

## EXPERIMENTAL RESEARCH ON THE WORK OF CENTRIFUGAL FILTER WHEN ELIMINATING SOLID PARTICLES FROM CLINKER COOLING SYSTEM

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**Abstract.** The elimination of solid particles from a clinker cooling system under industrial conditions in Moldova cement plant in Ribnica city is being analysed. In order to assess the influence of solid particles on the performance of six-channelled centrifugal filter, the general elimination effectiveness of solid particles and the one according to dispersion with the initial concentration of dust – 2.37 g/m<sup>3</sup> were examined. The dusty amount of gas flow 0,001 %, was extracted by a ventilator BII 6-28-3.15. During the experiment, the amount of the gas under cleaning was 140 m<sup>3</sup>/h at 60 – 100 °C. When the productivity of centrifugal ventilator is low, the amount of gas flow in the channels of the machine was 11 m/s. The identified aerodynamic resistance of the centrifugal filter I[Φ 2-6-02 was – 480 Pa. To measure solid particles a seven-step impactor model NIIOGaz was used which work is based on the identification of the size of particles in input and output air paths of gas flow of the centrifugal filter. The analysis of dispersal composition allowed indentifying that the median of solid particles at the input of gas flow was 20 μm, output – 15 μm. General effectiveness of 91 % of the centrifugal filter was identified. This paper compares the results of the experiment to the performance effectiveness of battery multicyclone and presents the methodology for the calculation of effectiveness. In addition, calculations of the effectiveness of typical cyclones demonstrating 500 Pa aerodynamic resistance are presented compared to the elimination rate of the centrifugal filter I[Φ 2-6-02.

**Keywords:** centrifugal filter, solid particles (SP), dispersivity, efficiency.

### 1. Introduction

Cyclones, according to their simplicity and low construction, exploitation, maintenance and energy consumption costs, are widely used in oil and processing industry for removal of solid particles (SP) from fluids/ gas. Having used appropriate materials and construction methods, the cyclones may be exploited under high temperature and pressure, when the use of high efficiency equipment may have great significance in the processes of the power and processing industry as follows: pressurized fluidized-bed combustion (PFBC), integrated gasification combined cycle (IGCC) and fluidized catalytic cracking (FCC). In these processes, cyclones are now almost the only fully-commercial method to separate particles from high temperature gas (Zhou and Soo 1990, Hu *et al.* 2005; Gujun *et al.* 2008).

Simple construction of a cyclone has been left almost the same for more than hundred years. There are two construction types of a cyclone: a direct-flow cyclone and a reverse-flow cyclone. However, reverse-flow cyclones, axial-flow cyclones and rotary-flow cyclones with tangential

gas inlet into the cyclone case most often are used.(Bernardo *et al* 2006; Vaitiekūnas and Jakštonienė 2010).

The main characteristics of a cyclone separator operation are efficiency of SP collection, fractional efficiency and loss of pressure. Seeking to identify the characteristics mentioned above, numerous studies had been performed; however, they were successful in the definite domain of the Reynolds number and geometry proportions (Avcı and Karagoz 2003). Therefore, development of more efficient cyclones in essence had been based on more experimental than mathematic models (Moore and McFarland 1993; Dirgo and Leith 1985; Kenny and Gussman 1995). As some samples of the above cyclones could be the Stairmand high-efficiency cyclone (Stairmand 1951), the Lapple cyclone (1951), Southern Research Institute cyclones (Smith *et al.*1979), German Z cyclone (König *et al.* 1991), air-flow cyclone (Upton *et al.* 1994; Kim and Lee 1990).

