Influence of design and technological parameters on the efficiency of the granular filter

R R Sharapov
Moscow State University of Civil Engineering (National Research University),
Moscow, 129337, Russia
ptdm_zavkaf@mail.ru

Abstract. The main types of devices for separating dust from process gases are considered. Their advantages and disadvantages are indicated. Granular filters are noted as the most effective ones. They can work in a very aggressive environment, both chemically active and with high-temperature gases. The design of a granular filter with high efficiency of cleaning dusty gases is proposed. An experimental installation of a granular filter was created for experimental confirmation of the high efficiency of the proposed filter design. The material used in the experimental setup as a filter material, its mineralogical and chemical composition are described. The central composite rotatable plan of the fractional factor experiment was chosen as the main plan of the experiment. To conduct experimental studies, the studied factors and levels of variation were determined. Based on the results of the experiment, a regression equation was obtained that expresses the efficiency of the cleaning process from the structural and technological parameters of the granular filter in encoded form. Graphical dependence of the effect of main design-technological parameters of granular filter efficiency depending on the time of his work were done. The high efficiency of the proposed granular filter for cleaning process gases from highly dispersed dust has been experimentally proved.

1. Introduction
The rapid growth of industrial production, the accumulation of huge amounts of waste, and significant energy consumption in various industries contribute to the pollution of our planet [1, 2]. The catastrophic growth of air pollution in the modern period is due to a sharp discrepancy between the development of industrial production and cleaning techniques, in particular air dedusting, which was not able to solve the problems posed to industry. Here, Russia lags far behind other developing countries in terms of technical implementation of the provisions of the Kyoto Protocol in the field of agreements to limit greenhouse gas emissions [3]. The production of any building materials is accompanied by a large dust emission.

One of the most common devices for dust cleaning is a cyclone. To increase the efficiency of its operation, many researchers are improving its design [4-6]. However, the efficiency of the cyclone does not always meet the production requirements, which does not exceed 90...92 % [7-9].

To increase the degree of purification of dusty gases in industry, filters have been widely used, in which the purification of gases from particles suspended in them occurs when the gases pass through a layer of porous material [9, 10]

Fabric filters are used in industry for fine cleaning of industrial gases, in which the filtration surface is made in the form of sleeves. Depending on the specific conditions, these filters can purify
gases at temperatures up to 300 °C [9-11]. Bag filters are able to capture dust particles ranging in size from a few microns to submicrons, which are captured when the fabric is clogged with larger particles. The hydraulic resistance of bag filters, depending on the type of filter material used and the filtration time, is 0.5...8.0 kPa. Efficiency of bag filters from 96...99 % and higher.

Having many positive qualities, bag filters at the same time have serious disadvantages: high power consumption, short service life of expensive filter fabrics, complexity of construction requires qualified service, sensitivity to changes in filtration conditions. These reasons are limiting factors for the widespread use of such filters.

Some experts call the electric method of cleaning dusty air the most perfect one [9, 10]. The degree of purification of gases in the electrostatic precipitators reaches 99...of 99.5% in the dust of all sizes. The power consumption in these devices is 0.1 ... 0.85 kWh / (100 m$^3$ of gas). The hydraulic resistance does not exceed 300 Pa. Regardless of the design, the electrostatic precipitators can clean chemically aggressive gases, high humidity with a relatively high temperature.

The cross-section and volume of the electrofilters are determined depending on the time of residence of the gas in the chamber, which is assumed to be 3...4 s. This duration is sufficient for the deposition of dust on the precipitation electrode. The speed of movement of gases reaches 2...2.2 m/s.

However, electric filters are complex electrical structures that require a lot of space and highly qualified service personnel. It should be configured very precisely for effective work. For these reasons, the field of application of these devices is to clean large volumes of dusty air-more than 100 000 m$^3$/h, and for installations with small volumes of dusty air emissions for small productions, electrofilters are not economically feasible. These reasons are limiting factors for their widespread distribution.

Granular filters are a separate class of filtering devices. They are widely used in various industries due to the simplicity of construction and maintenance, low cost, and a fairly high degree of efficiency, which can exceed 99 % [9, 10, 12]. For example, Duda notes [9] that granular filters are used in the USA cement plants everywhere where the temperature of hot gases reaches 500 °C.

