УДК 621.928.37

IMPROVEMENT OF DUST COLLECTORS FOR IMPLEMENTATION IN THE FOOD INDUSTRY

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This paper presents a study of the processes occurring in apparatus with counter–swirling flows and proposes a mathematical model for calculating the fractional and overall efficiency of the devices. An experimental stand was used to investigate a typical design and an advanced apparatus with counter–swirling flows. For determination of the overall efficiency, the samples were examined on a disperse composition using a scanning electron microscope with a low vacuum camera SEM–106 I and a ribbon with sprayed silver in the vacuum universal post VUP–5M. The disadvantage of the typical design of the improved apparatus with counter–swirling flows (ACSF) is the reduced rotational motion of the primary flow, which slows down the separation process and leads to a decrease in the fractional efficiency of cleaning of medium and small fractions of the dusty product from the air. The inhibitory effect is due to the small input momentum of motion in the primary flow compared to the momentum of motion in the secondary flow. One way to increase the rotational motion of the primary stream may be to double M_{input1} *, according to the law of conservation of momentum, due to geometric changes in the lower cylindrical part of the apparatus. That is, it is necessary to increase the diameter of the lower part of the ACSF, in order to increase the momentum in the primary flow of the axial swirler. In this case, the ratio of flow rates of air and impulses will be offset and the braking effect will be eliminated. Thanks to the developed mathematical model, it is seen that with increasing the momentum of motion in the primary flow of the axial swirler increases the efficiency of trapping fine particles of sawtooth product in the external and internal layers of the separation chamber of the improved ACSF. This has the effect of improving overall performance overall. After preparing the samples for analysis and examining them on a raster microscope, we obtained images of the dispersed composition of the product, which calculated the number of particles of a certain diameter, and then calculated them in percentage to the total number of particles in one sample, so that we obtained efficiency for each fraction of particles. Namely, the smallest fraction of particles captured was 1.99 microns of advanced ACSF, the typical design of the ACSF is 2.55 microns. Due to the developed mathematical model of the momentum of motion for the primary swirler, an improved design of the ACSF was created.*

Key words: *dust collector, flow rates, improvement, efficiency, capture, momentum.*

DOI https://doi.org/10.32845/msnau.2021.4.7

Introduction

The development of large cities, accompanied by the development of industry, increasingly leads to the pollution of residential areas with industrial gases (Azarov et al., 2017; Azarov et al., 2019). The content of harmful substances in the air significantly exceeds hygiene standards. Obviously, the current situation can be improved through the use of modern, more advanced technologies (Azarov et al., 2020; Azarov et al., 2016). It is important to increase the efficiency of systems for cleaning the city from pollution and industrial emissions (Azarov et al., 2017; Bakaeva & Chernyaeva, 2017). Assessment of the dust environment at industrial enterprises, as a rule, is understood as the study of air in working areas, the power of dust emissions into the atmosphere, as well as the efficiency of dust cleaning devices (Besarion Meskhi et al., 2021; Kalyuzhina, 2013). In papers (Bogomolov et al., 2016; Evtushenko et al., 2020) the research process is presented, identifying bottlenecks, which are characterized by dustiness, analysis of existing dust removal systems, their efficiency, performance and features of work in various environments. The articles (Bogomolov et al., 2016; Evtushenko et al., 2020; Klimenti et al., 2019) carried out comparative studies of the characteristics of silica clay dust, calcium silicate and chalk production in three intake zones for three types of dust collectors used in dust removal systems: fabric filters, cyclones and apparatus with counter–swirling flows (ACSF). Based on the measurement results, it was concluded that the dust from the dust collectors for all variants of dust collectors has a similar elemental composition and can be returned to the production process. The articles consider several more examples of the impact of industrial dust on the environment, as well as ways to reduce the technogenic impact on the environment (Kuzmichev & Loboyko, 2016; Kondratenko, 2021; Kondratenko et al., 2019; Kondratenko, 2020; Kondratenko & Lapina, 2020). The articles provide samples of dust–collecting equipment that can contribute to the task, however, all models of dust collectors do not give 100% cleaning efficiency (Kuzmichev et al., 2017; Koshkarev et al., 2019).