In Cement Factory of Ribnica City, Moldova, semi-dry method is applied for the production of clinker. A 4.5 x 56 m rotary furnace is used for burning the loaded mixture out, where the loaded mixture is burned out up to 1450° C and it

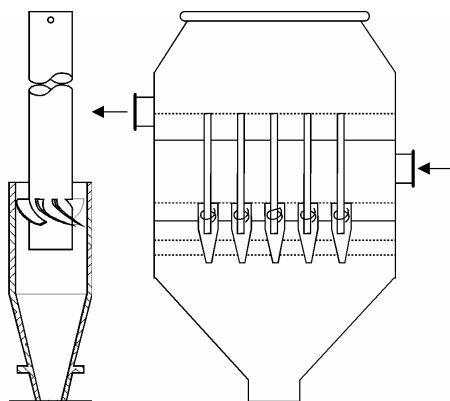
is overdone, turning it into granules, that are instantly cooled down by fans, blowing the environment air in the cooling chamber Volga – 50 C, with efficiency of 50 t/h. Thus, Portland cement clinker, which is the main half-finished product of cement production, is manufactured.

Cooled air in the cooling chamber down to 140–170 C<sup>0</sup> k, that flow amounts from 120–140 thousand m<sup>3</sup>/h, before eliminating it into the atmosphere, is purified in battery cyclones БЦ P-250/2 × 110. In the purified gas the clinker dust concentration reaches 2.85 g/m<sup>3</sup>. Efficiency of the battery cyclone amounts 85–90 %, the aerodynamic resistance is from 900 to 1200 Pa. Its construction is made of 110 cyclone elements, the diameter of every element cylindrical part of which is 250 mm, (Fig. 1. (a) Presented cyclone element, which is made of one case, gas inlet air duct 2) and gas outlet air duct 3).

Using multicyclones, equipment of smaller measurements is made, besides, resistance of the gas flow decreases. Fig. 1. b) general view of the battery cyclone with elements of the reverse-flow cyclone is seen.

In multicyclones under a significant fall of pressure, a lot of energy is consumed. Simultaneously, gas debit per separate cyclone is lower given large amount of the purified gas to be distributed into a lot of the above mentioned cyclones, where whirling flows do occur because of “a socket” or “a screw” (Denafas 2000).

Battery cyclones possess a general tank of the gas collection and this decreases purification efficiency comparing it with one-cyclone element, having one cyclone case. Gas purification efficiency decreases not only because of unequally distributing gas in separate elements of the multicyclone and different resistance, but due to distribution of the gas flow between the tank and separate elements of the multicyclone.



**Fig 1.** Battery cyclone БЦ P-250/2×110 (Zayanchovskyy 1979): a) an element with „a socket“, b) general view

One disadvantage of the above mentioned equipment is that battery cyclones are clogged by ashes since the resistance is decreasing in the cyclone. This is caused due to low velocity under low load in uneven gas distribution in the multicyclone elements. Non uniform gas distribution in separate elements depends on its configuration, gas direction and velocity. Unequal gas distribution in multicyclone elements and clogging by ashes cause wear and tear of

pipes. Having appeared some holes in outlet piping or in cases of the cyclone elements, battery cyclones leak unpurified gas. Under existence of narrow clearances between the cyclone elements, there is no opportunity available for the performance of the maintenance checkup (Belousov 1988).

**The aim of the research** is to determine efficiency of the centrifugal filter, which inside construction is made of six-channeled ring system; to compare the results of the research received with the battery cyclone БЦ P-250/2×110.

## 2. Research methods

In the Cement Plant of Ribnica City, Moldova, an experimental panel of the centrifugal filter had been assembled and the research had been made removing solid particles from the cooling system of the clinker.

The panel was made of the centrifugal filter ЦФ 2-6-02, the centrifugal fan БЦ P 6-28-3.15, the funnel, laboratory vessels and measuring devices: the electro-aspirator; velocity of the gas flow was measured by the Pitot-Prandtl construction tube; rubber hoses that inside diameter was 5–8 mm, the outside diameter was 9–12 m; a second-chronometer, its deviation was ± 0.2 s; differential micrometers TESTO 506 (measuring limits were from 0–10/200 GPa; the deviation allowed was ±1 %) used for measuring pressure of the gas flow in the air ducts of the inlet and the outlet. Treatment of the solid particles according to their size was identified, using a seven-step impactor of the NIIOGaz model, allowing separation of the gas directly from the outgoing gas flow in the chimney. Dispersivity of solid particles had been specified by the above mentioned measuring device and relative fraction of particles, accumulated in pulleys, fixed into the instrument. In order to collect the smallest particles, the pulleys were arranged according to the diameter decreasing order of their openings. The impactor allowed determining the diameter of solid particles in the dimension interval from 1 to 15 μm. The measurements had been performed, using the based-on gravimetric method, measuring the concentration of solid particles (Alyev 1986). General view of the panel is presented in Figure 2.

