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## METHODOLOGICAL BASES FOR DESIGNING DOUBLE-CIRCUIT CLOSED AIR PURIFICATION SYSTEMS

*О.Г. Бутенко, С.Ю. Смик, А.В. Карамушко, В.В. Гуцакова. Методологічні основи проектування двоконтурних замкнених систем очищення повітря.* У статті розглянуті основні методологічні принципи проектування двоконтурних замкнених систем очищення повітря від полідисперсного пилу. Ця система очищення має суттєву перевагу порівняно з її прямооточними аналогами, а саме – дозволяє уникати викидів у атмосферу не уловленої у апараті очищення частини пилу. Цей, переважно дрібнофракційний пил, уловлюється за рахунок багаторазового проходження потоку через уловлювач циркуляційного контуру. Тобто уникнення забруднення навколишнього середовища досягається за рахунок застосування нової схеми руху газового запиленого потоку, який підлягає очищенню. Запровадження інноваційної схеми руху потоку не дозволяє використовувати традиційні методи розрахунку, а отже метою статті є формулювання основних методологічних підходів до проектування двоконтурних замкнених систем очищення. Показано, що проектування системи очищення має складатися з двох основних етапів. Перший – розрахунок експлуатаційних показників елементів системи. Він ґрунтується на даних про фракційний склад пилу (диференціальній кривій розподілу) і характеристиках уловлюючих апаратів та проводиться для основного режиму роботи системи (режим очищення) і завершального (режим вибігу). Запропонована методика розрахунку, на відміну від усіх існуючих, дозволяє отримувати значення показників очищення у динаміці. Другий – гідравлічний розрахунок системи, яка складається з основного і циркуляційного контурів. Розрахунок пропонується проводити за рахунок складання балансів потужностей кожного контуру окремо і завдяки цьому обґрунтовано підбирати для них стандартне нагнітальне обладнання. Розрахунок ґрунтується на гідравлічних показниках, які визначаються або за звичними гідравлічними співвідношеннями (довідниковими даними), або за отриманими під час досліджень і наведеними у статті графіками.

*Ключові слова:* система очищення, методика розрахунку, коефіцієнт уловлення, втрати потужності, фракційний склад

*O. Butenko, S. Smyk, A. Karamushko, V. Gushchakova. Methodological bases for designing double-circuit closed air purification systems.* The article considers the main methodological principles of designing closed double-circuit systems for air purification from polydisperse dust. This cleaning system has a significant advantage compared to its direct-flow counterparts, namely, it allows avoiding emissions of dust not captured in the cleaning apparatus into the atmosphere. This, predominantly fine-grained dust, is captured by repeatedly passing the flow through the catcher of the circulation circuit. That is, the avoidance of environmental pollution is achieved using a new scheme for the movement of a dusty gas stream to be cleaned. The introduction of an innovative flow scheme does not allow the use of traditional calculation methods; therefore, the purpose of the article is to formulate the main methodological approaches to the design of two-loop closed treatment systems. It is shown that the design of a purification system should consist of two main stages. The first is the calculation of the performance indicators of the system elements. It is based on data on the fractional composition of dust (differential distribution curve) and the characteristics of the trapping apparatus and is carried out for the main operating mode of the system (cleaning mode) and the final one (run-out mode). The proposed calculation method, unlike all existing ones, allows obtaining the value of cleaning indicators in dynamics. The second is the hydraulic calculation of the system, consisting of the main and circulation circuits. The calculation is proposed to be carried out by compiling the power balances of each circuit separately and, due to this, it is reasonable to select standard injection equipment for them. The calculation is based on hydraulic indicators, which are determined either by generally accepted hydraulic ratios (reference data), or by the graphs obtained in the course of research and given in the article.

