Experimental study of hydrodynamics in a vortex contact apparatus

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Abstract. The outcomes of experimental investigations into ascertaining the hydraulic resistance of a vortex apparatus, featuring swirling gas and liquid flows under diverse design and operational conditions, are showcased. These examinations on pressure loss in vortex-type apparatuses facilitate the estimation of energy consumption for activities such as dust removal, contact heat exchange, gas absorption purification, and other processes conducted within gas-liquid systems. Notably, it has been observed that the hydraulic resistance of the scrutinized vortex apparatus is markedly lower compared to the pressure drop encountered in nozzle-type and plate-type apparatuses. Furthermore, it does not surpass the resistance exhibited by high-efficiency vortex-type apparatuses of alternative designs. The hydraulic resistance of hollow vortex apparatuses, equipped with tangential swirlers, is contingent upon variables such as gas phase velocity, liquid flow rate, apparatus design parameters, and the physical properties of the working media. Through the meticulous analysis of experimental data, calculation dependencies have been derived to determine the resistance coefficients of both dry and irrigated vortex apparatuses. These dependencies prove to be practical and convenient from an applied standpoint.

1 Introduction

The intensity of heat and mass transfer processes in contact heat exchangers significantly depends on the following hydrodynamic modes of operation of the apparatus: the flow structure and velocity fields of interacting phases; the residence time of interacting media in the working area of the apparatus, etc. The efficiency of heat and mass transfer devices is determined not only by the intensity of the processes carried out, and to no lesser extent by their hydraulic resistance, on which operating costs depend.

To date, studies have been conducted to study the hydrodynamics and heat and mass transfer efficiency of vortex apparatuses [1-4]. Various designs of vortex apparatuses have been developed to intensify the processes of dust cleaning, heat and mass transfer during evaporative cooling or heating of gases, cooling of liquids, absorption, rectification and other processes [5-12]. It has been established that devices with a swirling gas-liquid phase flow have a number of advantages in comparison with traditional equipment with axial flow: productivity, efficiency and reliability are significantly higher, hydraulic resistance is less,

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the area of stable operation is wide, the disruption and entrainment of liquid is less, the design is simple.

We have developed a design of a hollow, direct-flow vortex-type apparatus with a downward flow of gas and liquid. The main advantage of this heat exchanger in comparison with others is increased heat and mass transfer efficiency and productivity due to high gas speeds, as well as low hydraulic resistance and simplicity of design.

The purpose of this work is to obtain experimental data on pressure losses in a vortex contact device with a gas and liquid flow twist at various design and operating parameters to determine hydraulic characteristics.

2 Materials and methods

In the exploration of the hydrodynamics of a vortex apparatus featuring swirling gas and liquid flows, a dedicated experimental setup was meticulously crafted and installed (refer to Figure 1). The comprehensive analysis of the overall hydraulic resistance of the experimental vortex apparatus followed a standardized methodology widely acknowledged in the field. The experimental rig comprises a direct-flow vortex apparatus denoted as 1, a gas supply fan at position 5, a centrifugal pump facilitating water supply positioned at 8, an array of shut-off valves, and an assortment of measuring and control devices. The working media employed in this experimental setup encompass atmospheric air and tap water.

Vortex apparatuses made of glass tubes of various sizes have been tested for visual observation of the structure of gas and liquid flows in the working chamber.

We have manufactured and investigated the following swirlers: single-pass tangential, two-pass tangential, snail, involute and single-pass tangential cylindrical.

The dimensions of the investigated vortex apparatuses were as follows:

- Diameter of the vortex chamber: 0.1 m.
- Height of the vortex chamber: 1 m and 2 m, respectively, with a height-to-diameter ratio of H/D=10,0 and H/D=20,0.
- Diameter of the vortex apparatus: 0,056 m.
- Height of the apparatus: 0.61 m, hence H/D=10,9.

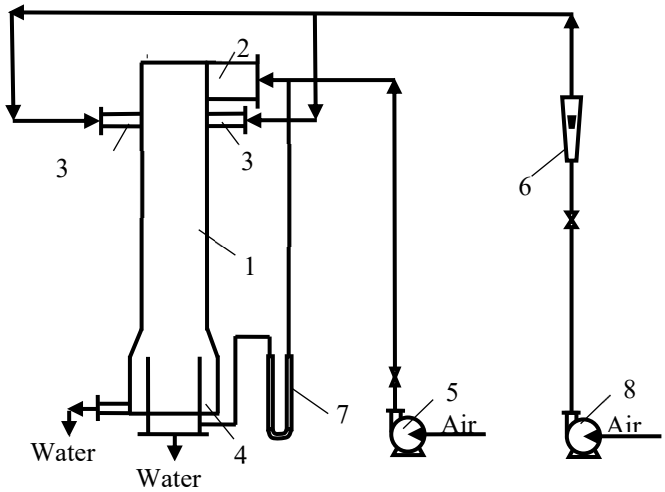
3 Results and discussion

Conducting experiments to study the hydraulic resistance of vortex apparatuses and the structure of gas and liquid flows in it at the value of the degree of twist A = 2, different ratios of the height of the apparatus to its diameter (H/ D = 10 and 20), at different gas velocities and fluid flow rates, allowed us to determine the optimal design and operating parameters of the studied apparatuses of the gas contacting process and liquids.