From the cooling chamber of the clinker, dusty amount of gas 0.001 %, had been extracted by the fan БЦ 6-28-3.15. During the experiment, the amount of the purified gas under 60–100°C made 140 m<sup>3</sup>/h. Under low efficiency of the centrifugal fan, velocity of the gas in the equipment channels amounted to 11 m/s. Aerodynamic resistance of the centrifugal filter was 480 Pa.

It is possible to achieve high efficiency of purification, using centrifugal filters with the ring system, arranged in it, where channels with closed contours (or with the feedbacks) are interconnected consecutively order (Fig. 3). Closed contours are composed of two flat lids and cylindrical rings of different curvature. Every pair of neighbouring channels makes a closed contour under axial rotation excentricity between even and odd rings (Serebryanskyy 2009).

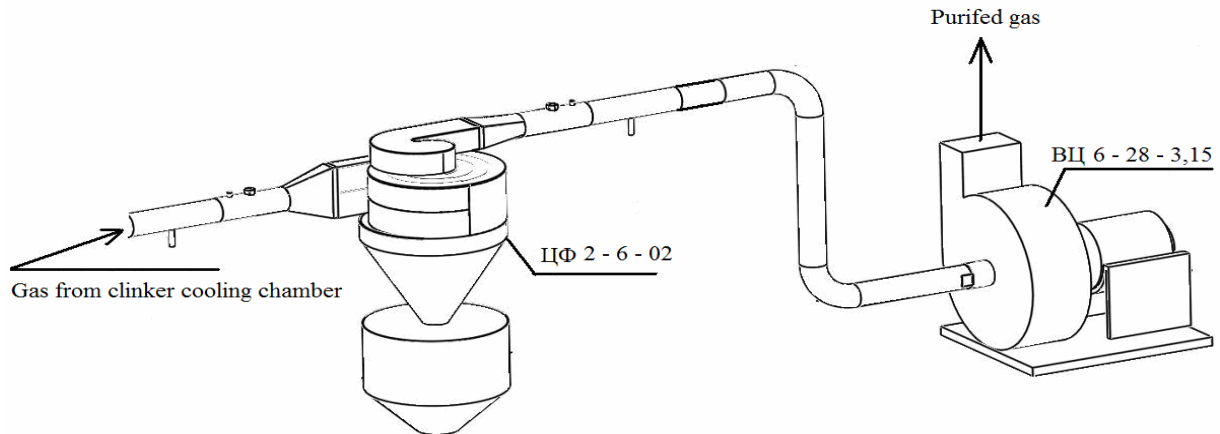


Fig 2. Experiment centrifugal filter panel

In the end of every channel, curvilinear gas flow is divided into two parts. The peripheral part, i.e. circulating flow returns into the previous channel of smaller curvature and the central part, i.e. entire flow is directed into the following channel according to the order of greater curvature. Having passed by all channels consecutively, the entire flow is eliminating from the system through the central opening, existing in the top lid.

In the system of closed contours, incoming solid particles with the gas are dividing into three groups: the smallest solid particles, which mass is higher than some certain size, are pumped in by the circulating current in the first channel and they are settled down in the dust collector, attached to it; larger particles with intermediate mass are distributing in equal-current orbits, and are circulating in closed contours.