In addition to the chemical and construction industries (Protodiakonov & Chesnokov, 1987), purification of polluted air from dust is also necessary in food production. With the help of dust collectors, dusty gas is separated into dust and purified air (Sergina et al., 2019; Sergina et al., 2017). Dust collecting equipment is used in food production to eliminate losses in the production of products that pollinate the air (salt, milk powder, food concentrates, sugar), as well as to reduce environmental pollution (Savchenko–Pererva & Yakuba, 2015; Sabadash et al., 2015). At the enterprises of the food industry, most of the production processes are accompanied by the release of dust. This reduces the safety of production, and is also an urgent problem both from an environmental and economic point of view. The problem of reducing losses during drying is of great economic importance. The value of the removal of the product with the exhaust air into the atmosphere due to the imperfection of cleaning methods and equipment reaches large volumes. Depending on the aerodynamic characteristics of the drying tower and cyclones, the speed of movement of the drying agent, product particles in the air entering the cyclone, the physicochemical properties of the product and its particle size distribution can be significant. The main disadvantage is the comparatively small fractional efficiency of this apparatus when capturing dust up to 5–10 microns in size (Vasiliev et al., 2019; Zhukova et al., 2016; Zhukova et al., 2017).

Recently, the world has been increasingly focusing on foods that have a long shelf life and high transport characteristics. Such requirements are achieved by the use of food drying technologies, which require the development of energy efficient and productive equipment that is directly related to the production of finished products, and auxiliary – dust, because first – it is expensive, and second – no 100% output of pure product (Azarov et al., 2019; Piralishvili & Kudryavtsev, 1992).

Dusting is a responsible operation, the output of the finished product at the end depends on the efficiency of the separation of the dispersed particles in the gas. Cyclones have the highest prevalence in processing plants. These devices are simple to manufacture and operate and provide trapping of particles up to 10 μm. The main disadvantage of these devices is their overall size and limited performance. Therefore, it is advisable for processing plants to use apparatus with counter–swirling flows (ACSF), which have the ability to control the process of separation of gas and liquid inhomogeneous mixtures. The field of study of the processes that take place in the ACSF is poorly understood. Their use in production allows you to increase productivity, reduce the size, material consumption of the structure and optimize the processes that take place in them (Savchenko–Pererva et al., 2016).

Materials and methods

Materials and equipment that were used in the experiments to determine efficiency were investigated.

At the Sumy National Agrarian University, an experimental stand was installed in the laboratory № 111m to investigate a typical design and an advanced apparatus with counter–swirling flows (Fig. 1).

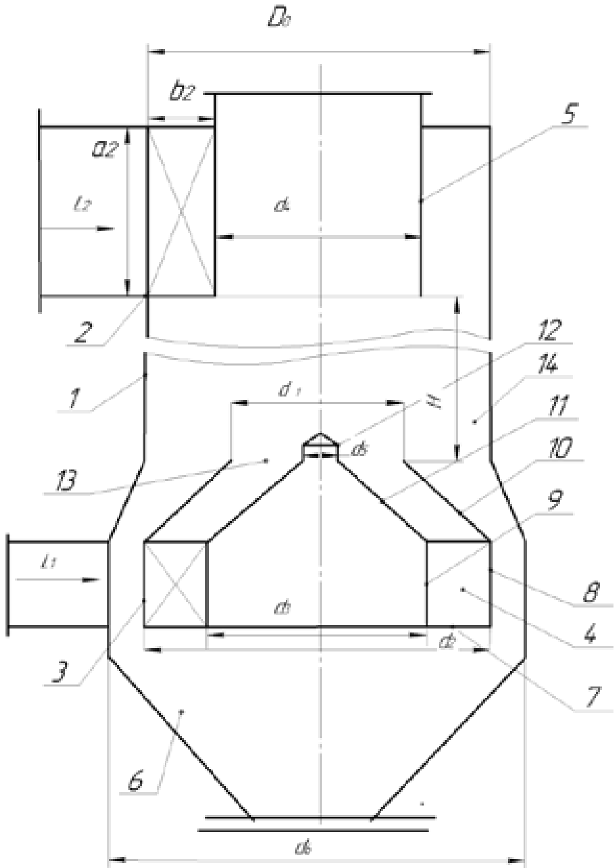

Figure 1. Scheme of the general view of the improved ACSF (with two cones): 1 – case; 2 – tangential input of the external (secondary) flow; 3 – axial lower (primary) arrangement; 4 – swirler of the primary flow; 5 – outlet pipe; 6 – conical hopper; 7 – flat washer bottom; 8 – outer shell; 9 – internal shell; 10, 11 – conical shells; 12 – flow suppressor; 13 – the outlet opening of the primary flow; 14 – hole between the washer and the dust collector case

The stand consists of the apparatus (1), depending on the tested ACSF, the lower cylindrical part was changed, the dust collector (2) into which the dusty product being trapped (as a powdered product used milk powder), artificial air dusting systems (3), flexible air duct (4), air flow regulator (5), high–pressure fan No. 3 – impeller on the shaft of the bearing assembly, which is connected to the electric motor by cogwheel transmission, and which allows to change the rotation of the impeller by pulleys (6) and system pulverization and analysis of experiments (7).

All studies were repeated 5 times with a discrepancy of results of no more than 5%.