The conducted studies of the hydrodynamics of the vortex apparatus at different ratios of the height of the apparatus to its diameter H/ D have shown that the best hydrodynamics of the apparatus is achieved at H/D ≤ 10. With an increase in this design parameter, the vortex structure of gas and liquid flows is destroyed in the lower part of the apparatus, the jet pitch increases and there is a significant attenuation of vortices, as well as droplet separation from the surface of the apparatus and liquid entrainment. Under such circumstances, the intensity of heat and mass transfer processes naturally worsens. In addition, at H/D >10, the design of the device becomes inconvenient and, accordingly, its manufacture and installation become more complicated.

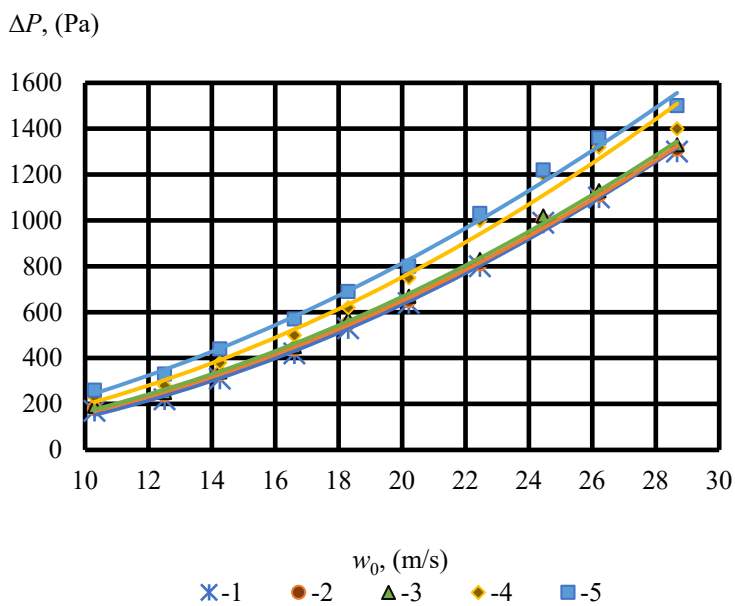
Figure 2 visually encapsulates the findings derived from meticulous experimental studies, portraying the relationship between the hydraulic resistance of the non-irrigated apparatus and the air velocity. The graphical representation vividly illustrates a consistent and

unswerving escalation in the hydraulic resistance of the apparatus as the gas velocity undergoes augmentation.



1 - Working chamber of apparatus; 2 - Gas inlet nozzle; 3 - Tangential inlet nozzle for liquid; 4 - Separator tank; 5 - Fan; 6 - Water flow meter; 7 - U-shaped water differential manometer; 8 - Pump.

Fig. 1. Schematic diagram of the experimental setup.



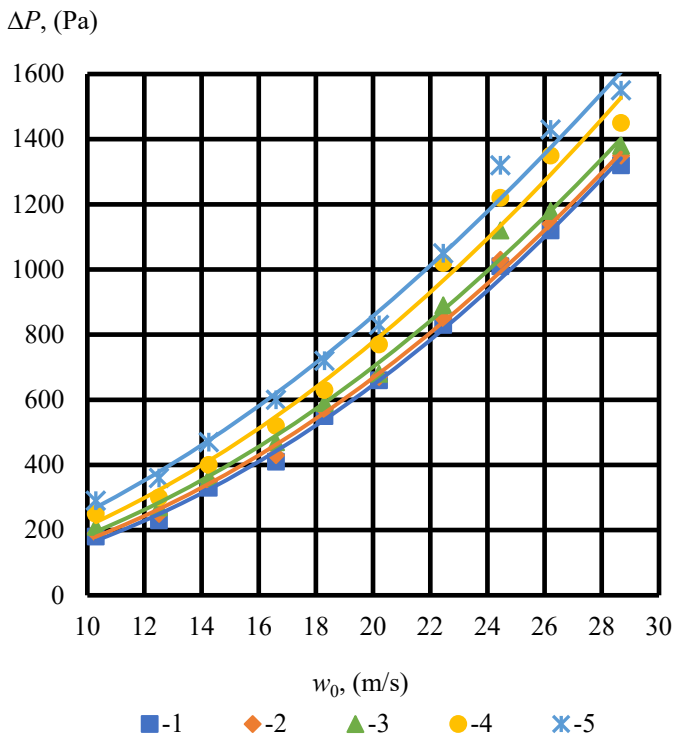
Vortex generator type: 1 - helical; 2 - tangential, single-entry; 3 - Tangential, double entry; 4 - involute;
5 - tangential-cylindrical, single entry.

