Numerical modelling of energy efficient exhaust orifices and hoods in ventilation and air conditioning systems in buildings and facilities of thermal power plants

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Abstract. The paper presents the results of numerical simulation of energy-efficient inlet parts of exhaust ventilation systems in the form of the last side orifice and an exhaust hood. The profiling of the inlet sharp edges is used, which is made according to the outlines of the vortex zones that generates when the flow is separated at this edges. For this, the non-profiled geometry of the exhaust orifices is first modelled, where the outlines of the vortex zones are determining. Then a numerical model with profiling is created and the energy losses of such an improved shaped elements is determined. A significant reduction in pressure loss has been obtained: for the exhaust hood more than 40% and 30% for the last side orifice.

Introduction

Ventilation and air-conditioning systems at industrial facilities of thermal power plants are a complex structure, constructed to provide normative sanitary and hygienic requirements of meteorological conditions in the working area of the premises - relative humidity, speed and air purity. The main elements of the systems include air ducts, which can have, depending on the purpose and location of the serviced premises in the buildings or thermal power plant (TPP) facilities, very complex configurations with a large number of fittings and various functional devices.

For example, [1] prescribes the provision in the engine and boiler rooms the multizone ventilation systems. At the same time, in the boiler rooms of the TPP main buildings operating on gaseous fuels, supply of fresh air must be provided in the amount of three times the air exchange per hour. Cable floors and cable tunnels that pass inside and outside buildings must be equipped with mechanical ventilation without recirculation with the removal of air from each compartment of the cable rooms outside of the building. In this case, the exhaust ducts can be combined into collectors, and the systems must be equipped with automation, which intensifies the ventilation to avoid exceeding the temperature in the premises above 35 °C. In the transformer chambers and in the rooms of current-limiting reactors, the supply and exhaust systems also operate with the function of temperature control, and in the air of storage battery rooms ventilation should ensure the content of sulfuric acid aerosols...
within the maximum permissible concentration (MPC) and hydrogen within the explosion-proof concentration. At the same time, the air ducts of the exhaust ventilation systems have functional devices with hoods and orifices for local exhaust of air from the process equipment, exhaust openings and other structural elements.

In [2] it was shown that the energy consumptions in the communications of TPPs significantly reduce the efficiency of innovative solutions introduced at the station. Thus, for example, a typical main building of a small 350 MW cogeneration plant has an area of about 11,000 m² [3]. Having determined in accordance with the instructions [1] air flow rate in the premises of the main buildings of TPPs operating on gaseous fuels with an air change rate equal 3 and having a room height of 6 m, we obtain an air flow rate of 198,000 m³/h. To supply such flow rate at a pressure of 8 kPa, 55x8 = 440 kW is required. Having estimated that the same amount is needed for the exhaust system and the energy consumption for maintaining the ventilation system of the entire station is twice as high, we will get the energy consumption for the system of 1.76 MW, which is 0.5% of the generated electric power of the TPP. For comparison, it can be recalled that widely developed in recent years generating systems for super-overcritical pressure above 38 MPa and a temperature of more than 700 °C allow to increase the generation efficiency by only 5%. Consequently, a decrease in the pressure losses in the ventilation system can make a tangible contribution to the improvement of the station's performance in energy efficiency.

The results of numerical simulation of flow to the last (at the duct end plug) side orifice and hood (Figure 1) of the exhaust ventilation system are given in the paper. Flows to the hoods have been studied for a long time; there are works both for determining the pressure losses of such devices [4] (and containing recommendations for their design) [5, 6], and for determining the velocity field in front of the hood [7, 8]. In this case, both experimental methods of research and numerical modeling were used. There is much less work to study the currents in front of the side orifice, although such a device in the exhaust ventilation systems is also very common. One can note the paper [9], where the resistance of such an orifice is determined, for the case of a circular channel. It is known that in such devices, when the air flow is detached from the sharp entrance edge, a separation zone arises that causes local pressure losses. If the inlet section of the exhaust hole is profiled according to the outlines of the vortex zone, as suggested in [10] for the duct ventilation elements - elbows, confusers and diffusers, vortex formation can be reduced or eliminated, and therefore the resistance of such devices can be reduced.

