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Research Article

Determination of The Flow Regime in A Wet Dust and Gas Cleaning Apparatus

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Abstract

The article experimentally determines the definition of the flow mode for cleaning dusty and toxic harmful gases generated during industrial technological processes in wet dust collection and gas cleaning devices.

Keywords

Wet method, lumped flow, liquid and gas consumption, contact element, gas density, slope angle, liquid film, flow regime.

Introduction

Today, one of the most pressing challenges facing scientists worldwide is environmental protection. Therefore, reducing the emissions of dust-laden and hazardous gases released from industrial enterprises has become an important scientific and engineering task. One of the key issues facing modern industries is the effective removal of dust particles and harmful gaseous emissions generated during manufacturing processes [1].

At present, various types of gas-cleaning equipment with different structural designs are widely used in industrial enterprises for the purification of dust-laden gases. Among the available technologies, wet gas cleaning is considered one of the most efficient methods for removing particulate matter from industrial gas streams. Consequently, a wide range of wet-type dust collection and gas-cleaning apparatuses with different конструкцион designs has been developed and implemented in industrial practice.

In wet dust collection and gas cleaning systems, various types of contact elements are employed to enhance the interaction between the gas stream and the liquid phase, thereby improving the capture of dust particles. However, the practical application of such apparatuses is often limited by the high resistance of the contact elements, increased hydraulic resistance, low efficiency of dust particle removal from the gas stream, and insufficient separation of dust particles from the resulting sludge. These factors reduce the operational efficiency and prevent the apparatus from operating under optimal conditions. The overall efficiency of conventional wet dust collectors generally ranges from 85% to 92%.

METHODS

To achieve a dust collection efficiency of 98–99.9% in wet gas cleaning processes, it is necessary to ensure intensive interaction between the liquid and dust particles and to determine the optimal hydrodynamic operating conditions of the apparatus. This approach enhances mass transfer processes, increases the gas–liquid contact area, and significantly improves the overall cleaning efficiency of the system [2].

The wet dust collector proposed in this study is based on the principle of capturing dust particles by generating a swirling gas flow inside the apparatus. To address the above-mentioned problems, a new design of a wet gas-cleaning apparatus for the removal of dust and hazardous gaseous pollutants from industrial gas streams was developed, and a series of experimental investigations was carried out. The operating principle of the proposed apparatus is illustrated in Figure 1 [3].

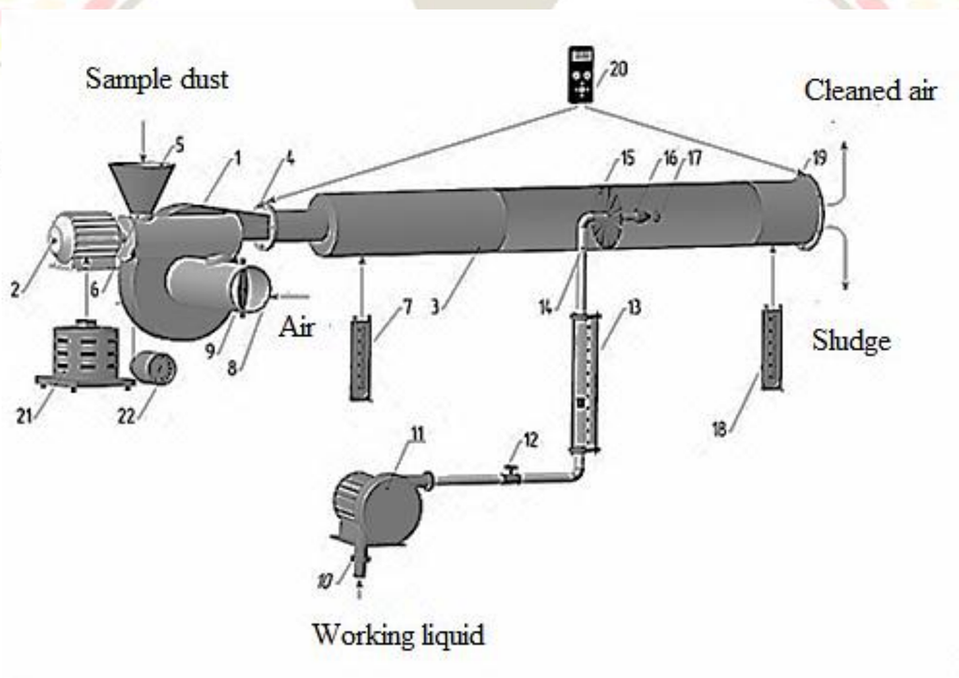

Figure 1. General view of the wet dust collection apparatus.

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To determine the gas velocity, gas flow rate, local resistance coefficient, and flow regimes in the wet dust collection apparatus, the following instruments and equipment were selected for the experimental setup.

1. VS-14-07 centrifugal fan with a maximum capacity of Q_{max}= 400 m^3/s, equipped with an electric motor of 1.5 kW and a rotational speed of 1200 rpm.
2. Pitot–Prandtl tubes with lengths of 50 mm and 100 mm, certified in accordance with State Register No. 50123-12.
3. VA06 TROTEC digital anemometer with an electronic sensor and digital display. The measurement range is 1.1–30 m/s with a measurement error of ±0.2%. For air velocities exceeding 30 m/s, the maximum measurement error does not exceed ±5%.
4. A steel measuring pipe with an internal diameter of D = 100 mm and a length of L = 1200 mm was used to determine the gas velocity. Two Pitot–Prandtl tubes with an inner diameter of **7** mm were installed in the pipe to measure the static and dynamic pressures of the gas flow. The Pitot–Prandtl tube was selected according to the standard requirements for gas velocity measurements and matched the diameter of the fan outlet duct.
5. To regulate the gas velocity, an air damper (shutter) with opening angles of 0°, 30°, 45°, 60°, and 90° was installed at the suction duct of the centrifugal fan. This configuration made it possible to investigate the hydraulic resistance coefficients of the apparatus under different gas flow velocities and to perform the corresponding experimental studies.