To determine overall performance, a typical ACSF design and an advanced ACSF design were used. Samples obtained from an advanced ACSF and model design were investigated for dispersion using a scanning electron microscope with a low vacuum camera SEM–106 I. The studies used tapes that had been pre–filled with silver at the Institute of Applied Physics using VUP –5M (vacuum universal post), after which they were transferred to a SEM–106 I sample holder pre–greased with a carbohydrate paste.

Results

Existing vortex dust collector (typical design) includes a case, an exhaust pipe, for the purification of purified air, two–channel suction air inlet nozzle, primary through the lower axial vortex, and a secondary, main air flow through a tangential or flywheel device. A deflector washer is located between the case and the lower vortex, to allow the dust product to be lowered into the hopper and to prevent its removal with clean air (Protodiakonov & Chesnokov, 1987).

The disadvantage of the typical design is the reduced rotational motion of the primary flow, which inhibits the process of separation and leads to a decrease in the fractional efficiency of cleaning the middle and small fractions of the dusty product from the air.

The rotational motion depends on the angular flow velocity, which is determined by equation:

$$\omega_0 = \frac{2M_{enter}}{\rho_{air} \cdot L_3 \cdot r_4^{\ 2}}, \quad (3)$$

where M_{enter} – momentum of motion (moment of amount of motion), (N·m); ρ_{air} – density of dusty air, (kg / m^3); L_3 – total flow of air flows, (m^3 / s); r_4 – radius of the exhaust pipe of the dust collector, (m).

The inhibitory effect is due to the small input momentum of motion in the primary flow compared to the momentum of motion in the secondary flow. Thus, in a typical ACSF (Fig. 3), the lower vortex is twice less than the upper one and at the flow rates of air $L_{enter2} : L_{enter1} = 2:1$ and the momentum of motion is $M_{enter2} : M_{enter1} = 4:1$. One way to increase the rotational motion of the primary stream may be to double M_{enter1}, according to the law of conservation of momentum, due to geometric changes in the lower cylindrical part of the apparatus. In this case, the ratio of flow rates of air and momentums will be offset and the braking effect will be eliminated.

In general, the momentum of motion at the entrance to the ACSF is calculated by the equation:

$$M_{enter} = m \cdot V_T \cdot r_0, \quad (4)$$

where m – body weight or air, kg; V_T – tangential velocity, m / s; r_0 – radius of entrance, m.

Fractional efficiency in internal and external layers

After some transformations (Savchenko–Pererva et al., 2016) found:

– the efficiency equation in the external layer:

$$\eta_{average2} = d^2 \cdot \frac{\pi \cdot H \cdot \omega_0^2 \cdot \rho_T \cdot r_*^4 \cdot (r_0 + r_*) \cdot (2,36(r_{average}^2 - r_0^2) + L_1 \cdot (r_0^2 - r_{average}^2))}{9\mu \cdot L_1 L_2 \cdot (r_0 + r_{average}) \cdot (r_{average}^2 - r_0^2)}. \quad (5)$$

where ω_0 – angular velocity of flow 1 / s; L_1, L_2 – loss of flows in primary and secondary channels m^3/ hour; r_* – radius border split streams (a constant), m; r_0 – the radius of the dust collector case (constant) m; $r_{average}$ – average radius of the flow (constant for each apparatus), m; H – height of the separation zone of the apparatus, m; μ – coefficient of dynamic viscosity of air, PA·s; ρ_T – density solid particles of milk powder, kg / m^3.

– the efficiency equation in the internal layer:

$$\eta_{average1} = d^2 \frac{\omega_0^2 \cdot \pi \cdot \rho_T \cdot r_*^5 \cdot H(2,36 + L_1 \cdot (r_* - r_{average}))}{9\mu \cdot L_1 L_2} \quad (6)$$

The theoretical overall efficiency

The overall efficiency ACSF after improvement will be calculated by the formula:

$$\eta_{overall} = \sum \frac{\eta_2 * f}{100} * \frac{L_2}{L_3} + \sum \frac{\eta_1 * f}{100} * \frac{L_1}{L_3} * \frac{\eta_{i2}}{100}, \quad (7)$$

where f – quantitative percentage ratio of dispersed particle size (Table 1).

The results of the studied samples from the improved ACSF and a typical design, which were examined for dispersion using a scanning electron microscope with a low–vacuum chamber SEM–106 I, are shown in the table 2.

Discussion

Using the obtained equations of theoretical total and fractional efficiency in the internal and external layers of cylindrical apparatus with counter–swirling flows, in the subsequent experiments it will be possible to take into account the influence of system parameters, which will allow to evaluate the ability of the devices to effectively capture the pulverized material.

