CYCLONE DEVICE TYPES AND PRINCIPLES OF OPERATION

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Anatation: A cyclone separator holds significant importance as the primary gas–solid separation apparatus in the industrial sector. Cyclone separators operate based on a fundamental principle, primarily harnessing the centrifugal force produced by the rotation of air in order to segregate solid particles from the gas stream and then collect them. In addition to the main vortex in the flow field, there are a number of secondary flows, which significantly impact the aggregation of fine particles and contribute to the heightened energy consumption.

Keywords: Cylindrical and Conical, NIIOGAZ Cyclones ,VSNIIOT Cyclone Design, **Battery Cyclone.**

1. Introduction

Cyclone separators are devices commonly used to separate particles from air or gas streams. These devices capitalize on the centrifugal forces created by a rapidly rotating flow, which forces denser particles to move outward, where they are collected in a dust chamber or hopper. Cyclones are favored for their simplicity, low maintenance, and effectiveness in removing particulates from gas streams. They are used in numerous industries, including cement, steel, and power generation, for dust collection, and in chemical processes for separating solid particles from gas or liquid flows.

The primary objective of a cyclone separator is to achieve efficient particle separation with minimal energy consumption. Over the years, various designs and configurations of cyclones have been developed to optimize performance and adapt to the specific needs of different industries. This paper will explore the principles of cyclone operation, the different types of cyclones, and how they are applied across various sectors.

2. Methodology

The methodology for this review involves a comprehensive examination of existing literature on cyclone design, operation, and performance. Sources were selected from reputable academic journals, industry reports, and engineering textbooks. Various cyclone designs were analyzed based on their operational principles, efficiency, and typical applications. Data regarding cyclone performance, such as particle separation efficiency and operational parameters, were gathered and synthesized to provide a comparative analysis.

Key performance metrics, such as pressure drop, particle size distribution, and collection efficiency, were assessed to understand how cyclone design influences their effectiveness. Furthermore, the development of multi-stage cyclone systems, and their advantages in terms of increased efficiency and reduced energy consumption, was also reviewed.

Taking the above into account, an experimental setup was assembled with the goal of deeply cleaning the air from dust particles. The geometric dimensions of the experimental setup are as follows:

- Diameter of the cylindrical section (D): 0.25 m
- Height of the cylindrical section (H): 0.25 m
- Height of the conical section (hk): 0.365 m
- Diameter of the dust-laden air inlet pipe (d1): 0.5 m
- Diameter of the purified air outlet pipe (d2): 0.70 m
- Depth of the purified air outlet pipe (ht) from the cylindrical section boundary: 0.01 m.

(See Figure 1).

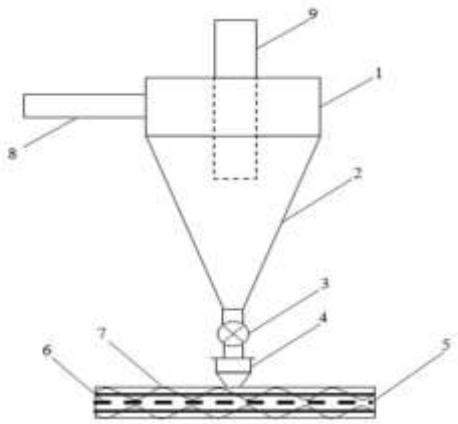

Figure 1. Experimental Cyclone Device for Dust Removal from Air

1 - Cylindrical section; 2 - Conical section; 3 - Slotted valve; 4 - Bunker for collected dust; 5 - Auger casing; 6 - Intermediate mesh; 7 - Auger; 8 - Dust-laden air inlet pipe; 9 - Clean air outlet pipe.

The technological device operates as follows: The dust-laden air flow, with an average concentration of 2600 mg/m³, enters the device through the dust-laden air inlet pipe (8). The air then enters the cylindrical section (1) of the device and, with a tangential motion, moves into the conical section (2). The collected dust mass is gathered in the bunker (4) via the slotted valve (3). The collected dust is separated into fine and coarse particles through the auger (7) and intermediate mesh (6). Finally, the clean air is discharged into the atmosphere through the clean air outlet pipe (9).

