Experimental investigation of aerodynamic properties of colour pigment for calcium silicate bricks

N Yu Klimenti, L I Khorzova, D V Azarov and O S Vlasova

Department of Fire Safety and Emergency Rescue, Volgograd State Technical University, 1 Akademicheskaya St., Volgograd, 400074, Russia

E–mail: khorzova–lidia@mail.ru, umois@mail.ru

Abstract. At construction industry enterprises, in particular at plants manufacturing coloured calcium silicate bricks, aerosols and fine dusts of raw materials are formed in the course of various processes of grinding, transporting, mixing, pouring etc. They are characterized by a high degree of dispersion and high concentration in working zone air and exceed the Maximum Permissible Concentrations by several times. One of the most significant reasons for increased dust amount in the air of working zones of industrial shops is the presence of locations of dust wastes storage. For the purpose of complete evaluation of dust conditions inside an industrial shop for components mixing for coloured calcium silicate bricks, it is necessary to investigate the dispersion process and the aerodynamic properties of the finest dust – colour pigment. The authors have conducted experimental investigations of the aerodynamic properties of colour pigment for calcium silicate bricks and formulated the conclusions.

Inside a manufacturing shop, a portion of dust floats in the air and a significant part of it penetrates into respiratory tracts of workers when they are not protected with personal protection equipment, it also deposits on the surfaces of walls, ceilings, floors, while a small proportion is removed by ventilation airflow [1,2]. The dust deposited on the surfaces and material spillage can return to suspended state due to the influence of air flows, surface vibrations, movement of transport or people; dust floating is often caused by convective flows to a considerable degree [3].

In order to obtain the complete idea of the dependences of dust particles motion inside a shop for components mixing, we will determine the floatation velocity of pigment particles. Any solid particle can be in suspension provided that the weight of the particle equals to the forces originating from air flow movement and acting on the particle in upward direction. The sedimentometry method was chosen to determine the fine fraction of particles through settling. The analysis of dust particle size distribution was carried out, which included the plotting of distribution graphs. In the process of fraction-by-fraction settling, the colour pigment sample under analysis is first accumulated in the upper part of disperse medium column, and the largest and heaviest particle fractions are the first to fall down, which will reach the bottom of the sedimentometer by a certain time $\tau$ in the cylinder of the height $H$ [4,5,6,7,8]. Hence, the minimum diameter of the particles deposited by the moment $\tau$ can be found through the value of particle settling velocity $\omega = H/\tau$, and the percentage of the particles with the smallest diameter $\delta$ is determined by the mass of the deposited particles. The laboratory facility aimed at determining dust particles size distribution through the method of settling in the air medium is given in figure 1.
The weighted amount of the colour pigment is uniformly distributed over object table. The powder is sprayed by a plunger through an abrupt push of air. The push causes the given suspended matter to get to the upper part of the unit and the pigment dust particles start settling down in still air under the action of the gravity force. The pigment particles move at various velocities, deposit on the paper band laid along the belt conveyer.

The belt of the conveyer is moved in jerks to the distance equal to the cylinder diameter at specified intervals of time. The results of the measurements are given in figures 2-4.

**Figure 2.** Dependence of the settling velocity on the particle size of iron oxide brown pigment 520, 510, 686 (1-5 curves): 1 higher than 0.4 m/s; 2 0.24 –0.4 m/s; 3 0.17–0.24 m/s; 4 0.13–0.17 m/s; 5 0.1–0.13 m/s.

**Figure 3.** Dependence of the settling velocity on the particle size of iron oxide red pigment H 130, H 190, 110 (1-6 curves): 1 higher than 0.4 m/s; 2 0.24–0.4 m/s; 3 0.17 –0.24 m/s; 4 0.13–0.17 m/s; 5 0.11 –0.13 m/s; 6 0.09 –0.11 m/s.
The analysis showed that all the pigments have the maximum particle size of no larger than 8 µm, in particular for yellow pigment it is no larger than 5 µm, for brown pigment – no larger than 6.5 µm and for red pigment – no larger than 8 µm. In all the ranges of the settling velocities, the integral functions of particle mass distribution according to equivalent diameters [8,9,10,11,12,13] are described by truncated log-normal functions.