Having become smaller and decreasing the mass, a circulating particle is passing by the smallest-radius channel and is eliminated by the entire flow. Increasing the mass and for the particles coagulating, their aggregation is moving from the centre towards periphery of the system and is passing consecutively into channels of larger radius, it is pumped into the first channel by the circulating current and settles down in the dust collector (Serebryansky and Pryemov 2007; Vaitiekūnas *et al.* 2010).

### 3. Results and analysis

It is possible to determine elimination of dust from the centrifugal filter approximately according to the empirical dependence upon the quantity of channels in the apparatus:

$$\varepsilon = \frac{1}{1 + 2^{n-1}} \quad (1)$$

Here: n- number of channels in the centrifugal filter.

Referring to the experiments performed and to the received results in Pobuzhsky Ferrous-Nickel Plant, it had been specified that quantity of channels, existing higher than seven, dust purification efficiency of 99.22 % is met; it may be compared with sleeve filters. Presented calculation dependence had been confirmed for a lot of

times, testing apparatus in various fields of production (Serebryansky and Novakovskyy 2009).

In order to research the impact of clinker dust concentration for the operation of the six-channeled centrifugal filter ЦФ2-6-02, an experimental research had been performed in Cement Plant of Ribnica City.

During the experiment collection of clinker dust was determined according to its size under dust velocity 11 m/s in the equipment channels and under primary dust concentration of 2.37 g/m<sup>3</sup>.

Purified dust is accumulated in pulleys, fitted inside the impactor and having flat surface. Pulleys of the impactor are arranged according to the order of their decreasing diameter openings; in order to collect small dispersal particles in the interval from 1 to 15 μm dimension. Calculated fraction of settled-down particles is presented in figures 3 and 4.

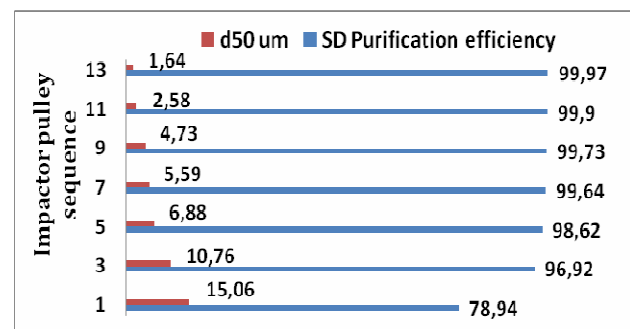


Fig 3. Determination of SP dimension by the centrifugal filter ЦФ2-6-02 in the inlet air duct

Settling the dust on the surface of the pulleys, every from the two ones, the settled-down dust residual is being calculated, accepting 100 % total weight in all pulleys of the device. Referring to the results received, in logarithm coordinates a curve of the dust dispersivity composition is drawn, following methodology of solid particles composition measurement in the gas flow (Alyev 1986).

$d'_{50}$  value is calculated according to the formula:

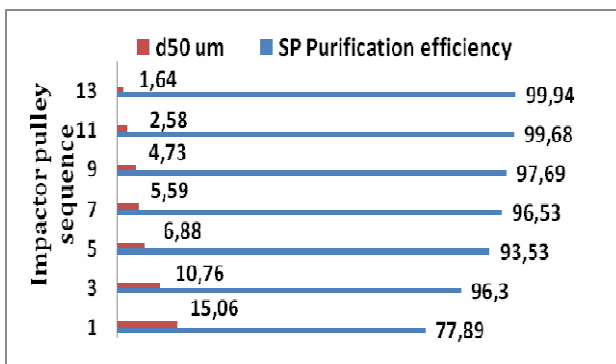
$$d'_{50} = d_{50} \times 0.86 \times 10^3 \sqrt{\frac{\mu'}{Q \times \rho'}} \quad (2)$$

here:  $d_{50}$  - dispersivity median;  $Q'$  - gas flow;  $\mu'$  - gas viscosity under  $t'$ ;  $\rho'$  - gas density.

