Influence of added aerodynamic resistance on stabilization of an air flow in mine air heater

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Abstract. Investigation into the wind speed effect on operation of open fanless air heater in Gramoteinskaya mine, Yuzhkuzbassugol, enabled to find that at a wind speed of more than 10 m/s from the leeward side of the building the heated air is discharged into the atmosphere. An experiment was performed on a physical model in the air channel of a boundary shaft at Gramoteinskaya mine in terms of the similarity conditions: geometric, kinematic and dynamic ones. At the stable fan operation mode the airflow velocity in the channel was measured before the aerodynamic resistance and after it for 10 minutes at regular intervals. Additional aerodynamic resistance provides at average twofold reduction in the airflow speed.

1. Introduction

Nowadays Kuzbass mines: Abasheskaya, Alardinskaya, Gramoteinskaya, Esaul'skaya, etc. employ open fanless air heaters (AH) where water is used as a heat carrier. Investigation into the wind velocity effect on AN operation at Gramoteinskaya mine, Yuzhkuzbassugol Co., made it possible to establish that the heated air is forced to discharge into the atmosphere at wind velocity of more than 10 m/s from leeward side of a building [1]. By Kemerovo Hydrometeocenter weather data, windy weather with snowstorms is specific for about 116 days (62 days in average) in Kuzbass region, when wind velocity is more than 10 m/s [2]. This indicates that AH works approximately one third of heating period with deviations from the schedule in terms of wind velocity (3–4 m/s) [3]. To fulfill acting regulations requires to lower twofold an air flow velocity at the air heater inlet [4]. The air, supplied to mine after its pass through AH sections, should correspond to the acting mine ventilation regulations at the expense of mine air pressure drop.

The problem can be solved by stabilization of an air flow supplied through the air intake ports by control of an air flow amount and velocity in front of AH sections thanks to mounting of additional aerodynamic resistances. The semipermeable shield of design parameters and porosity (0.628) is selected as an additional aerodynamic resistance [5].

2. Numerical modeling and mine experiment results

The physical model was designed to hold the respective experiment in order to find whether the additional aerodynamic resistance of 0.628 porosity is capable to lower twofold the air flow velocity at AH inlet ports. In physical modeling the nature of the phenomenon is preserved, but the scale is changed [6]. In the study case the problem arises on similarity conditions for the semipermeable shield and its model. Two physical processes are considered similar, given that the compatible parameters of
both processes are within rigorously defined relations [7]. These relations are three similarity types: geometric, kinematic, and dynamic ones.

The geometric similarity is fulfilled if dimensions of all similar elements of the model and nature differ at the same proportion. Thereto, the similar elements should be positioned at the same angles to the ram air velocity vector, viz., the below relations should be true [7]:

\[
\frac{l_1}{l_2} = k_l, \\
\frac{S_1}{S_2} = \frac{l_1^2}{l_2^2} = k_l^2 = k_S, \\
\frac{V_1}{V_2} = \frac{l_1^3}{l_2^3} = k_l^3 = k_V,
\]

where \( l \) is linear dimension, m; \( S \) is area or surface, m\(^2\); \( V \) is volume, m\(^3\).

To model the ram air flow from leeward side, the model should be mounted normally to the air flow.

The processes are kinematically similar, provided that geometric similarity (1) is fulfilled in them, if the below relations are true for all the pairs of time intervals during which the similar phenomena proceed [7]:

\[
\frac{t_1}{t_2} = k_t, \\
\frac{v_1}{v_2} = \frac{l_1t_1}{l_2t_2} = k_l = k_v, \\
\frac{a_1}{a_2} = \frac{v_1t_2}{v_1t_1} = k_v = \frac{k_l^2}{k_t} = k_a,
\]

where \( t \) is time, s; \( v \) is velocity (wind velocity \( V \) in our case), m/s; \( a \) is acceleration, m/s\(^2\). Time, wind velocity, and acceleration in natural conditions and in the model for all the pairs of time intervals are equal.

The processes are dynamically similar, if the kinematic similarity (2) is fulfilled and if relations for all the pairs of comparable forces are equal.

When considering dynamically similar processes it is explicit that the forces (gravity force, pressure, friction inertia, etc.) acting in them are different, and it is not simple to fulfill the dynamic similarity conditions for all the forces, in some cases it is impossible to do. In this connection the problem is solved approximately, considering the principal dominating forces, constituting the character of the hydraulic process [8].

When a body moves in ram air, the main acting forces are friction forces, so the dynamic similarity is fulfilled, if geometric (1) and kinematic (2) similarities are fulfilled, as well as Reynolds number values, calculated at comparable points of both flows, are equal.

