Issues of protection of atmospheric air against dust pollution in production of construction materials

N M Sergina, S V Shurshikov and D V Lyga
Chair of Health and Safety in Civil Engineering and Municipal Facilities, Volgograd State Technical University, Akademicheskaya St. 1, Volgograd 400174, Russia
E-mail: sergina.nsergina@yandex.ru

Abstract. To protect the atmospheric air from dust pollution in building materials’ production, systems of inertial dust control are most frequently used. The application of swirling inertial dust separators in the counter swirling flows (CSF) enables to considerably enhance the degree of purification of industrial emissions from dust especially from fine particles PM_{10} and PM_{2.5}. The authors carried out a complex of research works targeted at reasons of technical decisions providing an increase in the efficiency of dust control systems with the devices of CSF for the construction materials industry. As it was stated by the results of the research, the following decisions belong to the process: suction from the swirling dust separator bunker and supplying the dust and gas flows with various dust content to its top and bottom feeds. The article presents some results of laboratory and pilot studies the objective of which was both the validation of efficiency and practicability in application of the mentioned technical solutions and revealing operation parameters under which the least breakthrough of dust into the air is achieved in the dust control systems composed according to these solutions.

1. Introduction
Production of construction materials belongs to the dynamically developing branches of industry. In experts’ opinion, the tempo and volumes of construction both urban infrastructure objects and industrial ones will increase ahead of schedule. Whereas, this fact will determine the growth of volumes in building materials’ production (cements, construction mixes, concretes, etc.) as a basis for the whole building complex. For example, in Russia, nearly 75 million tones of cement were produced in the year 2015 and based on expert estimates, this amount will increase by approximately 8 percent pro year [1].

However, the industry of construction materials is one of the most hazardous in terms of dust emissions into the air. For instance, the specific emission of dust makes 190,9 kg pro 1 tone of product in the production of lime. The intensive dust formation is typical for the processes of breaking, grinding, sorting, transporting, et al. At that, the forming dust is a fine dust. For example, in the grinding section, the dust is formed with the median diameter 12-15 um, in the breaking section it is 12-17 um, and the most dust mass is with the particles of less than 10 um. In this connection, the problem of providing environmental safety intensifies at the branch enterprises.

At present, is many countries (Germany, France, Spain, Poland, and others), the application of swirling inertial devices in the counter swirling flows (CSF) is widely spread in the production of construction materials. The systematic study of dust cleaning in the swirling devices was begun by German specialists in the 50-s of the 20th century, when E. Schaufler and H. Zenneck had patented
their «Swirl-chamber for the separation of solid and fluid aerosol particles with the help of auxiliary swirling gas flow» in 1953. In 1963, H. Klein published study results of the prototype model of the swirling dust chamber with the diameter of 200 mm [2], in which the Schauffler’s model was taken as base model. Over the years, constructions of various elements of swirling dust chamber were improved, for example, in papers [3, 4], different approaches were used when studying the laws governing the processes of dust separation in the swirling devices, the basic ones are given in [2, 5-8].

It should be noted that the Russian researchers, for instance in the works [4, 9-11] and many others, a considerable contribution has been made into the development of theory and practice for purification of industrial dust emissions using the CSF. In particular, the results of multiple trials of devices for dry inertial dust separation at the operating enterprises in the construction industry and other branches showed that when organizing the suction from the cyclone-bunkers, the breakthrough of dust into the air is considerably decreased. According to the obtained results, it was proposed to perform the suction from the bunker of swirling dust separator with the swirling counter-flows [12-16]. Such a technical solution and the presence of two in-feeds of dust and air mixture in the CSF device enabled to diversify the conventional layout schemes aiming at their efficiency increase. However, the revealing of operating parameters for the dusting systems with these devices providing the minimizing of the dust breakthrough into the air required additional (experimental inclusive) research.

**The objective of the study** – is to increase the degree of purification of dust emissions into the air in construction materials production based on the application of the research results targeted at the increasing the efficiency for dust separation systems with the CSF devices.

2. **Methods and materials**

As was shown in the studies [16,17], to solve the problems of dust removal for the CSF devices, it is necessary to put the task well reasoned physically based on the probabilistic and stochastic approach. This technique was demonstrated and proposed by Professor Boguslavsky, E.I., and developed by the works of Professor Azarov, V.N.