Buzzi Unicem Concern (Italy) also makes extensive use of granular filters in cement plants. In particular, Cement Hravice has installed LURGI type granular filters on clinker coolers since 1992 [13]. Performance by air – 200 ... 223 thousand Nm$^3$/h at a gas temperature - 250...400 °C at a dust concentration of 18 ... 30 g/Nm$^3$.

The parameters of their operation are comparable to battery cyclones, but with greater efficiency, at which granular filters can be used in the dust cleaning system as an independent and sufficient unit [14].

Manufacturers of granular filters claim their efficiency of up to 99.9 % with a hydraulic resistance of up to 1500 Pa.

2. Materials and Methods
One of the most important tasks to prevent the consequences of air pollution is the use of modern dust cleaning equipment at all stages of technological processes associated with dust emission.

The analysis carried out above has shown that one of the highly effective devices for cleaning dusty air leaving the process equipment is granular filters that can be installed for cleaning high-temperature gases. We have developed a granular filter for cleaning high-temperature dusty gases [15].

For experimental confirmation of the efficiency of the proposed granular filter, we created an experimental installation, the photo of which is shown in figure 1.
Figure 1. Photo of the proposed grainular filter.

During all the experiments, pre-crushed cement clinker of the Belgorod cement plant of various sizes was used as a filter material.

The average diameter of the clinker used as a filter material was determined by the formula:

\[
d_m = \frac{m_1 d_1 + m_2 d_2 + \ldots + m_n d_n}{m_1 + m_2 + \ldots + m_n}
\]

where \(m_1, m_2, \ldots, m_n\) – the mass of clinker of different classes, kg; \(d_1, d_2, \ldots, d_n\) – the size of the various classes of clinker, mm.

Mineralogical composition of clinker used as a filter material: \(C_3S – 64.49\%; C_2S – 12.93\%; C_3A – 6.59\%; C_4AF – 13.49\%\). Chemical composition of clinker: \(\text{SiO}_2 – 21.48\%; \text{Al}_2\text{O}_3 – 5.33\%; \text{Fe}_2\text{O}_3 – 4.44\%; \text{CaO} – 66.28\%; \text{MgO} – 0.71\%; \text{R}_2\text{O} – 21.48\%; \text{SO}_3 – 21.48\%; \) other – 1.09%.

As the main plan of the experiment, we select the central composite rotatable plan (CCRP 2\(^5\)+1) of the fractional factor experiment (FFE).

In accordance with the adopted plan, five levels of factors are set: -1 – lower; 0 – middle; +1 – upper; -2, +2 – star.

All accepted factor levels are implemented on the combined granular filter model and correlated with the actual operating conditions of the dust cleaning equipment (table 1).

| Table 1. Studied factors and levels of variation FFE CCRP 2\(^5\)+1 |
|---------------------------------------------------------------|
| **Factors** | **Codeword notation-reading** | **Interval variation** | \(X = -2\) (star level) | \(X = -1\) (lower level) | \(X = 0\) (middle level) | \(X = +1\) (upper level) | \(X = +2\) (star level) |
| Height of the material layer \(h\), mm | \(X_1\) | 25 | 50 | 75 | 100 | 125 | 150 |
| Average size of grains \(d_m\), mm | \(X_2\) | 0.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| Dustiness of the inlet air, \(Z\), g/m\(^3\) | \(X_3\) | 1 | 6 | 7 | 8 | 9 | 10 |
| Volume flow rate of aspirated air, \(Q\), m\(^3\)/h | \(X_4\) | 20 | 160 | 180 | 200 | 220 | 240 |
| Filtration time, \(t\), min | \(X_5\) | 10 | 20 | 40 | 30 | 40 | 50 |
When conducting experiments as a dust fed to the developed granular filter, used dust selected from bag filters of cement ball mills of JSC “Belgorod cement”. The grain composition of cement dust is shown in figure 2. The presented diagram is obtained on the Micro Sizer 201 granulometer.