*Keywords:* purification system, calculation method, capture coefficient, power losses, fractional composition

### Introduction

Many companies emit a significant amount of polydisperse dust into the air during production. These are construction, chemical, concentrators, shops or terminals for transshipment of bulk materials, etc. Often the characteristics of dust mass are such that from the point of view of ecological safety it is necessary to limit their release into the environment as much as possible, and sometimes dust mass is a useful substance and its loss in the environment is economically impractical. Direct-flow aspiration dedusting systems used in such facilities provide only partial capture of polydisperse dust and therefore cannot completely solve the environmental problem of pollution.

### Analysis of recent publications

The current state of dust cleaning shows that in the most environmentally hazardous industry – thermal energy, currently used only direct flow systems with a single type of ash trap – battery cy-

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clone, wet scrubber or electrostatic precipitator. Hybrid systems [1, 2] are currently being developed, but no data on their implementation are available. In metallurgy, as a rule, more complex systems are used, which, however still remain essentially direct-flow [3, 4, 5, 6]. In addition to the above, they often use fabric filters and even at certain stages of cleaning – gravity units [7].

The main problem of most common devices, especially cyclones and wet scrubbers, is the low efficiency of capturing small fractions of dust. Therefore, most modern research is devoted to eliminating this shortcoming. However, constructive methods to improve the quality of capture of small fractions are almost exhausted and some research is aimed at solving this problem by artificial aggregation of the fractional composition of dust. Thus, in works [8, 9, 10] it is proposed to carry out preliminary acoustic treatment of dust flow in order to coagulate fine-grained dust. The effectiveness of this method has been experimentally proven, but the main disadvantage is the need to use additional equipment – acoustic wave generator.

To solve the problem of catching fine dust in the work [11], a double-circuit closed purification system was proposed. Its schematic diagram is presented in Fig. 1. Captured by the collection-return device 1 primary air flow with a mass flow rate of  $M_{1-2}$  is mixed with a pre-cleaned flow of the circulation circuit in the central ejector 2 and enters the separator 3, where it is divided into two parts by fractional sign. The flow with fine fractions with a mass of dust  $M_{3-5}$  is sent to the trap of the circulating circuit 5 with the hopper 9, and the flow with large fractions of mass  $M_{3-4}$  – to the main trap 4 with the hopper 8. Since the capture coefficient of large fractions is quite high, the leakage of dust in the main apparatus  $M_{4-1}$  is insignificant. This dust is returned to the room in the area of operation of the collection-return device and again after capture is cleaned. The flow of the circulating circuit with a mass of  $M_{5-2}$  after cleaning is mixed in the ejector 2 with the primary flow and again, through the separator, goes to cleaning. Thus, firstly, due to repeated passage of the dusty flow of the trap provides the removal of small fractions, and secondly, the system is closed, which eliminates air pollution.

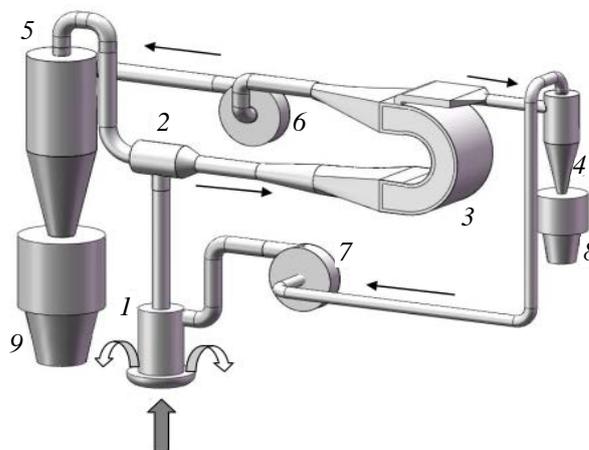


Fig. 1. Scheme of double-circuit closed purification system

Theoretical analysis and the first experience of application proved the effectiveness of the purification system. The implementation of the scheme did not require significant investment, but provided significant improvements in gas purification through the flow-sharing scheme. In addition, the system can be manufactured directly at the plant from publicly available and inexpensive materials and by local staff. The main obstacle is the lack of a methodology that could be used by the company's engineers, as previously published scientific materials, published in various publications and distributed over time, are therefore inconvenient for practical application. In addition, the issue of hydraulic calculation of the system has not been considered before.

