offered diffusers of the new design are much smaller and can be installed depending on the configuration of the heat exchange section. The connection of the diffuser to the turbine will be carried out using a flexible duct, which will make it possible to conveniently position the diffuse and the turbine relative to each other. To increase the efficiency of the ACU operation in conditions of elevated ambient temperatures, it remains possible to install annular collectors for air humidification.

3 The Results of Studies and Their Discussion

In order to confirm the operability of the declared design, a computer simulation of the movement of air flows in front of the entrance to the heat exchange sections and inside

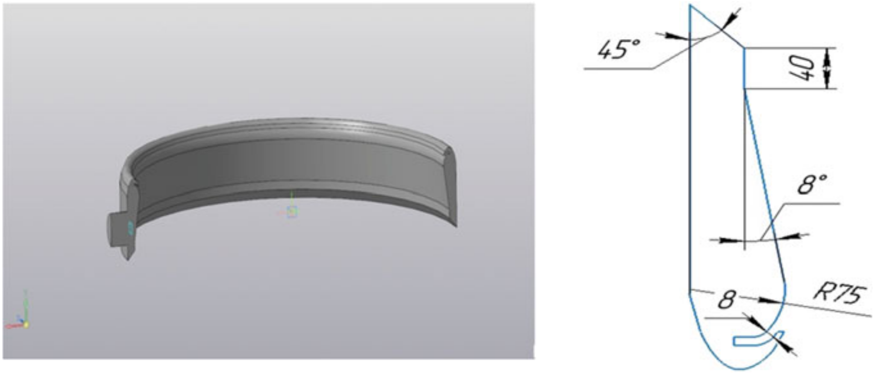

Fig. 3 Diffuser design

the diffuser was carried out. The proposed diffuser design was modeled in the compass-3D program (as shown in the figure). For the convenience of further calculations, the ANSYS Workbench software used half of the internal part of the diffuser due to the symmetry of the structure (Fig. 4).

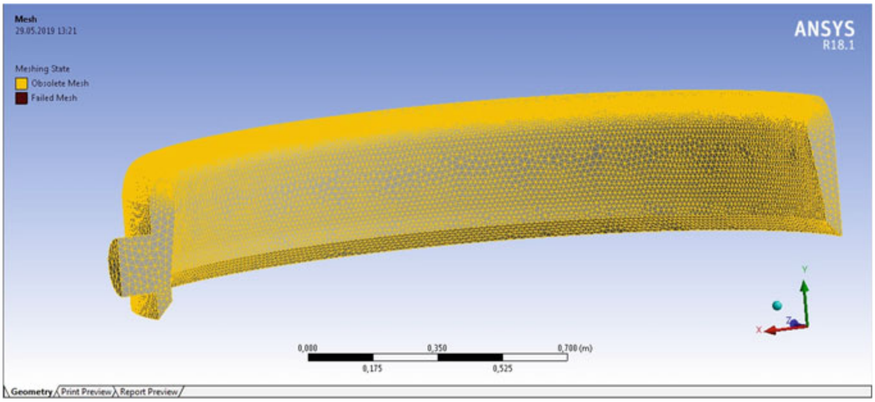

Fig. 4 Diffuser interior mesh in ANSYS Workbench

At the first stage, a mesh was built along the inner surface of the diffuser. The outgoing air flow from the turbine is distributed along the inside of the diffuser and then, at the outlet from the inside, is directed along the diffuser profile. The design profile of the diffuser was modeled so that the air exiting the diffuser was directed around the outer surface of the diffuser (Figs. 5 and 6). The diffuser profile partially repeats the simplified airplane wing profile, and this is done so that the outgoing flow forms a vacuum in the central part.

It is important that the flow is evenly distributed over the inner part of the diffuser, and this will provide a fast and uniform flow when it comes out to the surface of the profile and will allow the sucked air to be drawn into the general flow. The volume of

