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IMPROVEMENT OF THE SYSTEM FOR CLEANING DUST GAS FLOWS USING AN AERODYNAMIC INSERT

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Abstract. Air pollution is becoming a problem due to inefficient technological processes that accompany the mechanical processing of solid materials in various industries, including metalworking and woodworking, coal enrichment, coal burning in thermal power plants, metallurgy and construction materials industries. The problem is relevant for cement factories, since some of them use outdated equipment. Fine dust in this context becomes particularly important because the particle size of this dust affects the quality and grade of the concrete produced. Given the specifics of cement production and the goals of our research, which are to effectively collect small particles, it is important to note that wet cement production methods are not the best solution. The ideal solution for the problem of cleaning dust and gas flows in the cement industry is the use of a two-stage dust collection system, which combines an advanced cyclone and a bag filter. The system's periodic shaking mechanism allows for effective capture and control of fine dust particles, ensuring high quality cement production and reducing environmental impact. The combination of a cyclone, an acoustic coalescer and a block of bag filters, which is equipped with a periodic cleaning mechanism, as well as the addition of a system for collecting fine dust using a collector funnel, will split the collected dust into two fractions: fine ($a = 10^{-5}$ to 10^{-7} m) and coarse ($a > 10^{-4}$ m). The first fraction can be used to produce high-quality cement of high cost in the cement industry. The second fraction returns to the main technological process at its finishing stage.

Keywords: air, cement industry, cleaning, dust flows

1. Introduction

Cement dust and its constituent compounds (oxides of some metals) are harmful irritants to the respiratory tract. Excessive presence in the air of settlements and in the working zone causes irritation in the upper compartments of the lungs, leading to chronic diseases (such as bronchitis and tracheitis). In some cases, these processes can even result in oncological diseases.

Dust collection equipment, as per regulatory documents (particularly the state standard SSBP – GOST 12.2.043-82), is classified based on the physical phenomena occurring during their operation. They are divided into gravitational, inertial, filtering, and electrical types (Batluk, Paranyak, 2012). A more comprehensive approach, proposed in, categorizes all types of structures and equipment for protecting the biosphere from dust into two groups: dry and wet dust collectors (Polupindko,.Paranyak,, 2015).

All dust-collecting devices and devices in which the dry-cleaning method is implemented (Polupindko,. Paranyak,, 2015) are divided into three groups: dust-collecting chambers, the principle of operation of which is the action of the weight force (gravitational method); inertial dust collectors – the basis of the work is the forces of inertia; cyclones (battery cyclones) in which centrifugal forces prevail.

The efficiency of the conventional cyclones described above lies at the level of 60–80 %, battery cyclones – 97–99 %, bag filters – 99.5–99.7 %, but due to the low heat resistance of synthetic fabrics (1300 °C) and glass fabrics (2300 °C) due to clogging of the filter element, their efficiency decreases over time.

The ideal solution to the problem of cleaning dust and gas flows for the cement industry is a two-stage dust collection system, which combines an improved cyclone with a bag filter, which, with the

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help of a specially designed mechanism, is periodically shaken (Grave et al., 2021).

2. Theoretical part

Existing dust collection systems are often cumbersome and will not always cope effectively with dust collection, especially when it has a wide range of particle sizes from 10^{-7} – 10^{-4} m. This problem is of particular importance in the cement industry, where production is accompanied by a wide variety of dispersed dust composition.

Significant is the fact that the production of cement has a high degree of influence on the quality of concrete, and this, in turn, directly affects the construction industry and the environment. Fine dust, qualitatively captured and controlled, can have a positive effect not only on the environment, but also on the economic state of cement production, since a high grade of concrete leads to an increase in demand for products. Thus, improved dust collection systems become key to achieving improved production efficiency and reducing its environmental impact.

A known dust collecting system comprising a double wall diffuser type cyclone, the outer wall of which is solid, and the inner perforated inlet and outlet branch pipes of dusty and purified air; respectively connected to a narrower and wider part of the annular gap of the diffuser; located in the annular gap of the spiral guide of dust air movement attached to the inner wall of the diffuser; acoustic emitter, outlet branch pipe of trapped dust, as well as a louver-type dispersed dust separator (Batluk, Paranyak, 2012). The dust collection system is described in sufficient detail on p. 93–95, and its scheme is shown in Fig. 21 (p. 94) of the specified monograph.