Figure 4. Dependence of the floatation velocity on the size of particles of iron oxide yellow pigment (1-5 curves): 1 higher than 0.4 m/s; 2 0.24-0.4 m/s; 3 0.17-0.24 m/s; 4 0.13-0.17 m/s; 5 0.11-0.13 m/s.

One of the most significant tasks in the course of studying dust aerodynamic properties is the investigation of its behavior in the processes of breaking from a surface and starting moving inside horizontal ducts. When an air flow runs on dust particles lying in a horizontal plane at the velocity that can cause the dust rise into the air, this value is the threshold velocity which can be determined from the condition that the uplift force equals to the gravity force. In order to determine the threshold velocity of pigment particles, the substance was placed into a test air duct, and the precalibrated shutter was opening smoothly until the sample moved from its location.

At the starting moment of the sample movement, the air rate and flow depth were measured, and the mean velocity of the flow in the air duct was determined. The tests were repeated 6-10 times for each sample. The threshold velocity was found for three pigment samples. The aerodynamic tunnel shown in figure 5 was used as the laboratory facility to determine the threshold velocity.

Figure 5 – Wind tunnel for determining the threshold velocity of aerosols.

A wind tunnel is a facility which generates an artificial rectilinear uniform air flow with equal and parallel velocities, temperature and density in all the points of a cross-section. The experiment carried
out in an aerodynamic tunnel is based on the idea that air flow runs on a non-moving element and at the same time the air velocity is adjusted and its value is measured.

The wind tunnel is made of an air duct of circular cross-section with the diameter of 80 cm and the length of 4.5 m. It has a transparent test section, an air flow generator and an air diffuser located in the way of the air flow. The air flow generator located in the base of the wind tunnel is an axial-flow ventilating fan with the flow capacity of 110 W and the rotational frequency of 1500 rpm.

For the purpose of measuring and adjusting the air flow velocity, a thermal anemometer TTM-2-02 shown in figure 6 was used in the measurement points of the wind tunnel. The operating principle of the device implies that it transforms the sound velocity into air flow velocity and determines the temperature of the flow in the way similar to an acoustic thermal sensor.

In order to determine the air velocity, the minimum mean air velocity for the tunnel cross-section was found which causes a dust particle resting on the plate inside the wind tunnel to slide away from its location and start moving.

The results of the measurements of the threshold velocity for pigment particles are presented in table 1.

**Table 1. Results of the measurement of threshold velocity of pigment particles.**

| $d_a$, $\mu$m | Threshold velocity of particles, m/s |
|---------------|-------------------------------------|
|               | Iron oxide yellow pigment 313       |
| 1.5-10        | 0.53                                |
| 10-20         | 0.54                                |
| 20-30         | 0.54                                |
| 30-40         | 0.55                                |
|               | Iron oxide brown pigment 520, 510, 686 |
|               | Iron oxide red pigment H 130, H 190, 110 |
| 1.5-10        | 0.54                                |
| 10-20         | 0.55                                |
| 20-30         | 0.55                                |
| 30-40         | 0.56                                |

In the course of the investigation of the threshold velocity, it was revealed that in some cases temporary agglomerations with the size up to 40 $\mu$m can be formed on the horizontal surface or the bottom of air ducts due to coagulation or aggregation when pigments are kept in bulk. However, the threshold velocity for all the types of pigments belongs to a rather narrow range of air flow velocities from 0.55 to 0.6 m/s.

In order to avoid dusting inside an industrial shop, the air velocity in the transportation ducts and the charging device for components should exceed the dust particles entrainment velocity. The critical air movement velocity for a horizontal air duct section depends on the form, size and density of
particles, as well as on the mixture concentration and air density. The investigations in a wind tunnel allow determining the dependence of the amount of entrained colour pigment on the air velocity, which is shown as a graph in figure 7.

![Figure 7. Dependence of the amount of entrained substance on the air velocity, %: 1 - for yellow pigment; 2 - for brown pigment; 3 - for red pigment.](image_url)

According to the results of the investigations of entrainment velocities for various pigments, it has been revealed that the entrainment velocity for yellow pigment is 7.5 m/s, for brown pigment – 0.8 m/s and for red pigment – 8.5 m/s.

