

## INFLUENCE OF CYCLONE DESIGN ON THE SEPARATION OF VARIOUS PARTICLES

Ismail Mehmedov

Technical University – Varna, Bulgaria, [imehmedov.me@tu-varna.bg](mailto:imehmedov.me@tu-varna.bg)

**Abstract:** This research focuses on creating a multi-objective optimization for cyclones to reduce the impact of fine particulate matter on the human body. For this purpose, three main materials were used: sand, wood particles, and ash. Cyclone modeling was considered to generate conditions for creating a model with various parameters such as diameter, length, swirling velocity, separation of different particles, suction velocity, etc.

These three materials were specifically chosen for investigation because they contain particles smaller than 5  $\mu\text{m}$ , which deserve special attention as they are finer and affect human health.

Observations show that in models designed with Solidworks, the model's efficiency for the specified materials is reduced.

The percentage of unseparated particles increases, specifically those over 10%. In field studies, the efficiency of the respective cyclone design must be above 90% for the model to be considered adequate.

The subject of the research is the influence of various structural parameters and elements of the cyclone on particle separation efficiency.

The object of the research is cyclones as devices for separating two-phase gas-dust flows.

The aim of the article is to analyze and summarize the key constructive characteristics of cyclones. To achieve this goal, the following tasks were completed: explaining the basic principles of cyclone operation, including the role of centrifugal forces and the formation of secondary flows; identifying and detailing the key constructive elements of the cyclone; analyzing their individual influence on separation efficiency for different particle sizes; summarizing the achieved research results; and proposing guidelines for future developments in cyclone design for more effective separation of gas-dust flows.

Experimental studies were conducted with the aim of simulating aerodynamic flows and particle trajectories in the cyclone under different structural parameters.

Combined methods were used.

The results account for the efficiency of the cyclone model for each investigated material.

This allows for the evaluation of the design under the respective experimental conditions.

In conclusion, we can note that a universal separation design may not be equally effective for all types of materials.

**Keywords:** Cyclone, modelling, design, separation, efficiency, speed

### 1. INTRODUCTION

The design of the cyclone plays a decisive role in the efficiency of separating particles of different sizes and densities. Optimizing its shape, dimensions, and internal elements directly affects the gas flows inside the device and, consequently, the quality of separation. The cyclone works based on centrifugal forces acting on the dusty flow, pushing the dust particles toward the walls of the device. However, small dust particles can bounce off the walls of the structure and enter the secondary flow, thus reducing the efficiency of dust collection in the cyclones. In order to control and improve the design of cyclones for the separation of fine dust particles from the gas-dust flow, a number of laboratory and software studies have been conducted. These include fog injection (Yang, Yoshida, 2004) or the introduction of an electric field (e.g., attraction of charged particles mixed with the gas stream (Yoshida, Hayase, Fukui, Yamamoto, 2012; Mazyan, Ahmadi, Ahmed, Hoorfar, 2017), which allowed the authors to clarify the physical model of the dust capture process.

In the last ten years, the introduction of a magnetic field to the existing dust collector (e.g., using a special magnetic material mixed with the gas flow (Svoboda, Coetzee, Campbell, 1998; Mazyan, Ahmadi, Jesus, Ahmed, Hoorfar, 2016). In this case, the separation efficiency of dust-air mixtures is controlled by influencing the magnetic field with additives of ferromagnetic particles or non-ferromagnetic materials coated with a ferromagnet. In their work, specialists in the field (Siadaty, Kheradmand, Ghadiri, 2017; Pandey, Wasilewski, Mukhopadhyay, Prakash, Ahmad, Brar, 2024) investigate the influence of external magnetic field parameters, including the distance of the magnetic source from the cyclone, on the efficiency of fine dust particle capture without changing the shape and dimensions of the cyclone itself. This allows, according to the authors, the development of an adequate mathematical model and a program for numerical simulation of the process of gas stream purification from fine dust particles with a dispersion of 2...4  $\mu\text{m}$ , with a total purification efficiency of 97.03% achieved in the laboratory apparatus (Jiang, Liang, Zhu, Zheng, Zhu, Yang, Wang, Fu, 2025; Zinurov, Kharkov, Pankratov, Dmitriev, 2022). Since the

separation factor (purification efficiency) directly depends on a significantly larger number of parameters than those considered in the article, the process of separating fine dust particles from the contaminated flow, especially when scaling up the apparatus, becomes significantly more complicated (Diao, Yang, 2021; De Oliveira, Guerra, 2021).