In Fig. 3, distribution of solid particles in the impactor pulleys according to the diameter of particles in the inlet air duct and in Fig. 4 – in the outlet air duct -under 11 m/s gas velocity in the centrifugal filter channels and under primary dust concentration of 2.37 g/m<sup>3</sup>.

As it is shown in Fig. 4, it is seen that the amount of 1.64  $\mu\text{m}$  solid particles in the pulleys of the impactor is the largest one. In the inlet air duct, the amount of solid particles reached 99.97 %, and in the outlet air duct it was 99.4 %. Elimination rate of that dimension particles made 0.03 %. Elimination rate of solid particles, which dimension was 2.58  $\mu\text{m}$ , was equal 0.22 %; the above mentioned data were as follows: 4.73  $\mu\text{m}$  – 2.04%; 5.59  $\mu\text{m}$  – 2.81%; 6.88  $\mu\text{m}$  – 5.09%; 10.76  $\mu\text{m}$  – 0.62; 15.06 – 1.05%.

Having performed the analysis of the drawn curve of dust dispersivity composition distribution in the logarithm scale, the results of the experiment had shown that dispersivity median of solid particles amounted 20  $\mu\text{m}$  in the inlet air duct, and it amounted 15  $\mu\text{m}$  in the outlet air duct. Also it had been specified that discontinuously of the distribution of particles according to their diameter dimensions amounted  $\sigma=4.54$  in the inlet and amounted to  $\sigma=3.25$  in the outlet.



**Fig 4.** Determination of SP dimension in the outlet air duct of the centrifugal filter ИФ2-6-02

Using impactor methodology, fractional distribution of SP according to the dimension  $\mu\text{m}$  in the mass (100 %) yielded (1 table).

**Table 1.** Fractional distribution of SP according to the dimension  $\mu\text{m}$  in the mass (100 %)

SP size $\mu\text{m}$	0-5	5-10	10-15	15-20	20-30	30-50	>50
Before purification ИФ2-6-06 ( $d_{50}=20 \mu\text{m}$ , $\sigma=4,54$ )							
SP mass %	0,003	0,117	0,26	0,1	0,18	0,18	0,16
After purification ИФ2-6-06 ( $d_{50}=15 \mu\text{m}$ , $\sigma=3,25$ )							
SP mass %	0,003	0,197	0,26	0,24	0,22	0,075	0,005

The authors determined, the centrifugal filter working for 5 hours, 1550 g dust has been determined by weighing in the tank, the efficiency rate of the centrifugal filter amounted

91 % under aerodynamic resistance of 480 Pa; in the meantime, the efficiency of the operating battery multicyclone БЦ P-250/2 x 110 in the cement plant amounted 85 %–90 %, under 900–1200 Pa. Received data show twice less energy consumption of the centrifugal filter.

We are going to compare the received data of the experiment efficiency with standard cyclones under aerodynamic resistance of 480 Pa. Recently, calculating cyclone efficiency in practice, probability calculation methodology, referring to the dimensional arrangement of solid particles in the logarithm scale and to the dependence of solid particles efficiency in the cyclone upon the dimension of the collected particles, most often is used (Rusanova 1983). Operation of the cyclone is characterized by two main parameters:  $\sigma_{\eta 50}$ ,  $\sigma_{\eta}$ , that are necessary, using the above mentioned methodology.

For cyclones magnitude  $\lg \sigma_{\eta}$  may be used stable 0.35. Parameter  $d_{\eta 50}$  is determined according to the construction of the cyclone and it is specified in scientific references. According to the above mentioned two parameters and  $\sigma_n$ ,  $d_{50}$ , describing dust dispersivity, magnitude of the parameter is being identified:

$$T = \frac{\lg d_{50} - \lg d_{\eta 50}}{\sqrt{\lg^2 \sigma_n + \lg^2 \sigma_{\eta}}} \quad (3)$$

here:  $d_{50}$  – median dimension of particles;  $\sigma_n$  – dispersivity distribution according to the dimension of the collected particles;  $d_{\eta 50}$  – diameter of the collected particles with 50% efficiency probability;  $\sigma_{\eta}$  - fractional purification efficiency according to the dispersivity distribution.