![Grain composition of dust used in research at the experimental facility.](image)

**Figure 2.** Grain composition of dust used in research at the experimental facility.

### 3. Results

The figure 3 presents the results of a study of the process of cleaning dusty air, determined by the value of the passage of dust $K$ through the combined granular filter. The regression equation expressing the dependence of the cleaning process dusty air, determined by the value of leakage of $K$ from the dust layer height $h (X_1)$ filter material, the average grain size $d_m (X_2)$ filler filter layer, dustiness $Z(X_3)$, which included in the dust cleaner unit of air, volume flow $Q (X_4)$ the aspirated air and the time $t (X_5)$ filtration of dusty air combined granular filter in coded form has the form:

$$K = (83.0 - 8X_1 + 10.25X_2 - 5.9X_3 + 2.8X_4 - 13.4X_5 - 16X_6X_3 +$$
$$+ 2X_2X_5 - 2.5X_4X_5 - 0.8X_1X_2 + 0.9X_2X_3 - 1.1X_3X_4 + 0.9X_1^2 - 1.1X_2^2 +$$
$$+ 0.5X_3^2 - 0.8X_4^2 - 3.7X_5^2) \cdot 10^2.$$  \(2\)

Figure 3, a shows the results of the study of the influence of dustiness $Z$ of the incoming air at $Q = 220$ m$^3$/h, $h = 75$ mm and various $d_m$ parameters, equal to 3.5 mm (left) and 4.5 mm (right) at different time cuts offs $t$ of the operation of the combined granular filter on the parameter $K$ in the combined granular filter.

The left figure (figure 3, a) shows the dependence of the slip under the above conditions for $d_m = 3.5$ mm.

Line 1 (figure 3, a, left figure) characterizes the operation of the granular filter at $Z = 6$ g/m$^3$. With the minimum dust content of the input air and the filter running for 10, 20, 30 and 40 minutes, the $K$
parameter was 1.43, 1.19, 1.01 and 0.91% respectively. After 50 minutes of continuous filter operation, the $K$ parameter is 0.88.

With an increase in the dust content of the input air to $7 \, g / m^3$ (see figure 3, a, left figure, line 2) when the filter was running for 10, 20, 30, and 40 minutes, the $K$ parameter decreased to 1.31, 1.08, 0.93, and 0.85%, respectively. After 50 minutes of filter operation, the dust slip was 0.82%.

Figure 3, b presents the results of a study of the effect of the volume flow rate of aspirated air $Q$ at $d_m = 4.0 \, mm$, $Z = 8 \, g / m^3$ and various parameters $h$ equal to 75 and 150 mm at different values of the combined granular filter operating time $t$ on the parameter $K$.

Line 1 (see figure 3, b, left figure) characterizes the operation of the granular filter under the previously specified conditions ($d_m = 4.0 \, mm$, $Z = 8 \, g / m^3$), depending on the time of its operation at $h = 75 \, mm$ and $Q = 160 \, m^3/h$. With the minimum volume flow of the input air and the filter working for 10, 20, 30 and 40 minutes, the parameter $K$ was, respectively, 1.39, 1.10, 0.89 and 0.76%. After 50 minutes of continuous filter operation, the $K$ parameter is 0.70%.

**Figure 3.** Experimental dependence:

a – $K(Z)$: $Q = 220 \, m^3/h$; $h = 75 \, mm$; 1 – $Z = 6 \, g/m^3$; 2 – $Z = 7 \, g/m^3$; 3 – $Z = 8 \, g/m^3$; 4 – $Z = 9 \, g/m^3$; 5 – $Z = 10 \, g/m^3$;

b – $K(Q)$: $d_m = 4 \, mm$; $Z = 8 \, g/m^3$; 1 – $Q = 160 \, m^3/h$; 2 – $Q = 180 \, m^3/h$; 3 – $Q = 200 \, m^3/h$; 4 – $Q = 220 \, m^3/h$; 5 – $Q = 240 \, m^3/h$. 
When the \( Q \) parameter is increased to 200...240 m\(^3\)/h (see figure 3, \( b \), left figure, lines 3, 4 and 5) parameter \( K \) at the initial moment (\( t \) up to 20 min) remains at the same level \( \approx 1.1 \% \). After 30 minutes of filter operation, the parameter \( K \) begins to increase with increasing \( Q \), i.e. when \( Q \) is equal to 200, 220 and 240 m\(^3\)/h after 30 minutes of operation of the granular filter, the slip is 0.92, 0.95 and 0.99 \%, respectively, and after 50 minutes of operation, the parameter \( K \) is 0.81, 0.91 and 1.00 \%, respectively.