The subject of the presented study is the influence of various design parameters and elements of the cyclone on the efficiency of separation of particles of different sizes and densities from gas streams. This includes an analysis of how changes in the shape, dimensions, and internal modifications of the cyclone affect the gas flows and, accordingly, its ability to separate particles.

The object of the study is cyclones (dust collectors) as devices for separating two-phase gas-dust flows. The article discusses both standard and modified cyclone designs, as well as their principle of operation in the context of particle separation.

The aim of the article is to analyze and summarize the key design features of cyclones and their effect on the separation process, with an emphasis on improving the efficiency of fine dust particle capture.

To achieve this goal, the following tasks are set in the article:

- to explain the basic principles of cyclone operation, including the role of centrifugal forces and the formation of secondary flows;
- to identify and detail the key design elements of the cyclone (diameter, height, air inlet and outlet, cone, tank) and analyze their individual influence on the separation efficiency for different particle sizes;
- to summarize the results of the research and propose guidelines for future developments in the field of cyclone design for more efficient separation of gas-dust flows.

## 2. MATERIALS AND METHODS

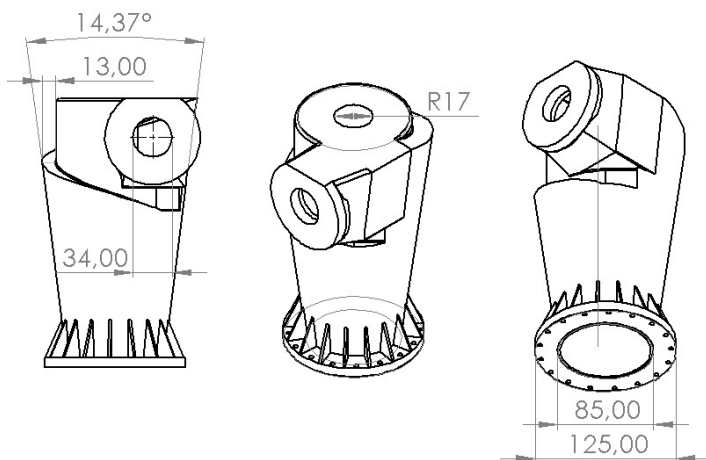
Experimental studies of the so-called cyclone 2A design were conducted with the aim of simulating the aerodynamic flows and trajectories of particles in the cyclone under different design parameters. Combined methods were used:

- design and construction of a test setup including a cyclone (or several cyclones with different configurations), measuring devices for quantity and time;
- selection of test dust: use of dust with known and controlled dimensions;
- measurement of dust concentration: use of devices before and after the cyclone to measure the quantity of the material under investigation. (e.g. filters, particle extraction);
- 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.

In the experimental studies, a cyclone 2A was used, which has the following design parameters, shown in Figure 1.

The measurement diagram is illustrated in Figure 2, which shows the dust collector, the cyclone 2A used, and the particle collection tank.

*Fig. 1. Cyclone studied*



*Fig. 2. Mounting structure*



Source: Author's research

When assessing the efficiency of the cyclone, a methodology was developed to allow the separated quantity of the respective material to be recorded. The study simulates the actual working environment of the cyclone, which is why the materials used in the study were selected. Authentic conditions are created in each tested design, under which the individual designs are compared for their efficiency with regard to the individual materials. After accumulating a database for the individual designs, the results will be summarized for the most efficient design, which will provide the maximum separated quantity in the shortest time.

The main objectives of the study are:

- to determining the best design for the materials;
- to maximum efficiency with a larger number of materials during separation.

### 3. RESULTS

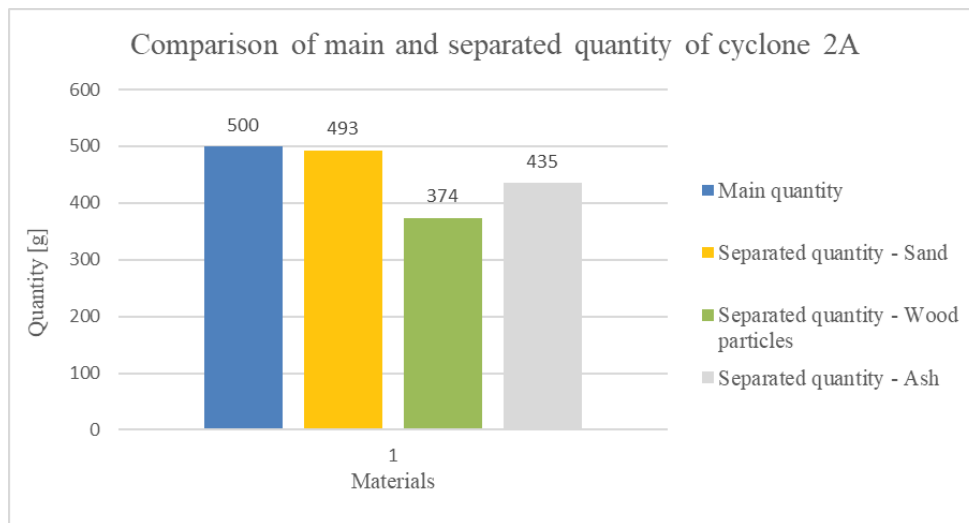
The experiment is conducted under the same conditions of temperature, humidity, suction power, and with the same amount of material used. During the process itself, the requirements for maintaining the same suction power are observed by replacing the filter in the vacuum cleaner container and thoroughly cleaning the container under the cyclone to ensure the maximum adequacy of the test method. The suction time of the individual materials is recorded when suction begins. The results of the measurements of the different materials are shown in Table 1 from cyclone 2A.

