To the problem of determination the aerodynamic resistance coefficient value to the swirled dust and gas flow in the air ducts of engineering and environmental systems

D P Borovkov¹*, K O Chicherov ²

¹Volgograd State University, 100, Universitetsky avenue, Volgograd, 400062, Russia
²Penza State University of Civil Engineering, 28 Titova street, Penza, 440028, Russia

E-mail: friggate@yandex.ru

Abstract. The experimental studies’ results of the aerodynamic drag of a swirling dust and gas flow passing through a network of air ducts of engineering and environmental systems are presented. The limits of the method applicability for determining the aerodynamic resistance coefficient of a gas-dust swirling flow passing in a round aspiration duct, without taking into account the solid phase presence in it, have been determined.

Introduction
Flow swirling in air ducts is an effective way to combat the formation of dust deposits that worsen the aspiration systems’ efficiency [1-5]. The coefficient value of specific aerodynamic resistance to movement in the channel of a swirling gas flow containing solid dust-like particles is known to exceed that for a pure gas flow with the same swirl intensity at lower values of mass concentrations of solid particles than those observed in the absence of the flow rotational ($c > 0.01 \text{ mg/mg}$) [6 - 8].

The reason for this discrepancy is the interaction of dust particles moving into the near-wall flow zone with the channel walls (air duct), which causes an increase in friction, and, as a consequence, additional expenditures of flow energy for moving along the channel.

The verification possibility of using the technique for determining the pressure loss of a swirling dust and gas flow when passing through the air ducts of engineering and environmental systems was carried out using the experimental methods. When conducting the experimental studies, the task to determine the solid phase mass concentration value effect on the specific aerodynamic resistance coefficient value to the movement of a flow with a rotary motion passing in a ventilation (aspiration) duct, circular cross-section, was set.

Giving rotational motion to the dust-gas flow was carried out by using a tangential-type swirling device, which provides the possibility of smooth control of the swirl intensity [9, 10]; the device is shown in Fig. 1. Regulation of the swirl parameter at the outlet of the turbulizer is carried out by adjusting the cross-sectional area of the tangential branch pipe. For this purpose, the filling device is equipped with a movable wall 3, which can be moved longitudinally by means of an adjusting screw 4 along the section of the tangential branch pipe 2. The range of the filling device $\Phi *$ shape parameter values varies within 0.5 ... 5.
Figure 1. Dependence of the specific aerodynamic resistance coefficient values to the swirling gas-dust flow movement on the intensity of the flow swirling averaged along the length of the duct 

\[ \lambda_{sf} (\Phi) \], at \( Re = 1 \times 10^5 \) and various values of the mass dust concentration: 1 – \( \varepsilon = 0,01 \); 2 – \( \varepsilon = 0,009 \); 3 – \( \varepsilon = 0,008 \); 4 – \( \varepsilon = 0,007 \); 5 – \( \varepsilon = 0,006 \); 6 – \( \varepsilon = 0,003 \).

The schematic diagram of the experimental setup created for the research is shown in Fig. 2. The unit is a horizontal air duct with a relative length of 50 ... 100 diameters, along which a dusty stream moves by means of a draft device. To ensure the possibility of generalizing the experimental data during the experimental studies, air ducts with diameters of 100 ... 400 mm were used. This range is most typical for most small and medium-sized suction and dust extraction systems. To impart a rotational motion to the flow, a tangential-type swirler is installed at the end of the air duct with the ability to change the initial swirl parameter. The flow dustiness was controlled by a metering device. The gas flow rate flowing through the installation was measured using a micromanometer and a pneumometric tube, the aerodynamic resistance was estimated as the difference in static pressures on the walls. The static pressure values were measured using a battery micromanometer connected to the fittings (8) located at equal distances of ten air duct diameters.