However, even with the presence of these dust-collecting systems, we face significant restrictions on their effectiveness, particularly in terms of dust collection. One of the main reasons for this is the inability of some systems to separate a fine dust fraction from the main stream of the dust-air mixture (Polupindko,.Paranyak,, 2015).

The acting forces characteristic of the known dust collection system – and this is gravitational, centrifugal, and at the last stage in front of the louver separator, acoustic coagulation, do not provide the necessary purity of the "purified" air.

It should also be emphasized that the fine fraction of certain types of industrial dust, in particular cement dust, is crucial for the quality of concrete. Thinner fractions of cement contribute to a high grade of concrete, and this, in turn, affects the strength of concrete structures and their resistance to aggressive environments, including precipitation.

Thus, the optimal solution to the problem of air purification in the cement industry requires the improvement of dust collection systems to ensure high quality products and reduce the negative impact on the environment.

In addition, it is important to note that in the case of catching fine dust particles together with other fractions, their further separation can be quite problematic, sometimes even impossible. This stage of the separation requires large financial and resource costs, which significantly increases production costs and complicates the technological equipment of the enterprise.

In practice, this can lead to a decrease in the competitiveness of the enterprise, since increased costs and process complications can affect the cost of production and product quality. The need for careful separation of fine dust particles creates serious technical and financial challenges for cement companies seeking to achieve a high grade of concrete and improve the economic result of their activities (Serebryansky et al., 2014).

3. Experimental part

Proposed dust collection system provides higher efficiency of dust cleaning and separate dust collection of fine dust. In the developed design of the dust collection system, the following stages of cleaning work:

– under the action of centrifugal forces in the annular space between the double wall of the cyclone body of the diffuser type;

– under the action of inertia forces in the same space, since the flow of dusty dust-air mixture is supplied to the narrower part of the diffuser;

– under the action of gravitational forces on particles of dust particles;

– centrifugal forces in the space between the inner wall of the cyclone body and the bag filter unit;

– under the action of inertia forces in the space between the perforated wall and the bag filter unit;

– under the action of acoustic field forces for short-term coagulation of fine-dispersed dust;

– under action of dynamic resistance forces passing through layer of porous material only particles of dust particles of smaller size (Yakuba et al., 2017).

Thanks to the above-mentioned cleaning steps, the dust collection system that we propose achieves a significant increase in its efficiency. This is achieved through an integrated approach and an optimal combination of different acting forces per fraction of dust during the purification process.

A special role in improving efficiency is played by the combination of a cyclone, an acoustic coalescer and a block of bag filters. This unit of bag filters is additionally equipped with a mechanism of periodic shaking, which contributes to increasing the duration of its effective operation (Dubynin et al., 2005).

It is also important to note the introduction of an addition to the dust collection system – a collecting funnel for fine dust. This allows the system to separate the trapped dust into two fractions. The first fraction, which contains fine dust, can be used to produce high-grade cement, which in turn is a product of high cost in the cement industry. The second fraction returns to the main technological process at its finishing stage, optimizing the use of resources and ensuring a more efficient production cycle. This integrated approach allows us to achieve optimal results both in terms of the production of high-quality cement and in terms of sustainable and effective dust management (Ratushnyak, Lyalyuk, 2005).

A schematic diagram depicting a dust collection system is illustrated in Fig. 1.