Based on the conducted analysis of aerodynamic properties of the finest dust of colour pigments emitted into the air of the working zone of an industrial shop for components mixing, the following conclusions can be drawn:

- All the pigments have the maximum particle size of no larger than 8 µm, given that it is no larger than 5 µm for the yellow pigment, no larger than 6.5 µm for the brown pigment and no larger than 8 µm for the red pigment. In all the ranges of the settling velocities, the integral functions of particle mass distribution according to equivalent diameters are described by truncated log-normal functions.
- The threshold velocity for all the types of the pigments belongs to a rather narrow range of air flow velocities from 0.55 to 0.6 m/s.
- The investigations in a wind tunnel revealed that the entrainment velocity for the yellow pigment equals to 7.5 m/s, for the brown pigment – 8 m/s, for the red pigment – 8.5 m/s.

References

[1] Azarov V N, Trokhimchuk M V and Sidelnikova O P 2016 Research of dust content in the earthworks working area Procedia Engineering 2nd Int. Conf. on Industrial Engineering vol 150 pp 2008-12

[2] Kozlovtsveva E Yu et al. 2017 IOP Conf. Ser.: Earth Environ. Sci. 90 012025

[3] Azarov V N et al. 2018 Research of aerodynamic characteristics of asbestos-cement dust in the ventilation emissions to the atmosphere Applied Mechanics and Materials 878 251-4

[4] Azarov V N, Evtushenko A I, Batmanov V P, Strel'yaeva A B and Lupinogin V V 2016 Aerodynamic characteristics of dust in the emissions into the atmosphere and working zone of construction enterprises International Review of Civil Engineering 7(5) 132-6

[5] Zhukova N S; Dobrin'skij D R and Azarov A V 2017 Reduction of pollutant concentrations under adverse weather conditions with optical dynamic measurement systems Int. Conf. on Industrial Engineering, Applications and Manufacturing (ICIEAM) (St. Petersburg) pp 1-3
[6] Azarov V N, Azarov A V, Dobrinsky D R and Lavrentieva L M 2018 About methodology of soil-environmental profiling for increasing environmental safety of construction International Conference on Smart, Sustainable and Sensuous Settlements Transformation (3SSettlements) Proceed. 7th - 8th March 2018 (München: Technische Universität München) pp 90-4

[7] Haritonova L P, Azarov V N and Igor Stefanenko 2018 About mathematical modeling of aerodynamic characteristics in devices with a leakage of the impact systems of plane-parallel streams on the heat exchange surface MATEC Web Conf. Int. Science Conf. SPbWOSCE-2017 Business Technologies for Sustainable Urban Development vol 170 (St. Petersburg) 03024

[8] Azarov V N and Sakharova A A 2019 Aerodynamic characteristics and fractional composition of the flask dust IOP Conf. Ser.: Earth Environ. Sci. 224 012027

[9] Azarov V, Burikaeva N and Solovyeva T 2016 Monitoring of fine particulate air pollution as a factor in urban planning decisions Procedia Engineering 2nd Int. Conf. on Industrial Engineering 150 2001-7

[10] Kuzmichev A A, Azarov V N and Kuzmichev A V 2017 The research of contamination regularities of historical buildings and architectural monuments by methods of computer modeling MATEC Web of Conferences Int. Conf. on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2017) vol 129 (Sevastopol: EDP Sciences) 05002

[11] Azarov V, Sergina N, Sidyakin P and Kevtunov I 2017 IOP Conf. Series: Earth and Environmental Science 90 012015

[12] Azarov V, Sergina N and Kondratenko T 2017 Problems of protection of urban ambient air pollution from industrial dust emissions MATEC Web of Conferences 106 07017

[13] Borovkov D P, Khorzova L I, Sidyakin P A, Tekushin D V and Bykadorova O A 2018 Improving the efficiency of cleaning smoke gases in the production of calcium carbide. 12th Intern. Scient. and Pract. Conf. “Science and Society” by SCIEURO in London (London: SCIEURO) pp 27-37