Figure 2. The experimental setup diagram: 1,2 - glass air duct sections; 3 - adjustable curler; 4 - inertial dust collector; 5 - control damper; 6 - metering air inlet; 7 - flow straightener; 8 – air inlets for removing static pressure; 9 - loading device; 10 - dust collection bin; 11 - fan.

The pressure loss of the swirling flow was determined as the difference between the static pressures in the initial section and the final section of the air duct. The position of the initial section is conventionally taken as a distance of four diameters of the duct, in order to achieve a damping flow behind the swirler. The final section is located at a distance of ten duct diameters in front of the flow damper (7), to avoid taking into account its influence on the kinematic flow pattern.
The dust particles’ mass concentration value in the gas flow was varied with the help of nozzle metering devices within the limits $\varepsilon = 10^{-3}...10^{-2}$ kg/kg. The aerodynamic operating mode of the experimental setup was determined based on the Reynolds criterion values (calculated from the axial components of the gas flow velocities averaged over the channel cross section), varied in the range $Re = 10^5...5 \times 10^5$, which is typical for the environmental engineering systems’ ducts.

For the experimental studies, pre-prepared quartz sand, which has a true density $\rho = 2600$ kg/m$^3$ and median diameter $\delta_{50} = 90$ mkm, was used. When using fibrous materials, as well as the materials with increased adhesion, as well as when significant electrostatic forces occur (for example, when using polymer materials for the air ducts’ manufacturing), the resistance to flow movement, both swirling and axial, can significantly increase.

Based on the data obtained during the experimental studies, the specific aerodynamic resistance coefficients values to the swirling flow $\lambda_{sf}$ were determined, corresponding to different values of the flow swirl intensity ($\Phi^*$) and the mass concentration of dust particles in it ($\varepsilon$).

The results of determining the resistivity coefficient values to the movement of a two-phase swirling flow, obtained in the course of experimental studies, are shown in Figure 1.

**Figure 3.** Dependence of the specific aerodynamic resistance coefficient values to the swirling gas-dust flow movement on the intensity of the flow swirling averaged along the length of the duct $\lambda_{sf}(\Phi^*)$, at $Re = 1 \times 10^5$ and various values of the mass dust concentration: 1 $\varepsilon = 0.01$; 2 $\varepsilon = 0.009$; 3 $\varepsilon = 0.008$; 4 $\varepsilon = 0.007$; 5 $\varepsilon = 0.006$; 6 $\varepsilon = 0.003$.

To improve the clarity and convenience of the comparison, the experimental data are presented in the form of the specific aerodynamic resistance coefficient values ratios of dusty and clean swirling gas-dust flows corresponding to certain combinations of the experimental factors $\lambda_{sf}/\lambda_0$ (Figure 2).
Figure 4. Dependence of the specific aerodynamic resistance coefficients ratio of the two-phase and single-phase rotating flows on the mass concentration of dust $\lambda_{sf}/\lambda_0(\varepsilon)$, at different values of the flow swirl intensity averaged over the duct length: 1 – $\Phi^* = 0.4$; 2 – $\Phi^* = 0.5$; 3 – $\Phi^* = 0.6$; 4 – $\Phi^* = 0.7$; 5 – $\Phi^* = 0.8$; 6 – $\Phi^* = 0.9$.

As follows from the experimental data, the specific aerodynamic resistance coefficient value to the axial flow movement is practically independent of the solid phase particles’ mass concentration over the entire region of the experiment, which fully corresponds to the data [6 - 8].

However, in the presence of a rotational flow motion, this situation changes. An exponential growth of the specific aerodynamic drag coefficient is observed with an increase in the flow swirl intensity value. In this case, the values obtained at mass concentrations of the solid phase in the range of values $\varepsilon = 0.001...0.004$ with practically sufficient accuracy correspond to the results of calculations performed according to the methods [6 - 8].