Consider magnitudes in Reynolds number formula for a shield with square cells [9]:

\[
Re = \frac{V_n a}{\nu},
\]

where \( V = V_1/m \) is average air velocity in shield cells, m/s; \( V_1 \) is wind velocity in front of the shield, m/s; \( a \) is dimension of cell side, m (Figure 1); \( m = a^2/b^2 \) is porosity factor of semipermeable shield; \( b \) is step of a cell, m; \( \nu \) is kinematic air viscosity, m\(^2\)/s. Then

\[
Re = \frac{V_1 a}{m \nu}.
\]
Kinematic air viscosity and wind velocity under natural conditions and in the model are the same, so to fulfill equality of Reynolds number at comparable points of the flows implies that geometric parameters of model cells are fulfilled at 0.628 porosity.

The model of a semipermeable shield is made of hot-rolled steel with circular cross-section under GOST 2590-88 V: rod diameter \( d = 8 \) mm; critical deviation + 0.3 – 0.5; rod cross-section area 0.5027 cm\(^2\), mass of 1 m of profile 0.395 kg. width and height of the shield are 980 mm. the design size of a cell is \( a = 0.03 \) m. The final cell appeared rectangular in shape because of poor manufacturing precision; number of vertical rods was 27 u., horizontal rods were 28 u.

The actual porosity factor of the model was determined by the ratio of cell area to total shield area. The shield area was 0.9702 (0.98×0.99) m\(^2\). Number of cells was 702 (26×27) u., average cell area was 8.35×10\(^{-4}\) m\(^2\), total area of cells was 0.5862 (8.35×10\(^{-4}\)×702) m\(^2\). Porosity was 0.6.

The experiment was held in an air channel of Gramoteinskaya boundary shaft. The air channel was made of metal shields for air supply to the mine with the help of fans. The cross-section of the air channel is 3.4 m\(^2\) (1.52×2.0). The experimental device was mounted at straight section of 5 m in length in the air channel (Figure 2).

The velocity meter \( \delta \) (SDSV 01), mounted in the middle of the channel cross-section to measure an air flow velocity. Its readings are reported in digital display 7 beyond the channel. The table is mounted in depth of the channel where the analogue air flow velocity meter 2 is provided at the level, identical to the level of sensor \( \delta \); the aerodynamic resistance, made as a metallic grate of 0.98×0.98 m in dimensions with porosity of 0.6. The readings of sensor 2 are at digital display 6 beyond the channel.

At the stabilized fan operation mode the air flow velocity was measured in the channel prior to aerodynamic resistance and post it, the measurement results recorded at digital display were read visually and recorded for 10 min at equal time intervals. By 92 air flow measurements the curves were plotted (Figure 3) and the readings were compared in Table. So, the actual value \( V_1 \) is 10.04 ± 0.99 m/s, \( V_2 \) is 5.17 ± 0.58 m/s.

![Figure 1. Semipermeable shield with square cells.](image)

![Figure 2. Scheme of the semipermeable shield in an air flow: (a) side view; (b) cross-section (1—table; 2—air flow velocity sensor; 3—semipermeable shield; 4—drive motor for a semipermeable shield; 5—screw; 6, 7—digital display of velocity meter; 8—air flow velocity meter; 9—air channel.](image)
Figure 3. Variations in air flow velocity before and after supplementary aerodynamic resistance: 1—air flow velocity, measured prior to aerodynamic resistance $V_1$; 2, 4—trend line; 3—air flow velocity, measured after aerodynamic resistance $V_2$.

Comparison of variations in airflow velocity prior to $V_1$ and post $V_2$ additional aerodynamic resistance

| Parameter, m/s | min  | max  | Mean arithmetic, $V_1$, m/s | Mean square deviation $\sigma$ | Cutoff value $V_1$ |
|----------------|------|------|----------------------------|-------------------------------|------------------|
| $V_1$          | 8.19 | 11.98| 10.04                      | 0.99                          | 9.05±1.03        |
| $V_2$          | 4.25 | 6.3  | 5.17                       | 0.58                          | 4.59±5.75        |

3. Conclusions

The body moving in air or ram air flow are subjected to friction force, so in physical modeling the dynamic similarity is fulfilled if the condition of geometric and kinematic similarities are fulfilled as well as Reynolds number values calculated for comparable points of both air flows under natural conditions and in the model are equal.

To gain equality of Reynolds number values at comparable points it is necessary that geometric parameters of model cells correspond to porosity of the semipermeable shield.

The scatter of experimental and in-situ measurements (about 10%) of air flow velocity is due to the fact that the air flow in the air channel was actuated by rotation of fan blades which failed to provide a uniform air flow motion, unlike air mass motion at an open site.

The factual porosity of the semipermeable shield is 0.60 and provides twofold reduction in the air flow velocity in average.

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