Fig. 2. Dependency of hydraulic resistance ΔP of dry vortex devices with various vortex generators on the air velocity w_0.

In Figures 3 and 4, a visual representation unfolds, illustrating the relationships governing the hydraulic resistance of irrigated vortex apparatuses equipped with diverse swirlers. These dependencies are delineated concerning gas velocity, holding the mass flow rates of liquid and gas at L/G ratios of 1 and 3. A comprehensive analysis of these graphical representations reveals intriguing patterns.

Visual observations of the structure of gas-liquid flows in the studied apparatuses with snail, tangential-cylindrical, involute-like and tangential-cylindrical swirlers showed that in them, in almost all modes, the twist step is large and the liquid is distributed unevenly over the inner surface of the apparatus. However, in an apparatus with two tangential swirlers, the liquid is distributed evenly over the inner surface of the apparatus. This suggests that for the studied design of the vortex apparatus, there is no pronounced transient mode, which occurs in devices with snail, tangential-cylindrical, involute-like and tangential-cylindrical vortices of the gas phase.

Consequently, this pattern leads to a deterioration of heat and mass transfer and an increase in fluid entrainment. It should be noted that the pressure drop in the apparatus with a ratio of H/D = 10 is significantly less than in the apparatus with H/D = 20. Thus, it is established that with an increase in the design parameter H/ D, the hydraulic resistance of the vortex apparatus increases.



Vortex generator designs: 1 - helical; 2 - tangential, single-pass; 3 - tangential, double-pass; 4 - involute; 5 - tangential-cylindrical, single-pass.

Fig. 3. Dependency of hydraulic resistance ΔP of irrigated vortex devices with various swirlers on the fictitious air velocity w_0 at L/G=1.

It should be noted that the developed designs of vortex apparatuses with two tangential swirlers work stably in a wide range of changes in gas and liquid loads than apparatuses with other swirlers.

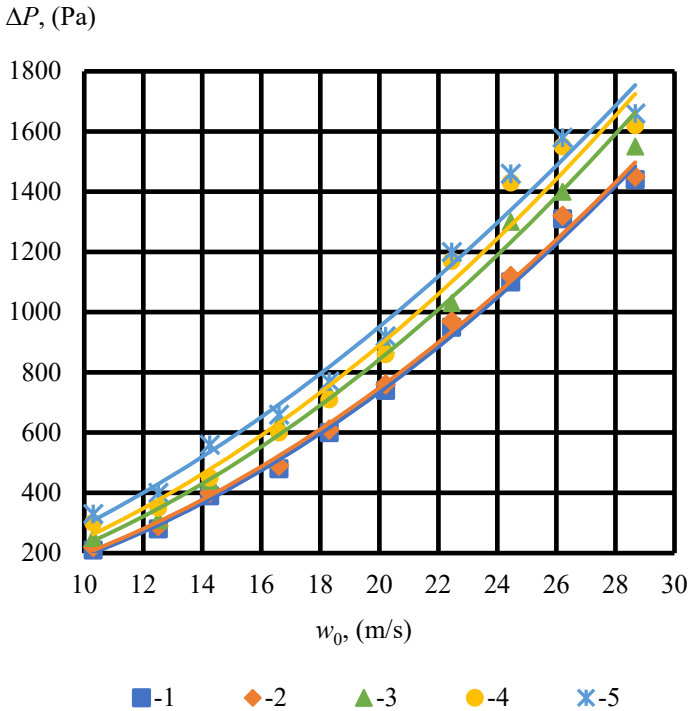


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Fig. 4. Dependency of hydraulic resistance ΔP of irrigated vortex devices with various swirlers on the fictitious air velocity w_0 at $L/G=3$.

4 Conclusion

Thus, experimental studies have established that in a device with two tangential vortices, the attenuation of the tangential velocity and, accordingly, the increase in the pitch of the swirling jet is less than in devices with other vortices, with the same values of the Reynolds criterion. Consequently, in an apparatus with two tangential swirlers, fluid entrainment will be less, the flow structure is better, and, accordingly, heat and mass transfer is more intense.

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