THE INFLUENCE OF ANGLE ON PARTICLE SEPARATION BY CYCLONE

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Abstract: In the presented article, a study was conducted on the influence of the structural angle on particle separation and collection efficiency in a straight-through cyclone, as well as its hydraulic resistance. Through software modeling and analysis, we obtained the trajectories of dust particles with various diameters at different points within the cyclone. This guided the selection of specific designs for experimental investigation, which were then manufactured using a 3D printer.
The size of the particles to be separated from the air plays a crucial role. Particles smaller than 5 µm deserve particular attention because their smaller size makes them more susceptible to the influence of centrifugal force.
The subject of this research is the impact of cyclone constructive angles on gas-dynamic characteristics.
The object of the report focuses on cyclones as devices for separating particles from gas streams.
The purpose of this study is to quantitatively determine and analyze the influence of changes in the cyclone's constructive angles. To achieve this, the following tasks were completed: theoretical aspects of gas flow and particle movement within the cyclone were analyzed, existing scientific research was reviewed, experiments were conducted, and recommendations for optimal constructive angles were formulated.
An experimental methodology was employed.
The results indicate that the separated, inclined particles contribute to increasing the collection efficiency of residues in the cyclone. This occurs by creating spaces with near-zero gas velocities between adjacent particles, forming "buffer zones."
In these zones, separated particles detach from the swirling dust-gas flow in the annular space, preventing them from bouncing back into the main flow.
The analysis of the results was conducted from two perspectives: determining the efficiency of the design for specific materials and developing an optimal configuration for fine dust particles.
Sand separation occurs in the shortest amount of time, while wood particles take the longest to be collected. The cyclone exhibits the lowest efficiency when collecting ash.
The cyclone operates most effectively with heavy and compact materials like sand, achieving maximum separation in minimal time.
Keywords: Separation, Dust particles, Cyclone, Design, Research

1. INTRODUCTION

The process of effectively separating particles from gas streams is of particular importance to various industries and is the basis for sustainable industrial development, which protects human health and the environment by ensuring product quality and increasing the safety and reliability of production processes. due to the wide range of negative consequences that can arise in the presence of suspended particles.
Cyclones emerged as a significant improvement in the early 20th century (Bahadar, Maqbool, Niaz, Abdollahi, 2016; De Oliveira, Guerra, 2021; Diao, Yang, 2021; Dmitriev, Zinurov, Dmitrieva, Galiev, 2018; Jiang, Liang, Zhu, Zheng, Zhu, Yang, Wang, Fu, 2025). The principle of centrifugal force has been known since the 19th century, but its engineering application for industrial-scale dust collection marked an important advance at a later stage. The first cyclones were relatively simple, but over time their design has been optimized for higher efficiency and lower resistance. Cyclones are mechanical dust collectors that operate on the principle of centrifugal force and inertia, and their advantages are as follows:
The dust-laden gas stream enters tangentially (perpendicularly) into the upper cylindrical part of the cyclone, imparting a rapid rotational motion to the gas.
Centrifugal force: as the gas rotates, the heavier dust particles (due to their greater inertia) are thrown towards the outer wall of the cyclone under the action of centrifugal force.
Resistance to abrasive and corrosive particles: since they have no filter elements, they are more resistant to abrasive particles and corrosive gases (with a suitable construction material).
dry dust collection: they collect dust in a dry state, which simplifies its disposal or recycling, unlike wet scrubbers, which generate sludge.
There are studies on the subject, but they focus mainly on industrial enterprises where waste gas purification or clean air in the workplace is required, for example in the manufacture of electronic equipment, pharmaceutical materials, in paint shops, etc. Therefore, the removal of suspended particles, even those of very small size and in any

concentration, is of paramount importance (Mazyan, Ahmadi, Jesus, Ahmed, Hoorfar, 2016; Pandey, Wasilewski, Mukhopadhyay, Prakash, Ahmad, Brar, 2024; Sabirzyanova, Uriev, Kharkov, Nikolaev, 2017; Zinurov, Kharkov, Pankratov, Dmitriev, 2022; Wasilewski, Brar, 2023).

The subject of the presented study is the influence of design angles (e.g., of the cone, of the angle of attack of the inlet air, of the outlet pipe flow rate, or of internal separation elements) of cyclones on gas-dynamic characteristics (flow structure, turbulence, velocity distribution) and particle separation efficiency.

The subject of the report is cyclones as devices for separating particles from gas flows, including their geometric configurations and operating parameters (gas velocity, concentration, and particle characteristics).

The aim of the study is to determine and quantitatively analyze the influence of changes in the design angles of the cyclone on its particle capture efficiency and hydraulic resistance, with a view to optimizing the design to achieve maximum efficiency with minimum energy losses. To achieve this goal, the following tasks were solved:

Study of theoretical foundations: the theoretical aspects of gas flow and particle movement in the cyclone are analyzed, as well as the influence of centrifugal and aerodynamic forces.

Literature survey: a review of existing scientific research and publications on the influence of various design parameters, including angles, on cyclone performance.

Conducting the research: experiments or numerical simulations were carried out, varying the selected design angles within certain ranges, as well as the main operating parameters (e.g., gas inlet velocity, particle size and density).