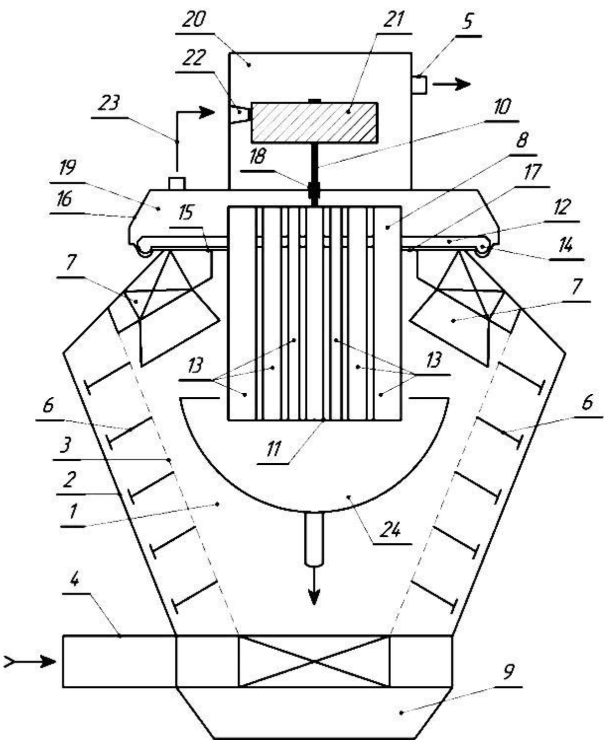

Fig. 1. Structural diagram of the dust collection system based on an improved cyclone, acoustic radiator-coalescer and aerodynamic insert in the form of a bag filter with a periodic shaking mechanism

The developed dust collection system contains a cyclone 1 of a diffuser type with a double wall, the outer wall 2 of which is continuous, and the inner 3 is perforated, the inlet 4 branch pipes of dusty and the outlet 5 branch pipes of purified air, which are respectively connected to the narrower and wider part of the annular gap of the diffuser. Located in the annular gap of the diffuser between the solid wall 2 and the perforated wall 3 is a spiral guide 6 for the movement of dusty air attached to the inner wall 3, the dusty air moving upward from below (Plashikhin et al., 2010).

Acoustic radiator 7 is installed in upper part of diffuser in annular gap between inner perforated wall 3 and finely dispersed dust separator 8, and in lower part of cyclone outlet branch pipe 9 is installed. In the developed dust collecting system, the fine dust separator 8 is made in the form of a block of bag filters (Petrushka et al., 2022).

The diagram of a bag filter unit can be found in Fig. 2.

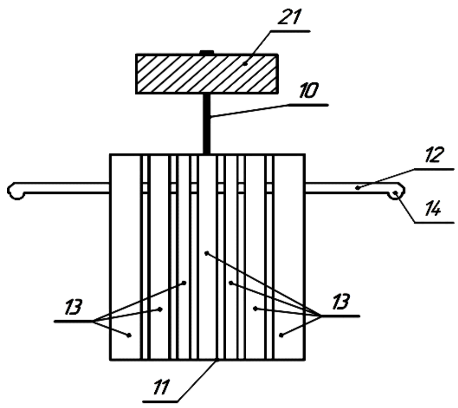

Fig. 2. The diagram of a bag filter

It consists of arranged concentrically and rigidly fixed on shaft 10 between lower disk 11 of smaller diameter perpendicular to it and upper disk 12 of larger diameter, set of hoses 13 of different diameter from special filter material. The sleeves of the filter material along their length occupy at least 0.75 of the shaft length, and the sleeves of a smaller diameter are located closer to the shaft, and the sleeves of a larger diameter – further from the common shaft. The minimum number of sleeves is set from the aerodynamic relations of parameters (diameters and shaft rotation speed) to ensure conditions of uniformity of dust settling on the filter material (Petrushka et al., 2022).

Fig. 3 shows the layout of bag filters in conic circles (minimum number – three), and each circle can be three or four.