#### The goal of the work

Based on previously conducted research to propose a method of engineering calculation (design) of the double-circuit closed purification system, which would predict the performance of individual elements of the system and its whole, as well as to conduct its hydraulic calculation.

#### Main part

The calculation of system efficiency indicators is based on data on the fractional composition of dust, which can be obtained by sieve analysis and presented in the form of a differential distribution curve  $N^i = f(\Delta)$ .

The collection-return device includes a volumetric flow rate of aspiration air  $Q_{1-2}$ , which introduces a mass of dust consisting of dust from the source of contamination  $M_0$  and dust leakage of the main catcher  $M_{4-1}$ :

$$M_{1-2} = M_0 + M_{4-1} = Q_{1-2} C_0 + M_{4-1},$$

where  $M_{4-1}$  – second mass of return dust, kg/s;

$C_0$  – dust concentration in the primary flow, kg/m<sup>3</sup>.

Differential distribution curve of the captured mass (in percent):

$$N_{1-2} = \frac{(M_0^i + M_{4-1}^i)100}{(M_0 + M_{4-1})10},$$

where  $M_0^i$  – the mass of the  $i$ -th fraction of leakage dust;

$M_{4-1}^i$  – the mass of the  $i$ -th fraction of dust coming from the source of dust (the entire range of particle sizes of dust mass should be divided into 10 equal segments).

The mixing device includes a mass:

$$M_{2-3} = M_{1-2} + M_{5-2},$$

whose differential distribution curve:

$$N_{2-3} = \frac{(M_{1-2}^i + M_{5-2}^i)100}{(M_{1-2} + M_{5-2})10}.$$

Mass of dust of leakage of the catcher of a circulating contour, kg/s:

$$M_{5-2} = M_{3-5}(1 - \eta_c),$$

where  $\eta_c$  – the coefficient of capture of the circulating circuit.

Differential distribution curve of the mass:

$$N_{5-2}^i = N_{3-5}^i(1 - \eta_c^i),$$

where  $\eta_c^i$  – partial coefficient of capture of the circulating circuit apparatus.

Volumetric flow rate of air entering the separation apparatus:

$$Q_{2-3} = Q_{1-2} + Q_{5-2}.$$

The main catcher receives the mass:

$$M_{3-4} = M_{2-3}\eta_p,$$

where  $\eta_p$  – the proportion of dust mass falling from the separation apparatus into the main trap (separation factor) [12].

Its differential distribution curve:

$$N_{3-4}^i = N_{2-3}^i\eta_p^i.$$

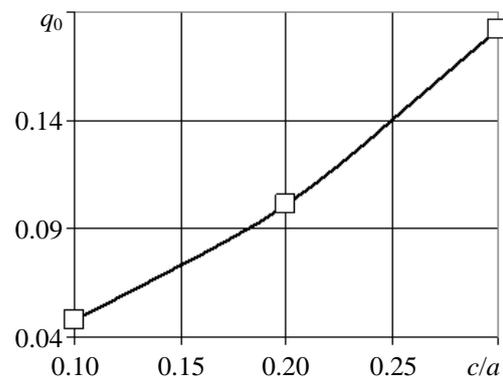
Volumetric flow of air entering the main catcher:

$$Q_{3-4} = Q_{2-3}q_0,$$

the share of gas entering from the separation apparatus into the main trap, which depends on the relative width of the  $c/a$  slit and can be determined from the graph in Fig. 2 ( $c$  is the width of the slit, and  $a$  is the width of the separator).