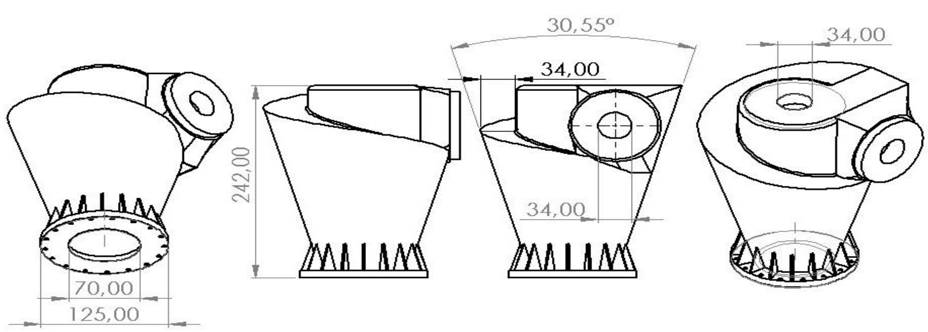
Formulation of recommendations: based on the analysis, recommendations were formulated for optimal design angles that ensure a balance between high separation efficiency and minimal hydraulic resistance.

Thus, the effective removal of particles from contaminated gas streams is a pressing issue.

2. MATERIALS AND METHODS

An experimental methodology was used, describing the cyclone installation, which we will call cyclone 1A, shown in Figure 1 (dimensions, materials);

Fig. 1. Cyclone studied (cyclone 1A)



Source: Author's research

Using CAD software for 3D modeling (SolidWorks), the cyclone for separating various elements from the air flow is designed and modeled. The prototype for experimental research is produced using a 3D printer, model Raise3D Pro2. Once the test model has been produced, the materials to be used for the research are selected. The materials for research are: ash (burnt wood particles), wood particles, and sea sand, all of which are shown in Figure 2.

Fig. 2. Materials used in the experiment

Source: Author's research

The following measuring instruments were used:

- electronic scale model: HG09959B;
- vacuum cleaner model: Karcher T7/1 classic with the following parameters: vacuum 235 mbar; air flow rate 40 l/s; container volume 7 l;
- NUODWELL digital chronometer.

The entire measurement setup is shown in Figure 3.

Fig. 3. Experimental setup

Source: Author's research

The main objective of this study can be considered in two aspects:

- to determine the effectiveness of the design for the specified materials;
- to develop an optimal layout for fine dust particles that are harmful to organisms.

When considering this topic, which affects many industries, it should be emphasized that it is necessary for each industry to develop, design, and manufacture a new design for the protection against fine dust particles in the relevant area.

3. RESULTS

The cyclone characteristics are measured at room temperature (29°C) and at a constant suction vacuum of 235 mbar. Under these conditions, the experiment is carried out for each measurement, replacing the vacuum cleaner filter that creates the vacuum and cleaning the container where the cyclone is located after each new attempt. The suction time is recorded after the suction process begins and ends when the particles of the respective material have been completely sucked in. After recording the suction time, the quantity separated by cyclone 1A is recorded. For the next experiment, the particle separation container is thoroughly cleaned and the vacuum cleaner filter is replaced.
The data from the experiments are presented in Table 1 and Figure 4.

Table 1. Data from the experiment

Materials	**Weight before measurement [g]**	**Separated quantity [g]**	**Time [s]**
Sand	500	493	8.83
Wood shavings	500	492	25.12
Ash	500	449	19.64

4. DISCUSSIONS

Fig. 4. Presentation of results in a diagram

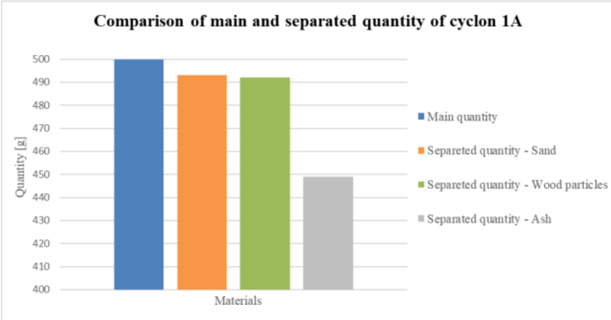
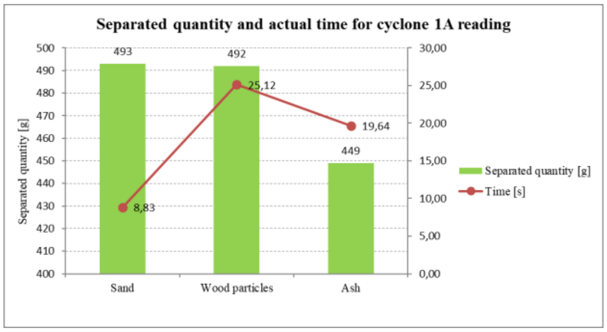


Fig. 5. Time required to suck in the quantity



Source: Author's research

Fig. 4 shows the results after comparing the initial and separated quantities of three different materials (sand, wood chips, and ash). The experiment shows that the separated quantity of sand is the highest in value – 98.6% and in the shortest time – 8.83 s, shown in Fig. 5. The wood chips after separation are 98.4%, but for the longest period of time – 25.12 s, shown in Fig. 5. and the amount of ash separated for the material studied is 89.8%, respectively for a time of 19.64 s, also shown graphically in Figure 5.

The conclusions we can draw are as follows:

- Sand is sucked in just 8.83 seconds, which, compared to other materials, gives us over 98.6% separation.
- Wood chips are sucked in for longer – 25.12 seconds, which is 2.8 times longer than the suction time, but the amount separated by the cyclone is also very high, at 98.4%.
- The ash is sucked in for 19.64 seconds and, compared to the other particles, in this case, the cyclone has the lowest efficiency. The reason may be the very fine particles that are carried away by the air flow.

5. CONCLUSIONS

In conclusion, we can summarize that the cyclone works most effectively with heavy and compact materials such as sand, where maximum separation is achieved in minimum time. Although light materials are separated relatively well, the suction time is longer, and in the case of ash, the separated quantity is even smaller.

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