The decrease in the efficiency of the cleaning process dusty air in a granular filter when increasing the parameter \( Q \) is due to the fact that an increase in the rate of passage of particles in the intergranular space, reducing the likelihood of deposition of dust particles on the surface of filler grains.

When increasing the height of the filter material layer up to 150 mm (see figure 3, \( b \), right figure) at \( d_m = 4.0 \text{ mm}, Z = 8 \text{ g/m}^3 \) depending on the time of its operation at \( Q = 160 \text{ m}^3/\text{h} \) (line 1) and the filter operation for 10, 20, 30 and 40 minutes, the parameter \( K \) was 1.27, 0.98, 0.73, and 0.58 \%, respectively. After 50 minutes of continuous filter operation, the \( K \) parameter is 0.49 \%.

4. Conclusion

Based on the experimental data presented in figure 3 for the dependence \( K(h, d_m, Z, Q, t) \), the following conclusions are made:

- with an increase in the value of \( Z \), regardless of other factors, the values of \( K \) slips decrease;
- increasing the flow rate of aspirated air \( Q \) through the combined granular filter more than 200 m\(^3\)/h reduces the efficiency of the combined granular filter;
- increasing the filter operating time \( \tau \), regardless of other factors, the values of \( K \) slips are reduced by reducing the live section of the pores through which the dusty air passes.

References

[1] Rashid Sharapov, Pavel Kapyrin, Svetlana Lozovaya, Valentina Yadykina and Aleksandr Agarkov, Research dedusting efficiency of the inertial hub with adjustable parameters 5th International Scientific Conference “Integration, Partnership and Innovation in Construction Science and Education” 86, (2016)

[2] Ovsyannikov Y.G., Gol’tsov A.B., Seminenko A.S., Logachev K.I., Uvarov V.A, Reducing the power consumption of ventilation systems through forced recirculation. Refractories and Industrial Ceramics. 57, 5 (2017).

[3] Leonard de Clerk, Koroboiva N.L, Russia and the Kyoto Protocol. Metallurgist. 7 (2007).

[4] DonnaLeeIozia and DavidLeith, Effect of Cyclone Dimensions on Gas Flow Pattern and Collection Efficiency, Aerosol Science & Technology, 10, (1989).

[5] L. S. Brar, R. P. Sharma, and K. Elsayed, The effect of the cyclone length on the performance of Stairmand high-efficiency cyclone, Powder Technology, 286, (2015).

[6] Rohlerl E, High temperature dedusting. World Cement. 34, 1 (2003).

[7] Logachev I.N., Logachev K.I., Uvarov V.A., Seminenko A.S., Goltsov A.B., Kireev V.M, Velocity field for fan weakly swirled jet of loading spouts for fine materials. International Journal of Pharmacy and Technology. 8, 4 (2016).

[8] J. F. Yao and M. Takei, “Application of Process Tomography to Multiphase Flow Measurement in Industrial and Biomedical Fields: A Review,” Ieee Sensors Journal, 17, 24 (2017).

[9] W.H. Duda, Cement-data-book, Band 1, Internationale Verfahrenstechniken der Zementindustrie, Wiesbaden, Bauverlag, Berlin, 1985, p. 617.

[10] S. Yu. Kabanov, Improving equipment for cleaning dusty gases, Belgorod, BSTU, (2010).

[11] Sharapov R.R., Ovsyannikov Y.G., Boychuk I.P., Agarkov A.M., Prokopenko V.S, Research Of Aerodynamics Of Recirculation Systems With Forced Aspirated Air. International journal of applied engineering research. 10, (2015).

[12] Sharapov R.R., Research of the hydraulic resistance of the granular filter of the sweeping mashnine E3S Web of Conferences Innovative Technologies in Environmental Science and Education (ITESE-2019) 135, (2019).
[13] Elinek P, Reconstruction of a clinker cooler dust collection system. Cement and its application. 4 pp. 88–90. (2009).

[14] Yu Y.S., Tao Y.B., Ma Z., He Y.L., Experimental study and optimization on filtration and fluid flow performance of a granular bed filter Powder Technol., 333 (2018)

[15] The patent of the Russian Federation for utility model No. 107484 “Granular filter”.