At the first stage of creating such energy-efficient exhaust devices, it is necessary to determine the outlines of the formed vortex zones (VZ). Works on determining the outlines of vortex zones at the inlets of the hoods are very few. The outlines of VZ are determined in [11, 12] for air flow to a circular hoods with an angle of inclination of the hood flange 90° by the discrete vortices method. For the circular hoods with a large range of sizes and angles of flanges, the results of experimental and numerical studies of both separation zones and velocity fields are given in [13]. Numerical studies were carried out using the methods of discrete vortices and computational fluid dynamics. The results are shown to be in good agreement with the experimental data. For slot hoods the work [14] is known, where the VZ parameters are determined by the method of conformal mappings. The found outlines of the VZ are limited by one angle of inclination of the flange, but there is some information on the length and depth on which the VZ develops in the hood. Thus, there is no systematic information about the outlines of the vortex zones formed due to flow separation at the inlets of the last side orifice and the flat exhaust hood.

**Numerical study of unprofiled exhaust orifices**

In this paper, we present the results of a numerical study of the flow, in order to determine the outline of vortex zones and the subsequent modeling of energy-efficient inlets of exhaust ventilation systems with the profiling insert. The study is carried out for one case of the geometry of each type of considered exhaust orifices. For the exhaust hood - the length of the flange is equal to the half-width of the channel \((d = b = 0.1 m, \alpha = 30°\), figure 1a - the symmetrical half of the computational domain is
shown), the dimensions of the computational domain are: height - 1m, width - 2m, channel length 2m, for the last side orifice - channel width \( H = 0.16 \)m, orifice dimension \( h = 0.3 \) m, dimensions of the computational domain (Figure 1b): height - 1m, width - 1.5m, channel length - 6m. Boundary conditions (BC) for the hood: \( AF \) – velocity outlet \( v_0 = 5 \) m/s (Re> 50000), \( FE \) – symmetry BC; \( BCDE \) - external free boundaries (gauge pressure is set to zero); \( ABGI \) - impermeable walls. BC for the side orifice: at the outlet \( AJ \) – mass flow rate \( G = 1 \) kg/s (Re> 50000); external boundaries \( BCDEF \) – external free permeable boundaries (gauge pressure is set to zero), on all solid walls \( (AI, GF, FJ) \) - BC "wall".

![Figure 1. Geometry of the computational domain and a flow streamlines to the exhaust hood (a) and the last side orifice(b).](image)

The tasks are solved in a two dimensional formulation, with ANSYS® Fluent Software using RANS models, which are the most suitable for modeling such flows based on the results of preliminary studies—"standard" k-ε for the side orifice and the "Reynolds Stress Model" for the hood. For modeling a boundary layer “Enhanced Wall Treatments” is used. For each task, a grid convergence study is carried out – the grid is refined in stages, with solving and determining of a local resistance coefficient (LRC) at each stage.

\[
ζ = \frac{P_b - P_e - ΔP_{fr}}{P_d},
\]

here \( P_b \) is the initial excess pressure assumed to be zero; \( P_e \) is the final pressure at the end of the duct (at the \( AF \) boundary for hood and \( AJ \) for the side orifice) [Pa]; \( ΔP_{fr} = R_{fr} \cdot l \) is a pressure losses in the duct due to the friction [Pa]; \( P_d = \frac{ρv_0^2}{2} \) is a dynamic pressure in the duct [Pa]; \( R_{fr} \) is a unit friction losses
of pressure in the duct determined by processing the numerically computed field of total pressures in
the duct [Pa/m]; and \( l \) is the length of the duct [m] (Figure 1).

Further figure 2 shows the dependence of LRC on the dimensionless distance \( y^+ \), which
characterizes the degree of refinement of the computational grid.

