Modern approaches to the intensification of heat and mass exchange in multi-temperature condensation filters

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Abstract. The article considers the problems and features of heat and mass exchange on developed surfaces in the conditions of both single-phase and vapour-liquid flow during its condensation. We give a brief analytical review of studies of hydrodynamics and heat exchange in such systems. We analyzed the efficiency of the working channel of the condensation filter and identified problematic points. We offer possible methods for intensifying heat and mass transfer on working surfaces.

1. Introduction
Currently, in connection with the active development of the oil and gas industry, the issue of cleaning gases from mechanical and chemical impurities is quite acute. Capturing aerosols is necessary to recover valuable substances and prevent environmental pollution. Gas purification can be carried out quite successfully using a multi-temperature filter [1]. The impure gas is fed into the working channel, the walls of which have different temperatures (figure 1).

At some distance from the channel entrance, a zone of stable supersaturation is formed, characterized by the formation of moisture drops with a further increase in their size and subsequent condensation on gas ions, mechanical inclusions, and various impurities. Moisture vapours independently trap impurities, and, increasing to the size of drops, condense on the cold wall.
Studies [2, 3] showed that the efficiency of heat and mass exchange processes in a different-temperature channel is influenced by the intensity of heat exchange between the channel wall and the gas flow, an increase in the flow rate, as well as the intensity of moisture evaporation on a hot surface, followed by condensation on a cold wall. The capture coefficient of the liquid aerosol phase in this case substantially depends on the gas flow rate and has a pronounced nonlinear character (figure 2).

![Figure 2. Efficiency of capturing the liquid phase depending on the gas flow rate.](image)

Thus, the task is to increase the efficiency of work, which consists in intensifying the processes of heat and mass exchange, including phase transitions in a small range of gas flow rates. This task can be successfully solved due to the formation of developed surfaces of heat and mass exchange in the working area.

2. Heat exchange on large-scale developed surfaces

One of the ways to intensify heat exchange is to create developed surfaces, which have confirmed their high efficiency [4, 5]. The simplest technical solutions include the use of plates of various shapes [6] (figure 3), sandwich panels filled with metal gratings [7] (figure 4), surfaces with dimples of various configurations [8] (figure 5).

![Figure 3. Scheme of Plate Heat Exchange channel corrugated field with various forms of plates corrugations: 1, 2 – two neighbour plates intersection; 3 – channels cross-sections with sinusoidal corrugations; 4 – channels cross-sections with triangular corrugations.](image)

Surfaces with various types of ribbing are widely used, for example [9]. In [10], the authors presented a comparative analysis of surfaces with lamellar-ribbed, mesh-wire and needlelike ribbing under conditions of forced convection. Thus, the aerodynamic efficiency of a surface with transverse ribbing is 1.15-1.65 and 1.8-2.0 times higher than that of a standard plate and a needlelike one, respectively, and also surpasses the mesh structure by 3.0-3.2 times. It is shown that partial cutting of
smooth plates perpendicular to the base of the surface leads to an increase in thermal efficiency. In this case, greater efficiency has been achieved for wire mesh ribs, and the use of needlelike ribs leads to a 40% increase in efficiency compared to wire mesh surfaces. Similar experiments were carried out in [11, 12], where they obtained similar qualitative results and established the effect of the anisotropy of mesh materials on hydrodynamics and heat transfer.

Figure 4. The sandwich panels cored with the metallic lattices fabricated with different methods to bear mechanical and thermal load concurrently.

Figure 5. The sandwich panels cored with the metallic lattices fabricated with different methods to bear mechanical and thermal load concurrently.

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Figure 5. Packs of sparse single (a) and zigzag (b) corridor packages of oval-trench holes.

The methods for intensifying heat exchange proposed above are typical, as a rule, for macroscales. In this case, we observe a pronounced separation of the flow into the main core and the near-wall region, where heat transfer will directly occur. In the context of increasing the compactness and efficiency of the devices being developed, this may not be sufficient. To further increase efficiency, it is necessary to use microchannel and porous media.

3. Heat exchange in microchannels and porous media

The use of microchannels and porous media makes it possible to significantly intensify heat exchange, which is a prerequisite for the creation of compact heat exchange devices. Mesh materials and classical porous structures with interchannel transpiration of the heat transfer agent have become widespread [13, 14]. In modern realities, the most promising is the use of highly porous [15] and/or anisotropic media [16, 17]. The use of such technologies makes it possible to make the heat exchange process in different-temperature filters as efficient as possible. The efficiency of heat exchange [4] is characterized by the ratio of hydrodynamic efforts for pumping the heat transfer agent when the heat transfer coefficient exceeds the one at the common section.

Anisotropic media deserve special discussion since they allow a high heat transfer coefficient in combination with relatively low efforts for transporting the heat transfer agent. Figure 6 offers various types of anisotropic media [18, 19]. It is shown that the use of media with a similar geometry makes it possible to significantly intensify heat exchange.
4. Influence of the structure and properties of developed surfaces on heat and mass exchange

Cleaning in multi-temperature filters is also associated with the mass exchange and the surface state of the phase transition. As in the case of heat exchange, the mass transfer takes place most intensively on developed surfaces. Thus, in [20], the authors investigated the effect of surface roughness and inhomogeneity on vapour condensation. Similar studies were also carried out in [21]. They showed the effect of the surface structure, including the wetting angle, on the heat transfer coefficient in smooth microchannels. Similarly, in [22], they studied the behaviour of drops and heat transfer during condensation on a microrelief surface made of copper by mechanical processing. Comparison of indicators for a smooth and hydrophobic surface showed that microchannels contribute to an increase in the removed heat flow by 55-102% but, at the same time, the growth of droplets is significantly limited.

In [23], the authors carried out a study of condensation on microstructured surfaces (figure 7). They assessed the effect of surface wettability on heat exchange. In this case, a hybrid surface was considered: the wettability of the base and pillars changed from superhydrophobic to hydrophilic. They showed that the heat exchange in the hybrid case of wettability increased by 28% in comparison with the superhydrophobic case.

Similar studies were carried out in [24, 25] for microstructured surfaces made of aluminium within the framework of a free convective flow of a coolant. The authors found that a structured hydrophilic surface demonstrates an increase in convection by 10-12%, and the maximum value of heat transfer corresponds to a superhydrophilic wall. Similar experiments for condensation were carried out in [26]. Also, in [27 - 29], combined use of surfaces with variable wettability is proposed to improve the thermohydraulic characteristics and improve the removal of condensate during drop condensation. These developments have found their application in the creation of heat pipe condensers.

5. Conclusions of the study

The analysis of the conducted studies showed that the intensification of heat transfer is achieved through the use of developed surfaces of various configurations, and the highest efficiency is achieved...
for highly porous microchannel heat exchange elements. Their use in combination with hybrid properties of wettability makes it possible to form a developed system of centers of drop formation and condensation, as well as to intensify the process as a whole. Since hybrid surfaces is a complex material science problem, further work is to produce a developed heat and mass exchange surface with desired properties. As a possible option, the authors considered a highly porous surface or a microchannel one based on silicon single crystals. [13, 14].

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