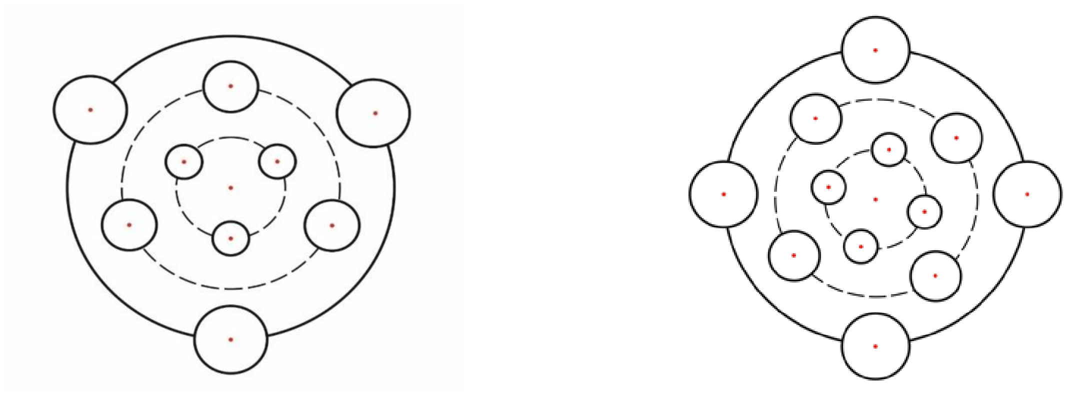

Fig. 3. Layout of bag filters on the shaft

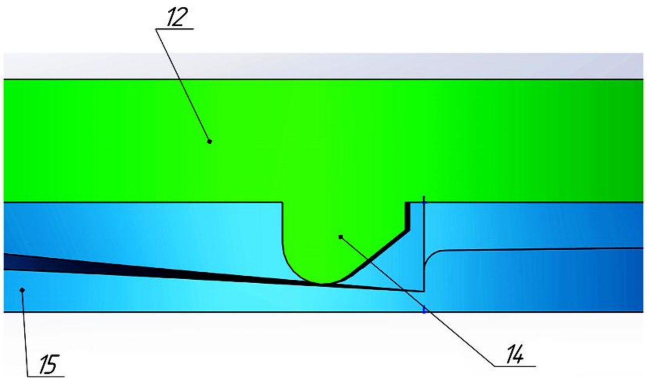

Fig. 4. A portion of the upper disc entering the annular depression of the upper flange that covers a portion of the cyclone body

The outlet of all the sleeves protrudes beyond the edge of the upper disc 12, on the lower surface of which there are uniformly protruding three or four support cams 14, which enter the annular depression of the upper flange 15, which closes the wider part of the annular gap of the cyclone body 1.

Part of the volume above the outlets of the bag filters, which is bounded from above by a solid partition 16, from below by a slot gap 17 between the flange 15 and the movable disk 12, and in the center of the partition 18 there is a gland seal 18 for the shaft 10 of the filter unit, forms a clean air chamber 19. Chamber of smaller diameter 20 for air turbine 21 with nozzle 22, which is directed to upper part of turbine wheel 21, and connected with clean air chamber 19 by means of air duct 23, is rigidly fixed on top of said partition 16, outlet branch pipe 5 of cleaned air is connected on opposite side of air turbine chamber (Petrushka et al., 2022).

The annular depression of the upper part of the flange 15, covering the annular gap of the cyclone body, has a profile, respectively divided into three or four zones, which are characterized by a sequential slow rise at an angle of 5–10 degrees, and a sharp descent in the opposite direction at an angle within 85–90 degrees. Thus, in the dust collecting system, it is possible to convert the rotational motion of the shaft of the bag filter unit to its inverse available for periodic shaking of fine dust from the filter surface of the bag filters into the collecting funnel 24. The above funnel is located inside the cyclone under the bag filter unit (see Fig. 2), fine dust is collected in this collecting funnel, which is strained from the filter material of the bag filters (Petrushka et al., 2022).

In Fig. 4 shows in colour a part of the upper disc 12 with support cams 14 (movable member) entering the annular depression of the upper flange 15 (fixed member) which covers the wider part of the cyclone body 1.

The dust collection system operates as follows. The flow of dusty air, taken from the working zone, or from the technological apparatus under dynamic pressure, is directed to the lower (narrower) part of the diffuser-type cyclone 1 through its inlet branch pipe 4, and enters the space between its solid wall 2 and the inner 3 perforated wall. In this annular space a spiral guide 6 is arranged and rigidly fixed to the inner wall 3, by means of which the flow is swirled and raised upwards. Coarsely dispersed dust particles in the course of the dust-air flow (first heavier and then lighter) penetrate under gravel and centrifugal forces through the perforated holes of the inner wall 3 and descend through the branch pipe 9 of the collected dust into the collecting bin (not shown in the diagram, since the composition of the dust collection system is not included).

Dust-air flow with smaller particles of dust particles in the upper wider part of the cyclone 1 of diffuser type penetrates into its internal cavity. Here this flow is influenced by an acoustic field which is generated by an acoustic radiator 7 which is in the form of an annular diffuser. It is attached to the inside of the confuser, which covers the wider part of the cyclone, and promotes coagulation (enlargement) of small dust particles into their larger fractions. The flow of enlarged dust particles under the influence of gravitational forces is spontaneously divided into two flows: larger (coarser) dust particles fall down towards the branch pipe 9, and then into the bunker, and the rest are somewhat smaller, reflected from the separator 8, also fall, like the previous ones, into the bunker. But some of them, thanks to their small tonus, fall into the collecting funnel 24.