When the indicated values of $\varepsilon$ are exceeded, the values of the coefficient of specific aerodynamic resistance to the movement of the swirling flow begin to exceed those obtained by the calculation (see Figure 2). Figure 3 graphically shows the dependence of the ratio of the coefficients $\lambda_{sf}/\lambda_0$ on the intensity of the flow swirl $\Phi^*$. 
Figure 5. Ratio dependence of the specific aerodynamic drag coefficients of two-phase and single-phase rotating flows on the swirl intensity $\frac{\lambda_{sf}}{\lambda_{0}(\Phi^*)}$, at various values of the dust mass concentration: 1 - $\varepsilon = 0.01$; 2 - $\varepsilon = 0.009$; 3 - $\varepsilon = 0.008$; 4 - $\varepsilon = 0.007$; 5 - $\varepsilon = 0.006$; 6 - $\varepsilon = 0.003$.

According to the shape of the curves shown in Figures 2 and 3, it can be concluded that the high degree of influence exerted by the mass concentration on the ratio $\lambda_{sf}/\lambda_{0}$ value. In addition, it follows from the data presented that the influence exerted on the sought ratio by the mass concentration value is noticeably increased with an increase in the flow swirl $\Phi^*$ intensity.

From a practical point of view, the most important result of the described experimental studies is the dust particles mass concentration values’ determination, at which it is possible with sufficient accuracy to use the calculated dependences intended to determine the specific aerodynamic resistance coefficient values of a single-phase swirling flow passing through a circular steel ventilation duct. It follows from the results obtained that this value does not exceed the value $\varepsilon = 0.005$, which is two times lower than the similar values typical for the axial dust flows.

However, it should also be noted that the obtained value $\varepsilon = 0.005$ corresponds to the volumetric concentration values of the reference dust (quartz sand) with $\varepsilon = 600 \text{ mg/m}^3$ under normal conditions, which is quite enough for the overwhelming majority of currently operated engineering and environmental systems.

Summary

1. Practically significant differences in the aerodynamic resistance values of dusty and pure swirling flows start becoming obvious at lower values of the solid particles’ mass concentrations than those characterizing the axial flows.
2. The studies carried out confirm the possibility of using the calculated dependencies to determine the values of the specific aerodynamic resistance coefficient to the movement of a swirling gas flow to the movement of a dusty flow in steel circular air ducts of engineering and ecological systems at the dust particles’ mass concentration values $\varepsilon < 0.005$.

References

[1] Azarov V N, Borovkov D P, Redhwan A M 2014 Application of swirling flows in aspiration systems International Review of Mechanical Engineering 8 (4) 750-753.
[2] Azarov V N, Borovkov D P 2003 Application of swirling flows in aspiration systems in the construction industry United scientific journal 5 102-104.
[3] Azarov V N, Borovkov D P 2012 Application of swirling flow in aspiration systems at enterprises of the construction industry Construction Materials 5 65-67.
[4] Azarov V N, Borovkov D P 2012 On the use of swirling flow in aspiration systems at the construction industry enterprises Bulletin of the Central Regional Branch of the Russian Academy of Architecture and Construction Sciences 16 12-17.
[5] Borovkov D P, Chicherov K O 2013 Aspiration systems with swirling flow in air ducts Regional architecture and construction 1 115-121.
[6] Borovkov D P, Chicherov K O 2012 Aerodynamic calculation of aspiration systems when organizing flow swirling in air ducts Regional architecture and construction 3 145-148.
[7] Schukin V K, Khalatov A A 1982 Heat transfer, mass transfer and hydrodynamics of swirling flows in axisymmetric channels (Moscow, Mechanical engineering) 200.
[8] Khalatov A A 1989 The theory and practice of swirling flows (Scientific thought) 192.
[9] Azarov V N, Zheltobryukhov V F, Borovkov D P A 2003 Device for cleaning air ducts of aspiration systems under excess pressure. Utility model patent RUS 35325 05.06.2003
[10] Azarov V N, Borovkov D P, Martyanov V N, Azarov D V 2003 Device for cleaning air ducts from dust. utility model patent RUS 33755 05.06.2003