With the theoretic study of process patterns for dust removal in the swirling devices with the counter swirling flows, the basics on the probability of the complex process of dust removal was used [17,18]. Herewith, it is considered that the mass transfer processes occur from two quasi parallel entry zones – zone A and zone B (Fig.1). In this case the probability of this complex process makes [19]

\[
P = \frac{P_{m_{\text{in}}} + P_{m_{\text{out}}}}{m_{\text{in}} + m_{\text{out}}}\]

The experimental studies were carried out in laboratory and pilot scale conditions. By the results of the analysis of dust removal processes in the CSF device with suction from the bunker performed on the basis of probabilistic and stochastic approach, in the tests, the following varied parameters were taken:

- total air fed for the purification to the device \((L_c)\), or the flow speed determined by this magnitude in the midsection of the dust chamber \((v)\);
- rate of air entering the device through its bottom input \(\bar{L}_{\text{bot}} = L_{\text{bot}} L_c^{-1}\);
- rate of air suction from the dust chamber bunker \(\bar{L}_{\text{suc}} = L_{\text{suc}} L_c^{-1}\);
- dust loading in the flow delivered to be purified;
- dust concentration ratio in the flows put into the CSF device through the bottom and upper inputs \(C_{\text{bot}}\).

To measure pressure and speed in the air feed pipes, the thermoelectric anemometer testo 435 was used with a set of Pitot tubes. The measurements of dust particle content in the air flow were carried out with the help of electric aspirator EA-1A intended for discrete sampling to the absorption vessels aimed at the further determination of the air dust load.
3. Discussion

To assess the fractional efficiency of the CSF device, relations were obtained characterizing the probability of the mass transfer from the entry pipes to the frame and the bunker zone [18]:

- from \(A\) zone (Figure 1)

\[
P_A = \left[ 1 - \frac{\exp\left(-\lambda \left(1 - W_{sl} V_{sl}^{-1}\right) R\right) - \exp\left(-\lambda \left(1 - W_{sl} V_{sl}^{-1}\right) R_B\right)}{(1 - W_{sl} V_{sl}^{-1})(R_R - R)} \right] \cdot \text{erf} \left[ \frac{(R_R - R_B)^2}{2\mu \beta (\tau_R - \tau_B)} \right]^{0.5}
\]

(2)

- from \(B\) zone

\[
P_B = \left[ 1 - \frac{\exp\left(-\lambda \left(1 - W_{sl} V_{sl}^{-1}\right) R_B\right) - \exp\left(-\lambda \left(1 - W_{sl} V_{sl}^{-1}\right) R_B\right)}{(1 - W_{sl} V_{sl}^{-1})(R_R - R_B)} \right] \cdot \text{erf} \left[ \frac{(R_R - R_B)^2}{2\mu \beta (\tau_R - \tau_B)} \right]^{0.5}
\]

(3)

where

\[
W_{sl} V_{sl}^{-1} = \left[ 1 - \frac{2\pi^2 \cos^2 \alpha_s H L_{sl}^2}{3D \rho_{ent}^2 \left(1 - L_{sw}\right)^2} \right] \cdot \bar{V}_{s} \cdot \rho_{at} Z_{at} \left(1 + A_a\right) \left(C_{at} \cdot \text{Re}_{at} \cdot \mu\right)^{-1}
\]

(4)

\[
W_{sl} V_{sl}^{-1} = \left[ 1 - \frac{2\pi^2 \cos^2 \alpha_s H L_{sl}^2}{3D \rho_{ent}^2 \left(1 - L_{sw}\right)^2} \right] \cdot \bar{V}_{b} \cdot \rho_{at} Z_{at} \left(1 + A_a\right) \left(C_{at} \cdot \text{Re}_{at} \cdot \mu\right)^{-1}
\]

(5)

Thus, the efficiency of the CSF dust chamber with suction from the bunker zone is determined by the basic design data of the device, hardware enforced \(\bar{L}_{sw}\) modes (by the mass of the \(A\) and \(B\) particles entering the zones).