*Table 1. Results from cyclone 2A*

Materials	Main quantity [g]	Separated quantity [g]	Time [s]
Sand	500	493	5.57
Wood particles	500	374	18.70
Ash	500	435	11.18

The separation characteristics of the cyclone are illustrated graphically in Figure 3, which shows the amount of separated material.

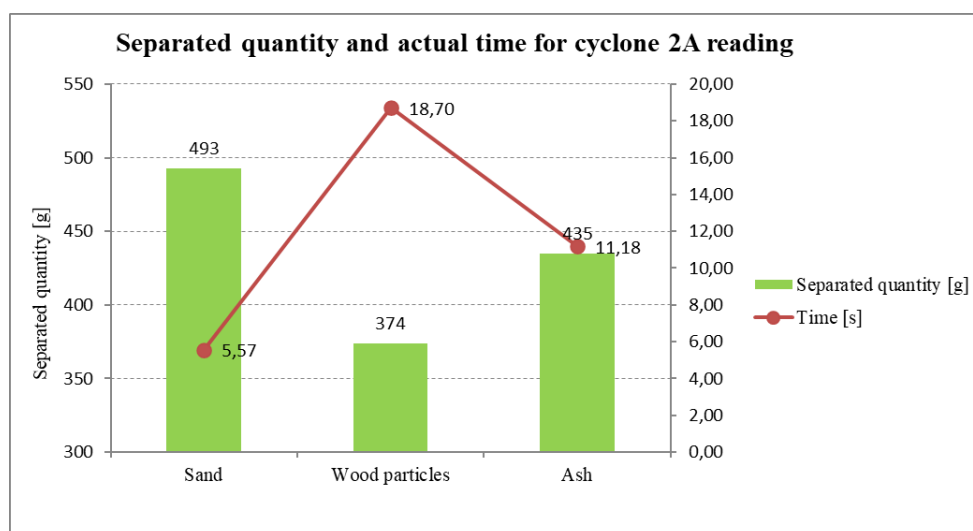
*Fig. 3. Separated quantity*



Source: Author's research

To analyze the characteristics of cyclone 2A, data from experiments on the separation of different materials are used, with an analysis performed for each material. Additionally, a graph is created for greater clarity, illustrating the separated quantity and the time required for the material to be sucked in. This is visualized in Figure 4.

*Fig. 4. Suction time and quantity*



Source: Author's research

The graph shows the efficiency of the cyclone model for each material tested. This allows the design to be evaluated under the relevant experimental conditions.

#### 4. DISCUSSIONS

When separating sand, the separated quantity has losses of less than 1.4%, which makes this design suitable for working with this material.

The study with wood chips shows that the separated quantity is only 375 g out of 500 g of material tested, which means 25.2% losses during separation.

Ash is a more complex material to separate due to its fine structure, which makes separation difficult in this design. Separation losses are 13% for this material.

The conclusion we reach is that the separation efficiency of a given design is highly dependent on the characteristics of the material.

The conclusion we reach is that the separation efficiency of the given design is highly dependent on the characteristics of the material. It is extremely effective for heavy and dense particles such as sand, but struggles with lighter, bulkier materials (such as wood shavings) or very fine particles (such as ash). To improve its versatility or adapt it for specific applications involving problematic materials, additional design optimizations or modifications to the operating mode are necessary.

#### 5. CONCLUSIONS

In conclusion, we can summarize that the difference in the degree of separation between different materials shows that the efficiency of the separation process strongly depends on the physical and mechanical properties of the material. This gives reason to note that a universal separation design may not be equally effective for all types of materials. For this purpose, it is necessary to design different designs for different types of materials.

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