The gas velocity supplied from the fan to the apparatus was determined using the following equation:

$$v = \sqrt{2gh},\ m/s \qquad (1)$$

where:

h–height (reading) of the **Pitot–Prandtl tube**, m;
g – acceleration due to gravity, m/s^2.

The gas flow rate corresponding to the air damper opening angles of 0°, 30°, 45°, 60°, and 90° installed on the fan was determined using the following equation:

$$Q = \pi \cdot \left(\frac{D}{2000}\right)^2 v \cdot 3600, \quad m^3/h \qquad (2)$$

where:

D – inner diameter of the pipe used for the **Pitot–Prandtl tube,** m.

The flow regime in the apparatus was determined using the following equation:

$$\mathrm{Re} = \frac{\vartheta \cdot d}{\nu}, \qquad (3)$$

where:
v– gas velocity, m/s;
d – inner diameter of the pipe, m.

Each experiment was repeated five times, and the arithmetic mean of the measured values was used for further analysis. The kinematic viscosity of air was assumed to be 1.51 × 10^{-5} m^2/s.

Experimental studies were conducted to determine the flow regime in the proposed wet dust collection apparatus based on the Reynolds number, using the gas velocity and volumetric gas flow rate generated by the selected centrifugal fan. The experiments were carried out according to the established procedure. The experimental results are presented in Table 1.

Experimental studies were carried out without supplying liquid to the apparatus using contact elements with blade inclination angles of 30°, 45°, and 60°. The gas flow was regulated by an air damper installed at the fan inlet with opening angles of 0°, 30°, 45°, 60°, and 90°.

The experiments were performed separately for each contact element with blade inclination angles of 30°, 45°, and 60° in order to investigate the influence of the contact element geometry on

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the gas flow regime under dry operating conditions.

Table 1. Experimental Determination of the Flow Regime Based on Gas Velocity and Flow Rate in the Apparatus

№	Determination of the Flow Regime Based on the Reynolds Number with a 30° Contact Element under Dry Operating Conditions				
	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
α	90°	60°	45°	30°	0°
v	17,34	14,05	12,58	7,11	3,87
R_e	114834	93046	83311	47086	25629

Experiments were carried out without supplying liquid to the apparatus, using a 30° contact element. The gas flow was regulated by an air damper installed at the fan inlet with opening angles of 0°, 30°, 45°, 60°, and 90°, and the flow regime in the apparatus was determined.
The experimental results showed that, when the air damper opening angle varied from 0° to 90°, the Reynolds number ranged from 25,629 to 114,834. These values indicate that the gas flow in the apparatus remained within the turbulent flow regime throughout the investigated operating conditions.

Table 2. Determination of the Flow Regime Based on the Reynolds Number with a 45° Contact Element under Dry Operating Conditions

№	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
α	90°	60°	45°	30°	0°
v	16,07	13,13	11,88	7,39	3,39
R_e	106423	86953	78675	48940	22450

Experiments were conducted without supplying liquid to the apparatus, using a 45° contact element. The gas flow was regulated by an air damper installed at the fan inlet with opening angles of 0°, 30°, 45°, 60°, and 90°, and the flow regime in the apparatus was experimentally determined.

The experimental results showed that, when the air damper opening angle varied from 0° to 90°, the Reynolds number ranged from 22,450 to 106,423. These results indicate that the gas flow in the apparatus remained in the turbulent flow regime over the entire range of operating conditions investigated.

RESULTS

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Table 3. Determination of the Flow Regime Based on the Reynolds Number with a 60° Contact Element under Dry Operating Conditions

№	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
α	90°	60°	45°	30°	0°
V	15,27	12,12	11,18	6,35	3,22
R_e	86755	80132	74039	42052	21324

Experiments were conducted without supplying liquid to the apparatus, using a 60° contact element. The gas flow was regulated by an air damper installed at the fan inlet with opening angles of 0°, 30°, 45°, 60°, and 90°, and the flow regime in the apparatus was determined.

The experimental results showed that, when the air damper opening angle varied from 0° to 90°, the Reynolds number ranged from 21,324 to 86,755. These findings indicate that the gas flow in the apparatus remained within the turbulent flow regime throughout the investigated operating conditions.

The experimental investigations showed that, under dry operating conditions (without liquid supply), the average Reynolds number was 17,871 when the apparatus was equipped with a 30° contact element. When the blade inclination angle of the contact element was increased to 45°, the average Reynolds number decreased to 16,794. For the 60° contact element, the average Reynolds number was further reduced to 13,086.

Based on both the theoretical analysis and the experimental results obtained under dry operating conditions using contact elements with blade inclination angles of 30°, 45°, and 60°, and with the fan air damper set at opening angles of 0°, 30°, 45°, 60°, and 90°, the overall average Reynolds number was found to be 15,917.

The results demonstrate that increasing the blade inclination angle of the contact element increases the hydraulic resistance of the apparatus, leading to a reduction in gas velocity and, consequently, a decrease in the Reynolds number. Nevertheless, the Reynolds numbers obtained in all experiments indicate that the gas flow remained in the turbulent flow regime, which promotes intensive gas mixing and creates favorable hydrodynamic conditions for efficient dust collection and gas purification in the proposed wet cleaning apparatus.

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