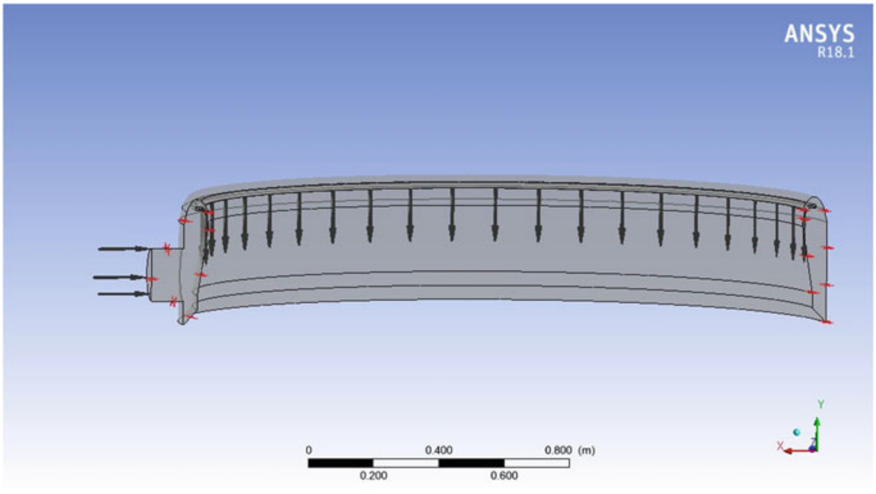

Fig. 5 Air inlet and outlet

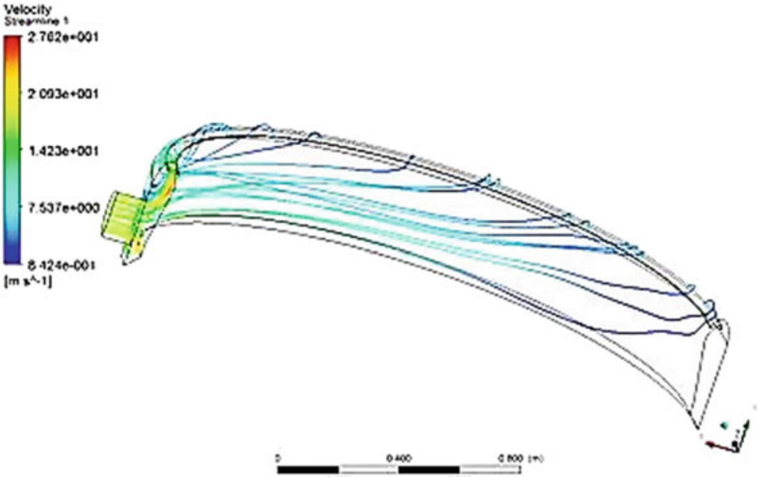

Fig. 6 Distribution of air velocity flows inside the diffuser

entrained air depends on the flow rates and on the vacuum generated by them in the central part [6].

As can be seen from the calculation (Fig. 7), the diffuser of the proposed design allows you to evenly distribute the air flow. In this case, the flow rate remains significant. It is important that the outgoing flow along the entire perimeter has approximately the same outlet velocity, and this allows the entrained air flow to be formed more evenly.

The next step was to simulate the distribution of air flows at the outlet from the diffuser in front of the heat exchange section. In order to consider the process of drawing in the

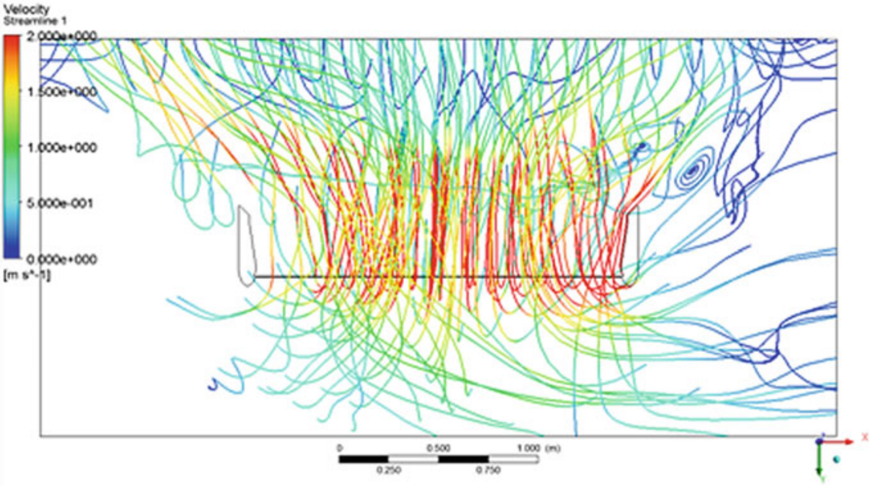

Fig. 7 Distribution of air flows in front of the heat exchange section

air located near the diffuser and the formation of an air flow in front of the heat exchange sections.

The suction air flows in the central part are clearly visible (Fig. 8). The flow of entrained air forms a large volume flow of air in front of the heat exchange section, which creates more optimal conditions for heat exchange (Fig. 2).

Lateral vortices of the flows outside the diffuser can be neglected; since in reality, heat exchange sections are installed behind the diffuser and the air flow will pass through them. It is in the heat exchange sections that heat exchange takes place; therefore, the air passing through the sections must have a large volume. Since the space between the heat exchange tubes does not change, the flow through must have a sufficient velocity for the tube bundle to pass.

AVO must have a high air capacity at low hydraulic heads. For an axial fan with a blade diameter of 0.8–7.0 m, it is a difficult task to develop an air flow speed in front of the heat exchange section of more than 4 m/s. For effective heat exchange, the air flow speed in front of the heat exchange section should be at least 3–6 m/s [2, 3]. Values in this range generally provide a reasonable balance between air side heat transfer and pressure drop.

Changing the rotation speed of the air turbine allows you to adjust the speed and volume of the air flow in front of the heat exchange section in a wider range.

Also, the possibility of using existing methods to increase the efficiency of heat transfer is not excluded, such as:

- installation of nozzles supplying cooling water to the air stream;
- use of louvers with heat exchange sections.

4 Conclusions

The proposed design is effective, since it allows to significantly increase the volume of air pumped through the heat exchange sections. The volume of pumped air increases 15 times, which will increase the efficiency of heat exchange and, therefore, increase the efficiency of the AVO. The design of the diffuser has a much smaller size and can be installed depending on the configuration of the heat exchange sections in any spatial position. You can connect the diffuser to the turbine 'with a flexible' duct, which will allow you to conveniently position the diffuser and the blower relative to each other.

This design will reduce the occupied area of the device itself and will allow placing the modules of the device more compactly. The design is compact, modular, and has modernization potential.

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