Study of hydraulic resistance of tangential swirlers

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Abstract. This article presents the results of experimental research and simulation of the hydraulic drag of tangential swirlers. Three types of swirler devices made with straight, profiled, and circular channel walls were studied within a wide range of design and process parameters. Simulation modelling on the Comsol Multiphysics platform was used to calculate hydraulic drag and determine the velocity and pressure fields. This allowed obtaining a dependence of the hydraulic drag coefficient of the investigated swirlers and identifying parameters affecting their hydraulic drag.

1. Introduction
Swirler devices are used in scrubbers for cleaning gas emissions [1–3], as well as in contact stages of rectification columns [4,5] evaporators [6], vacuum-cooling units [7], cyclonic separation devices [8][, cooling towers [9], and reactors [10,11]. Swirler devices have also become widespread in gas turbines and combustion chambers [12], as well as in contactors [13], absorbers and desorbers [14–17], fractionators, and pulp sorting machines [18].

The widespread use of rotating gas and liquid flows is due to the achievement of significantly intensified transfer of pulse, heat, and mass in various devices compared to the well-known phase interaction methods.

One of the main requirements for swirler design is the creation of a device with low hydraulic drag and high liquid or gas (steam) flow capacity. This allows for small equipment dimensions with low operating and capital costs.

Out of many different types of swirlers used in industry, tangential devices (figure 1) are of interest. Swirlers with straight channel walls (figure 1a) are easy to manufacture and efficient. However, an increase in the gas channel width results in gas slippage, leading to a decrease in the rotational motion of the flow. In this regard, swirlers having profiled channel walls (figure 1b) are of interest. They have less drag and a high tangential velocity of the flow out of the channels. Swirlers with annular channel walls (figure 1c) have the least drag and provide a developed interphase area.

Despite numerous studies conducted in this field, the known data require generalisation taking into account swirler design parameters and mathematical simulation results.
Figure 1. Scheme of swirlers with straight (a), profiled (b) and annular channel walls (c).

2. Materials and Methods
Air at a temperature of 20°C was used for the test flow. The gas flow rate was measured using a diaphragm. The total hydraulic drag was the difference between inlet and outlet pressures.

Swirler designs were made based on a 3D model on a CNC machine using layer-by-layer printing technology.

The experimental value of the swirler drag coefficient was calculated using the following dependence

\[ \xi = \frac{2P}{\rho \bar{u}^2}, \]  

where \( P \) is a pressure drop, Pa; \( \rho \) is the density of air, kg/m\(^3\); \( \bar{u} \) is the average mass flow rate of air in the swirler channels, m/s.

The drag coefficient obtained in the simulation was determined using equation (1) into which the design pressure drop was substituted.

The Reynolds number of the gas was determined from this dependence

\[ \text{Re} = \frac{\bar{u} b \rho}{\mu}, \]  

where \( b \) is the channel width, m; \( \mu \) is the dynamic viscosity coefficient of the gas Pa×s.

During experimental research and simulation on the Comsol Multiphysics platform, the design parameters of the swirlers were: channel wall inclination angle \( \alpha = 26^\circ \), channel width \( b = 0.001-0.009 \) m, channel length \( l = 0.001-0.025 \) m.

3. Results and discussion
Figure 2 shows the results of simulation and experimental studies of the hydraulic drag coefficient of swirlers having straight, profiled, and circular channels.

According to the data, swirlers with annular channels (figure 2a, Point 3) have the least drag, and those with straight channel walls (figure 2a, Point 1) have the greatest. The greatest effect on the value of the total hydraulic drag is made by head losses caused by the forces of viscous friction against the walls of the channel and at its inlet (figure 2b). Where \( P_{\text{out}} \) is the outlet pressure loss, \( P_{\text{fric}} \) is the friction pressure loss, \( P_{\text{chan}} \) is the inlet pressure loss.

According to the data, the transition to the developed turbulent mode (dashed line in figure 2a) for channels with straight walls was \( \text{Re} = 6000-7000 \), and the drag coefficient has the dependence \( \xi \approx \text{Re}^{-0.265} \). For the profiled channels \( \text{Re} = 6500-8000 \), \( \xi \approx \text{Re}^{0.297} \), and for the annular channels \( \text{Re} = 8000-10000 \), \( \xi \approx \text{Re}^{-0.396} \).

It was also experimentally established and confirmed by simulation that for all types of channels under study, an increase in hydraulic drag is observed with an increase in their width.
Figure 2. Dependence of the drag coefficient value on the Reynolds number (a) and the pressure drop on the swirler type (b). At \( l = 22 \) mm, \( b = 3 \) mm, \( l = 25 \) mm. Experimental points for three types of swirler: 1 - straight walls of the channels; 2 - profiled; 3 - annular channels.

Figure 3 presents a diagram for calculating the pressure drop in a preset swirler section. The design velocity (at the channel input and output) during simulation and data processing was read along the L lines, figure 3d.

Figure 4 shows the distribution of the total gas velocity at the channel inlet and outlet for the swirlers under study. According to the data presented, the swirler channels show a different velocity profile at the inlet depending on their design. As a result, the velocity is redistributed along the channel length, which causes a difference in the drag of the swirlers at the same Reynolds number. And when the width of the channel increases, the average mass flow rate of the gas decreases, and therefore, the dynamic velocity on the wall decreases, which leads to an increase in the thickness of the boundary layer [19,20] and an increase in head losses.

In the interval of the swirler channel length under study, the drag coefficient obeys the dependence \( \xi \approx l_{\text{chan}}^{0.19} \).
Figure 4. Epures of full speed at the inlet (I) and outlet (II) at Re = 2200, b = 0.003 m for straight (a) and annular channels (b).

The dependence of the drag coefficient in the turbulent mode is obtained from the design data of the swirler in the form

$$\xi \approx Re^{-m}l_{chan}^{0.19}b^{0.6}h^{-0.13},$$  \hspace{1cm} (3)

where $m = -0.281$ for straight and profiled channels, $m = -0.396$ for annular channels.

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