Cyclones are classified into two types based on their structure: cylindrical and conical (Figure 8.3). In cylindrical cyclones, the cylindrical part of the casing is made significantly longer, while in conical cyclones, the conical section is made considerably shorter. Cylindrical cyclones have higher efficiency, while conical cyclones provide a higher level of dust removal. However, in conical devices, pressure loss tends to be greater. In conical cyclones, the decrease in cross-sectional area from top to bottom causes a faster separation of dust particles near the wall of the device. The diameter of a cylindrical cyclone should not exceed 2 meters, while the diameter of a conical cyclone should not exceed 3 meters. If the diameter of the cyclones exceeds 2-3 meters, the dust removal efficiency of the device decreases.

3. Cyclone Types and Principles of Operation

3.1 Basic Principle of Cyclone Operation

Cyclone separators operate on the principle of centrifugal separation. A gas stream enters the cyclone tangentially, creating a vortex. As the gas spirals downward, particles are subjected to centrifugal forces that push them toward the cyclone wall. The heavier particles are thrown against the wall, where they either slide down to a collection hopper or are removed via other methods, while the cleaner gas exits through a central outlet. The cyclone thus relies on centrifugal force to segregate particles based on their mass and size.

Key factors affecting cyclone performance include:

- **Particle size**: Larger particles are more easily separated.
- **Flow velocity**: Higher velocity increases centrifugal forces, improving separation efficiency.
- **Cyclone geometry**: The shape of the cyclone (conical, cylindrical, etc.) affects the flow pattern and particle separation.

3.2 Types of Cyclone Separators.

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In **NIIOGAZ cyclones**, the dust-laden gas inlet pipes are arranged at an angle. The following three types of cyclones are the most commonly used:

1. **Inclination angle 24° (CN 24)** – These cyclones have high efficiency and low hydraulic resistance, and they are used for capturing large dust particles in the gas flow.
2. **Inclination angle 15° (CN 15)** – These cyclones ensure a high level of dust removal with relatively low hydraulic resistance.
3. **Inclination angle 11° (CN 11)** – These cyclones have high efficiency and are recommended as advanced dust collectors.

The schematic of the cyclone with the **VSNIIOT** design is shown. The cone of this cyclone expands from top to bottom. Due to the expansion of the device's cross-sectional area, the rotational motion of the gas and the pressure on the particles near the wall decrease. For this reason, such cyclones should be used to separate particles with high abrasive properties from the gas mixture.

4. Results and Discussion

The performance of a cyclone separator can be quantified by several key metrics, including the collection efficiency, pressure drop, and particle size distribution. Cyclones are generally most efficient at separating larger particles, with the efficiency declining for particles smaller than 10 microns. This limitation has led to the development of high-efficiency cyclones and multi-stage systems to address fine particle collection.

- **Collection Efficiency**: Single-stage cyclones typically achieve efficiencies between 60% and 90% for particles larger than 10 microns, but the efficiency drops significantly for finer particles. Multi-stage and high-efficiency cyclones can achieve up to 99% efficiency for finer particles.
- **Pressure Drop**: The pressure drop across a cyclone is an important consideration because it represents the energy consumption of the system. A higher pressure drop generally indicates higher separation efficiency but at the cost of increased energy consumption. Optimizing the cyclone's geometry can balance these two factors.
- **Particle Size Distribution**: Cyclones are most effective at removing particles larger than 10 microns, and their performance diminishes as particle size decreases. In industrial applications requiring the removal of fine particles, multi-stage cyclones or additional filtration technologies may be necessary.

Performance in Specific Industries:

- In the **cement industry**, cyclones are used to collect particulate matter from exhaust gases, where they play a vital role in reducing emissions.
- In **power plants**, cyclones are used as pre-cleaners for flue gas, removing large particles before they reach more complex filtration systems.
- In the **chemical industry**, cyclones serve as a first stage of separation for materials like powders and dust from process gases.

5. Conclusion

Cyclone separators are an effective solution for separating particulates from gas or liquid streams. The design of cyclones has evolved to accommodate the growing need for efficiency in particle separation, particularly for fine particles. While single-stage cyclones are sufficient for coarse separation, multi-stage cyclones offer a more efficient method for finer particles, and innovations in cyclone geometry and operation have led to significant improvements in efficiency and energy consumption. The applications of cyclone separators span a wide range of industries, from air pollution control to material recovery. The future of cyclone design lies in balancing high-efficiency particle collection with low energy consumption, ensuring optimal performance in diverse applications.

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