The mass that enters to the circulating circuit catcher:

$$M_{3-5} = M_{2-3}(1 - \eta_p),$$



**Fig. 2.** Distribution of air flow in the separation apparatus

its differential distribution curve:

$$N_{3-5}^i = N_{2-3}^i (1 - \eta_p^i).$$

Volumetric flow rate of air entering the circulating circuit catcher:

$$Q_{3-5} = Q_{2-3} (1 - q_o).$$

From the catcher of the circulating circuit comes out the mass:

$$M_{5-2} = M_{3-5} (1 - \eta_c).$$

It's differential distribution curve:

$$N_{5-2}^i = N_{3-5}^i (1 - \eta_c^i).$$

The coefficient of capture of the main apparatus:

$$\eta_o = \sum_{i=1}^{10} \frac{\eta_o^i N_{3-4}^i 10}{100},$$

where  $\eta_o^i$  – partial capture coefficient of the main apparatus.

The coefficient of capture of the circulatory system:

$$\eta_c = \sum_{i=1}^{10} \frac{\eta_c^i N_{3-5}^i 10}{100}.$$

The mass captured in the main apparatus:

$$M_4 = M_{3-4} \eta_o.$$

The mass captured in the circulatory system:

$$M_5 = M_{3-5} \eta_c.$$

The mass of leakage of the main catcher:

$$M_{4-1} = M_{3-4} (1 - \eta_o).$$

A characteristic feature of the double-circuit closed purification system is that after the cessation of dust from the source, to catch the dust of the circulation circuit requires a short period of work – run-out time. Therefore, the calculation of the system according to the above method should be performed for the standard mode of operation (cleaning mode) and run-out mode ( $M_0=0$ ). The calculations performed according to the above formulas are repeated for a certain number of cycles of the system (cycle time is the time during which the flow makes a complete circle along the circulation circuit). Such repetitive calculations are convenient to do with the help of computer technology. Their results allow us to assess the dynamics of changes in system parameters over time during purification and run-out.

The main task of hydraulic calculation is a reasonable choice of fans of the main and circulation circuits (elements 7 and 6 of Fig. 1). The complexity of the hydraulic calculation of the system is that the air ducts form annular pipelines with a common section “ejector – separator”. The use of the ejector, in addition, causes a variable value of the flow in the circulation circuit, which does not allow the use of conventional hydraulic methods for calculating complex pipelines, in particular the method of characteristics. Therefore, it is proposed to solve the problem by drawing up a balance of capacity.

The power of the circulating fan  $N_c$  is spent on overcoming its hydraulic resistance:

$$N_c = \Delta N_{c5} + \Delta N_2 + \Delta N_{c3} + \Delta N_{c8} + \Delta N_{c1},$$

where  $\Delta N_{c5} = \zeta_{c5} \frac{\rho u_c^2}{2} Q_c$  – loss of power in the catcher of the circulation circuit ( $\zeta_{c5}$  – the coefficient of losses of the circulating circuit catcher,  $u_c$  – characteristic speed,  $\rho$  – air density,  $Q_c$  – volumetric air flow of the circulation circuit);

$\Delta N_2$  – power losses in the ejector, which are the sum of nozzle losses, inlet losses, hydraulic friction losses, mixing losses in the mixing chamber and losses in the diffuser (determined depending on the type of selected jet apparatus);

$\Delta N_{c3} = \zeta_{c3} \frac{\rho v_c^2}{2} Q_c$  – loss of circulating flow power in the separator ( $\zeta_{c3}$  – separator loss coefficient for circulating flow,  $v_c$  – characteristic speed);

$\Delta N_{c8} = \left( \lambda_c \frac{l_c}{d_c} + \sum_{i=1}^n \zeta_{ci} \right) \frac{8\rho Q_c^3}{\pi^2 d_c^4}$  – power losses along the length and in local supports ( $\lambda_c$  – hydraulic coefficient of friction,  $l_c$  і  $d_c$  – the length and diameter of the channel of the circulation circuit,  $\zeta_{ci}$  – the coefficient of loss of the  $i$ -th local resistance of the circulation circuit).

$\Delta N_{c1} = \lambda_{c1} \frac{l_{c1}}{d_c} \frac{\rho v_{c1}^2}{2} Q_m$  – loss of power in the central pipe of the collecting-return device (due to the small size of  $Q_m$  and  $v_{c1}$ , these losses can be neglected).