And the smallest (finely dispersed dust particles that have not undergone acoustic coagulation) fall into the zone of the separator 8, specially designed in the form of a block of bag filters (see Fig. 2).

A characteristic feature of their design is that bag filters are made from a combination of natural and synthetic fibrous materials, mainly from organic high-molecular compounds. Their specific composition is selected taking into account the range of operating temperatures of the dust-air mixture. Depending on the performance of the dust collection system, which is related to the power of the sources of generation and emission of the dust-air mixture, we recommend the smallest number of concentric circles, on the trajectories of which three or four sleeves are located, in accordance with Figures 3a and 3b. In each specific case for variants 3a and 3b on each of three concentric circles, fabric sleeves should be located on the basis of condition of maximum blowing by dust-air flow which is achieved by change of angular distance between sleeves on each trajectory.

Thus, the captured fine dust particles at the first moment of time from the beginning of the dust collection system operation accumulate on the surface of the filter material of the bag filters, and at a certain thickness, the efficiency of the filter material of the bag filters begins to decrease.

In the proposed dust collection system, in order to avoid this drawback, a periodic shaking mechanism developed by the authors operates. It is formed by two units, which include the upper part of the cyclone body (flange 15 as a fixed element) and the upper disk 12 of the bag filter unit with support cams 14 on its lower part. The periodic shaking mechanism for cleaning the filter surface of the bag filters operates according to the following algorithm. The dust-free air leaves the inside of the bag filters, the upper side of which protrudes slightly beyond the edge of the upper disc 12 of the bag filter unit, and enters the clean air chamber 19, which is formed by the upper flange 15 on the underside and the solid partition 16 on top. From the chamber of air 19 through the air duct 23 into the chamber of 20, of smaller diameter behind the chamber of 19 clean air, in the chamber 20 on the upper part of the shaft 10 the block of bag filters the air turbine of the 21 is rigidly fixed. At the level of the upper edge of the air turbine 21, a nozzle 22, which is also rigidly attached to the inside of the chamber 20, and connected to the air duct 23, fits closely. At the same time, under the action of the reactive force of the air jet, the turbine 21 rotates, and with it the entire block of bag filters. The support cams 14 located on the lower surface of the disc 12 move along the annular depression of the upper flange 15, which covers the wider part of the annular gap of the cyclone body 1. Due to the special profile of the annular depression on the upper surface of the flange 15, the bag filter unit first slowly rises, and then sharply falls down under its own weight, while shaking off the dust accumulated on the surface of the filter material. Due to this, the filtering ability of the specified material is restored, and in the next period of rotation the procedure is repeated. Such cycles during one full circle can be three or four, depending on the features of the selected design of the dust collection system, and this number is determined after several tests of the developed system, taking into account technological requirements. These requirements are generally included in the parametric and structural complexes, which can be used in the calculation of the dust collection system (Petrushka et al., 2022).

Construction of the dust collection system in compliance with all the conditions described above improves its performance, in particular increases the efficiency of dust collection, and also provides separation of finely dispersed fraction.

4. Conclusions

The introduction of the proposed system, which includes two elements – a cyclone and a bag filter, built in a single structure or complex housing, will be very effective for automatically shaking the captured fine dust into a special collecting funnel. It is important to note that before this shaking process in the inter-hull space of the cyclone, thanks to the spiral guide, according to the described features of its design, the dust cleaning efficiency is significantly increased and can compete with the existing bag filters of the GAL-GLk series of Agricon, the DLMV series of Donaldson and FRIR (purification degree 95–99.8 %).

The effectiveness of this dust collection system, in particular in the context of cement production, determines the improvement of the environmental situation in the sanitary protection zone. Obtaining a fine fraction allows the manufacturer to obtain high-quality cement. At the same time, in the technological process of manufacturing concrete products, their strength, as well as the cost, will be much higher. This integrated approach not only contributes to the effective reduction of environmental impact, but also provides the company with competitive advantages, improving product quality and economic performance.

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