![Figure 2. Verification of the tasks](image)

It can be seen that on the last two calculated grids, the results in both problems no longer depend on
the degree of grid refinement, and the LRC equal 5.29 for the side orifice and 0.121 for the hood. In
this case, the cells have minimum dimensions of the order of 0.005 mm, and their total number is more
than 2 million.

**Modeling of energy efficient profiled exhaust orifices**

Next, a numerical model of energy-efficient exhaust orifices was built, where the inlet part is
profiled using the outlines of the vortex zones (see figure 1). Boundary conditions and models were
used the same as in the study of non-profiled elements. Also, all solved tasks were studied to grid
convergence. Similarly, for the last computational grids, the independence of the local resistance on
the dimensions of the calculation cells is characteristic. As a result, it was found that for the exhaust
hood, the decrease of LRC was 42% (\( \zeta = 0.07 \)), and for the last side orifice – 30% (\( \zeta = 3.7 \)). In this
case, the streamlines for the profiled exhaust hood shows that after the profiling insert a secondary VZ
appeared, which, although much less, leads nevertheless to pressure losses (Figure 3).

![Figure 3. Flow to profiled exhaust hood (a) and side orifice (b)](image)

Therefore, further it is interesting to simulate an exhaust profiled with the outlines of the secondary
VZ. For the case of last side orifice, such a secondary VZ did not observed. Thus, we can talk about
the possibility of reducing the pressure loss, and hence the energy consumption of the exhaust
ventilation systems by profiling its input elements in the form of the exhaust hood and the last side orifice.

References
[1] SP 90.13330.2012. 2012 Thermal power stations (Moscow: Ministry of Regional Development of Russia) p 113
[2] Ziganshin A M 2015 Reduction of energy consumption of flow by profiling of fittings in power plants communications Safety & Reliability of Power Industry 63–8
[3] Kupcov I P and Ioffe J R 1985 Design and construction of thermal power plants (Moscow: Jenergoatomizdat) p 408
[4] Figueroa C E 2011 Hood entry coefficients of compound exhaust hoods. J. Occup. Environ. Hyg. 8 740–5
[5] DallaValle J M 1952 Exhaust hoods (New York: The Industrial Press) p 146
[6] Logachev I N and Logachev K I 2014 Industrial Air Quality and Ventilation (CRC Press) p 417.
[7] Cascetta F 1996 Experimental evaluation of the velocity fields for local exhaust hoods with circular and rectangular openings Building and Environment 31 437–49
[8] Betta V, Cascetta F, Labruna P and Palombo A 2004 A numerical approach for air velocity predictions in front of exhaust flanged slot openings Building and Environment 39 9–18.
[9] Khanzhenkov V I and Davydenko N I 1959 Resistance of the lateral openings of the pipeline end section Industrial aerodynamics 15 38–46
[10] Ziganshin A M, Aleshchenko I S and Ziganshin M G 2016 Connection fitting with profiling inserts PatentRUS2604264
[11] Logachev K I, Averkova O A, Tolmacheva E I, Logachev A K and Dmitrienko V G 2016 Modeling of Air and Dust Flows in the Range of Action of a Round Suction Funnel Above an Impermeable Plane. Part 1. A Mathematical Model and Algorithm for its Computer Implementation Refractories and Industrial Ceramics 56 679–83
[12] Logachev K I, Averkova O A, Tolmacheva E I, Logachev A K and Dmitrienko V G 2016 Modeling of Air and Dust Flows in the Range of Action of a Round Suction Funnel Above an Impermeable Plane. Part 2. Characteristics of Separation Region and Efficiency of Capture of Dust Particles Refractories and Industrial Ceramics 57 103–7
[13] Logachev K I, Ziganshin A M, Averkova O A and Logachev A K 2018 A survey of separated airflow patterns at inlet of circular exhaust hoods Energy Build. 173 58–70
[14] Posokhin V N, Salimov N B and Safiullin R G 2003 On the form of the vortex zones at the entrance to the exhaust hood News of higher educational institutions. Problems of power engineering 3-4 39–47