Power of the main circuit fan is:

$$N_m = \Delta N_{m3} + \Delta N_{m1} + \Delta N_{m4} + \Delta N_{m9},$$

where  $\Delta N_{m4} = \zeta_{m4} \frac{\rho u_m^2}{2} Q_m$  – loss of power in the catcher of the main circuit: ( $\zeta_{m4}$  – the coefficient of losses of the main circuit catcher;

$u_m$  – characteristic speed;

$\rho$  – air density;

$Q_m$  – volumetric air flow of the main circuit);

$\Delta N_{m3} = \zeta_{m3} \frac{\rho v_m^2}{2} Q_m$  – loss of main flow power in the separation apparatus ( $\zeta_{m3}$  – coefficient of loss for the main flow,  $v_m$  – characteristic speed);

$\Delta N_{c9} = \left( \lambda_m \frac{l_m}{d_m} + \sum_{j=1}^n \zeta_{mj} \right) \frac{8\rho Q_m^3}{\pi^2 d_m^4}$  – power losses along the length and in local supports ( $\lambda_m$  – hydraulic coefficient of friction,  $l_m$  і  $d_m$  – the length and diameter of the channel of the main circuit,  $\zeta_{mj}$  – the coefficient of loss of the  $j$ -th local resistance of the main circuit);

$\Delta N_{m1} = \zeta_{m1} \frac{\rho v^2}{2} Q_m$  – power loss in the annular channel of the collection-return device ( $\zeta_{m1}$  – complex coefficient of hydraulic losses in the annular channel of the collection-return device, which takes into account both length losses and local losses,  $v$  – average flow rate).

To determine the  $\zeta_{m1}$ , we should use the graphs obtained as a result of processing numerical simulation of the twisted flow in the annular channel of the collection-return apparatus (Fig. 3).

Here  $D$  is the inner diameter of the annular channel

$$Re = \frac{H\rho v}{\mu},$$

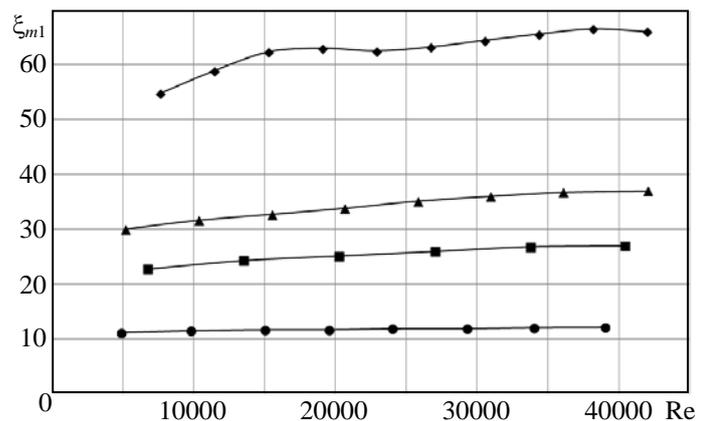


Fig. 3. Graphs for the complex coefficient of hydraulic losses in the annular channel of the collection-return apparatus:

● –  $D/H = 8$ , ■ –  $D/H = 12$ , ▲ –  $D/H = 16$ , ◆ –  $D/H = 22$

where  $H$  – width of the annular channel, m;

$\mu$  – dynamic coefficient of air viscosity, Pa sec.

### Conclusions

For wide application of the double-circuit closed system the basic methodological principles of its design are formulated, which can be applied not only by scientists - authors of development, but also by engineering personnel of the enterprises interested in introduction of this system. The design involves two main stages: the calculation of system performance and design calculation. At the first stage, the main indicators of flow cleaning efficiency and the nature of their change over time are determined. The design calculation is based on the compilation of power balances for the main and circulation circuits. The ultimate goal of this stage is a reasonable selection of injection equipment.

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