Thanks to the mathematical model developed in equation (7), it is seen that by increasing the momentum of motion in the primary flow of the axial swirler, the efficiency of trapping of fine particles of the sawtooth product in the external and internal layers of the separation chamber of the ACSF is increased. This is to improve overall performance overall. In the advanced ACSF, the overall efficiency of capturing milk powder was $\eta_2 = 99,6\%$, in the typical design – $\eta_1 = 94,4\%$.

After preparing the samples for analysis and examining them on a scanning electron microscope, they obtained images of the dispersed composition of the product, which calculated the number of particles of a

Table 1

Dispersion of particles of powdered milk

d, m	5.1	8.2	10.5	20.8	32.5	41.6	55.1	60
f %	1.15	6.3	14.8	17.3	23.7	12.4	12.4	9.15

Table 2

Disperse composition of experimental samples of milk powder

Type ACSF	Number particulate, n	The average diameter of particles $d_{average}$, m	The smallest diameter solids d_s, m	The largest diameter solids d_l, m
Typical	89	31.13	2.55	142.00
After improvement	99	25.59	1.99	135.51

certain diameter, and then calculated them in percentage to the total number of particles in one sample, so that we obtained efficiency for each fraction of particles. Namely, the smallest fraction of particles captured was 1.99 microns of advanced ACSF, the typical design of the ACSF is 2.55 microns.

Conclusions

Due to the developed impulse equation for the primary swirler, an improved design of the ACSF was created, which was then conducted and then experimental studies were conducted. The samples obtained were compared with those made on a typical construction. The obtained results of efficiency confirm the correct method of increasing the diameter of the lower part of the ACSF, in order to increase the moment of the amount of movement in the primary flow of the axial swirler. In the advanced ACSF, the overall efficiency of capturing milk powder was $\eta_2 = 99,6\%$, in the typical design – $\eta_1 = 94,4\%$.

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УДОСКОНАЛЕННЯ ПИЛОЗБІРНИКІВ ДЛЯ ВПРОВАДЖЕННЯ У ХАРЧОВІЙ ПРОМИСЛОВОСТІ

У даній роботі представлено дослідження процесів, що відбуваються в апаратах із зустрічними закрученими потоками, та запропоновано математичну модель для розрахунку часткової та загальної ефективності пристроїв. На експериментальному стенді було досліджено типову та удосконалену конструкції апарату із зустрічними закрученими потоками. Для визначення загальної ефективності зразки досліджували на дисперсний склад за допомогою скануючого електронного мікроскопа з низьковакуумною камерою СЕМ–106 І та стрічкою з напиленим сріблом у вакуумному універсальному посту ВУП–5М. Недоліком типової конструкції вдосконаленого апарату із зустрічними закрученими потоками (АЗЗП) є зменшений обертальний рух первинного потоку, що уповільнює процес сепарації та призводить до зниження фракційної ефективності очищення середніх і дрібних фракцій запиленого продукту з повітря. Гальмуючий ефект обумовлений малим вхідним імпульсом руху в первинному потоці порівняно з імпульсом руху у вторинному потоці. Таким чином, у типовій конструкції АЗЗП нижній вихор вдвічі менший за верхній, а імпульс потоку дорівнює швидкості повітряного потоку. Одним із способів збільшення обертального руху первинного потоку може бути збільшення вдвічі $M_{вх1}$, відповідно до закону збереження імпульсу, за рахунок геометричних змін нижньої циліндричної частини апарату. Тобто, необхідно збільшити діаметр нижньої частини АЗЗП, щоб збільшити імпульс у первинному потоці осьового завихрювача. У цьому випадку співвідношення витрат повітря та імпульсів буде зрівноважено і ефект гальмування буде усунений. Завдяки розробленій математичній моделі видно, що зі збільшенням імпульсу руху в первинному потоці осьового завихрювача підвищується ефективність уловлювання дрібних частинок пилоподібного продукту у зовнішньому та внутрішньому шарах розділової камери вдосконаленого АЗЗП. Це покращує загальну продуктивність. Після підготовки зразків до аналізу та дослідження їх на растровому мікроскопі отримали зображення дисперсного складу продукту, на якому розраховували кількість частинок певного діаметра, а потім розраховували їх у відсотках до загальної кількості частинок в одному зразку, таким чином отримали ефективність для кожної фракції частинок. А саме, найменша частка захоплених частинок склала 1,99 мкм удосконаленого АЗЗП, типової конструкції – 2,55 мкм. Отже, завдяки розробленій математичній моделі імпульсу руху для первинного завихрювача була створена вдосконалена конструкція АЗЗП.

Ключові слова: *пилозбірник, витрати, покращення, ефективність, захоплення, імпульс.*

Дата надходження до редакції: 02.12.2021 р.