General efficiency of solid particles is calculated:

$$\eta_{\text{general}} = \Phi(T) = \frac{1}{2\pi} \int_{-\infty}^T (\exp) \frac{T^2}{2} dT^2 \quad (4)$$

here:  $\Phi(T)$ - the Gaussian integral is specified according to the identified data in probability tables (Rusanova 1983). By the above calculating method, it is necessary to specify  $d_{\eta 50}$  parameter as  $d_{50}$ ,  $\sigma_n$ ,  $\sigma_{\eta}$  are known.

Having a mind to calculate value of  $d_{\eta 50}$ , referring to 20 cyclone authors analysis, it is proposed using the form of dependence (Rusanova 1983):

$$d_{\eta 50} = 33 \left[ \Phi_1 \left( \frac{\bar{H}_{\text{general}}}{\bar{D}} \right)^{\frac{2}{3}} \right]^{-0,78}, \mu\text{m} \quad (5)$$

here:  $\Phi_1 = 0,785 \frac{1-\bar{a}}{\bar{a}\bar{b}}$  - for cyclones with tangential gas

inlet;  $\Phi_2 = 0,785 \frac{1+\bar{a}}{\bar{a}\bar{b}}$  - for cyclones with tangential-screw

gas inlet. Under the cyclone operation conditions, according to the expression of the third formula:  $D = 0.6 \text{ m}$ ;  $V = 3.5 \text{ m/s}$ ;  $\mu_e = 22.2 * 10^{-6} \text{ Pa} * \text{s}$ ;  $\rho = 1930 \text{ kg/m}^3$ .

It is possible to calculate formula (3) as follows under different conditions:

$$d_{\eta 50}^* = d_{\eta 50} \sqrt{\frac{D^*}{0,6} \times \frac{3,5}{V^*} \times \frac{\mu^*}{22,2 \times 10^{-6}} \times \frac{1930}{\rho_n^*}}, \mu\text{m} \quad (6)$$

Sizes marked by \*, correspond to real cyclone operation conditions. Calculation data are: gas debit – 140 m<sup>3</sup>/h; t – 65C<sup>0</sup>; median of solid particles – 20 μm; σ<sub>n</sub> = 4,54; gas viscosity – 22·10<sup>-6</sup> Pa·s; density of solid particles - 3160 kg/m<sup>3</sup>. The results are presented in table 2.

**Table 2.** Purification efficiency of clinker dust by standard cyclones and the centrifugal filter under not higher than 500 Pa aerodynamic resistance

Cyclone type	Gas flow inlet velocity, m/s	Collection rate, %	Dispersion rate, %
ЦН-11-200	1.24	87.7	12.3
ЦН-15-200	1.24	85	15
СКЦН-33-300	0.55	86.9	13.1
СКЦН-34-300	0.55	86.4	13.6
СЦН-40-300	0.55	91	9
<b>ЦФ2-6-02</b>		<b>91</b>	<b>9</b>

#### 4. Conclusions

1. General centrifugal filter ЦФ2-6-02 efficiency of 91 % had been specified, in the meantime, efficiency of the operating-in-the-cement-plant battery multicyclone БЦ Р-250/2 x 110 amounted 85 %, under aerodynamic resistance of 900–1200.
2. SP dispersivity in the centrifugal filter inlet and outlet air ducts identified: SP dispersivity median in the inlet air duct made 20 μm, and in the outlet air duct 15 μm, distribution discontinuity of the particles according to their diameter dimensions: 4.54 in the inlet and 3.25 μm in the outlet.
3. Having performed efficiency calculations of standard cyclones of SP purification from the gas flow, under resistance not higher than 500 Pa, comparative indices were allowed to determine in the centrifugal filter with cyclone СЦН-40 of high efficiency. Resistance rate in the centrifugal filter cross-section was about 200 Pa, and in СЦН-40 – 1200 Pa.

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