The results of the experimental assessment of the efficiency of the CSF device are presented in tables 1 and 2.
Table 1. Results of experimental assessment for the efficiency of the dust chamber with counter swirling flows with suction from the bunker depending upon the operation modes.

| $v$, (ms$^{-1}$) | $\bar{L}_{\text{bot}}$ | $\bar{L}_{\text{suc}}$ | Efficiency, % |
|-----------------|-----------------|-----------------|----------------|
| 5.3             | 0.3             | 0               | 96.2           |
| 3.3             | 0.3             | 0               | 95.4           |
| 5.3             | 0.1             | 0               | 95.8           |
| 3.3             | 0.1             | 0               | 95.0           |
| 5.3             | 0.1             | 0.3             | 96.7           |
| 3.3             | 0.1             | 0.3             | 95.9           |
| 5.3             | 0.3             | 0.1             | 96.8           |
| 3.3             | 0.3             | 0.1             | 96.0           |
| 5.3             | 0.1             | 0.1             | 96.4           |
| 3.3             | 0.1             | 0.1             | 95.6           |

Table 2. Results of the experimental assessment of the dust chamber efficiency with counter swirling flows and suction from the bunker when the flows are fed with different dust concentration.

| $v$, (ms$^{-1}$) | $\bar{L}_{\text{bot}}$ | $\bar{L}_{\text{suc}}$ | $\bar{C}_{\text{bot}}$ | Efficiency, % |
|-----------------|-----------------|-----------------|-----------------|----------------|
|                 |                 |                 | 0.75             |                 |
|                 |                 |                 | 0.5              |                 |
| 5.3             | 0.3             | 0               | 96.3             | 96.6           |
| 3.3             | 0.3             | 0               | 95.3             | 95.7           |
| 5.3             | 0.1             | 0               | 95.8             | 95.4           |
| 3.3             | 0.1             | 0               | 95.1             | 95.3           |
| 5.3             | 0.1             | 0.3             | 97.3             | 97.5           |
| 3.3             | 0.1             | 0.3             | 96.5             | 96.7           |
| 5.3             | 0.3             | 0.3             | 96.9             | 97.2           |
| 3.3             | 0.3             | 0.3             | 96.2             | 96.4           |
| 5.3             | 0.1             | 0.1             | 97.0             | 97.2           |
| 3.3             | 0.1             | 0.1             | 96.1             | 96.4           |
| 5.3             | 0.3             | 0.1             | 96.6             | 96.8           |
| 3.3             | 0.3             | 0.1             | 95.7             | 96.0           |

The obtained data given in Table 1 confirm the practicability of the suction from the bunker of the CSF device for the increase of its efficiency. For instance, with the same other mode parameters ($v = 5.3$ ms$^{-1}$, $\bar{L}_{\text{bot}} = 0.1$) with the relative volume of the vented air $\bar{L}_{\text{suc}}$ making 10% ($\bar{L}_{\text{suc}} = 0.1$), the system efficiency grows from 95.8% to 96.4% (table 1). These data were obtained for the case of feeding to the bottom and upper entries of the flows dust chamber with an equal dust content. The results of the experimental research on the assessment of the efficiency of the swirling dust chamber with counter swirling flows with feeding flows with differing dust concentration are shown in table 2.

It stands to reason that the lesser the flow is dust laden when it is fed to the dust chamber through its bottom entry compared to the dust loading of the flow fed through the upper entry, the more is the efficiency of the CSF device.
Thus, the suction from the bunker of the swirling inertial dust chamber in the volume of 20-25% of the dust and air mixture fed to be purified and feeding the flows with different dust content to the CSF device enable to enhance the efficiency of emission dust catching in the device itself and in general in the dusting plants composed using the swirling CSF dust chambers. Herewith, the above mentioned constructional and mode solutions can be applied in the dust collecting systems both with one cleaning step and with more steps too [13-16,19,20].

4. Conclusion

Based on the results of the research work, major principles have been set up which are to be followed to enhance the efficiency of dust emission cleaning when designing dust control systems with the swirling inertial devices on the counter swirling flows with one or more cleaning steps.

Among these principles are:

- suction from the bunker of one of the CSF devices feeding the vented flow to the entry of the dust control system, to the entry of another device or to the processing;
- the relative volume of the vented air from the bunker makes 20-25%;
- a flow with lesser dust concentration is fed to the bottom entries of the CSF devices than in the flow fed to the upper entries; if possible, clean air from the environment is to be fed to the bottom entry.

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