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“ASPHALT-CONCRETE PRODUCTION: A SYSTEMATIC ANALYSIS OF GAS-DUST MIXTURE CLEANING EQUIPMENT”

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Abstract:
In this study, the efficiency of the gas–dust mixture cleaning process was investigated. A five-stage systematic analysis model for evaluating gas–dust cleaning equipment was developed in the MATLAB environment. The model takes into account particle size distribution, hydrodynamic parameters of the gas flow, liquid-to-gas ratio, and rotor rotation speed. Vertical and horizontal types of equipment were compared based on parametric analysis. The calculation results were analyzed, revealing that the horizontal-type apparatus demonstrates higher cleaning efficiency and relatively lower energy consumption under asphalt-concrete production conditions.

Keywords: Asphalt-concrete production, gas–dust mixture, dust cleaning equipment, vertical apparatus, horizontal apparatus, MATLAB modeling, system analysis, cleaning efficiency, energy consumption.

INTRODUCTION:

In asphalt-concrete production processes, a significant amount of fine dust particles is generated during the drying, mixing, and transportation of mineral materials. The size of these particles typically ranges from 0.5 to 80 micrometers, and if released into the atmosphere, they can cause environmental pollution, pose health risks to workers, and reduce production efficiency. Therefore, the application of effective gas–dust mixture cleaning equipment is of great importance in industrial practice.

In asphalt-concrete plants, widely used gas–dust cleaning equipment includes cyclones, bag filters, and various types of scrubbers. The efficiency of these devices depends on factors such as gas flow velocity, liquid consumption, particle diameter, and the design of the apparatus. Therefore, in modern research, mathematical modeling and computational methods are widely used to evaluate the performance of different designs in advance.

In this study, vertical and horizontal types of apparatus that can be used for cleaning dust generated in asphalt-concrete production were investigated based on a five-stage systematic analysis model developed in the MATLAB environment. The main objective of the research is to compare the cleaning efficiency, energy consumption, and operational characteristics of both designs, and to determine the most effective option.

METHODOLOGY:

The study was carried out based on a computational algorithm developed in the MATLAB software environment. During the modeling process, gas flow, particle size distribution, and apparatus parameters were taken into account. The system analysis consisted of five stages.

In the first stage, the structural characteristics of the apparatus were analyzed. In the vertical apparatus, the gas flow moves from top to bottom, and sludge accumulates in its conical section. In such a design, there is a possibility of particle re-entrainment under high dust loading. In contrast, in the horizontal apparatus, the gas flow moves in a horizontal direction, and sludge is collected in a special tank. This increases contact stability and reduces the likelihood of dust re-entrainment.

In the second stage, the main operating parameters were analyzed. In the study, the gas flow rate was assumed to be 2.5 m^3/s. The inlet dust concentration was taken as 8 g/m^3. The gas density was assumed to be 1.2 kg/m^3, while the dust density was 2600 kg/m^3. The dynamic viscosity of air was 1.8×10^{-5} Pa·s, and the system temperature was set at 120°C.

The particle size distribution was assumed to follow a logarithmic law. The median particle diameter was taken as 12 micrometers, with a geometric standard deviation of 2. In the modeling process, particle diameters were considered within the range of 0.5 to 80 micrometers.

For the vertical apparatus, the gas velocity was assumed to be 3.5 m/s, the liquid-to-gas ratio 1.2 L/m^3, rotor rotation speed 900 rpm, and pressure drop 1400 Pa. For the horizontal apparatus, the gas velocity was 3.0 m/s, the liquid-to-gas ratio 1.0 L/m^3, rotor rotation speed 850 rpm, and pressure drop 1200 Pa.

The cleaning efficiency, depending on the particle diameter, was calculated using the following mathematical expression,; %

$$\eta(d) = 1 - e^{-K(L/G)^a n^b v^c d^m} \qquad (1)$$

Here, L/G is the liquid-to-gas ratio, nnn is the rotor rotation speed in rpm, v is the gas velocity in m/s, d is the particle diameter in µm, and K,a,b,c,m are model coefficients.

The energy consumption in the MATLAB model was calculated as the sum of the fan and rotor powers. The fan power depends on the gas flow rate, pressure drop, and fan efficiency, and was determined using the following formula, W;

$$P_{fan} = \frac{Q\Delta P}{\eta_{fan}} \tag{2}$$

Here, P_{fan} is the power consumed by the fan in watts (W); Q is the gas or air flow rate in m³/s; ΔP is the pressure drop in the apparatus in pascals (Pa); and η_{fan} is the fan efficiency.

The power of the rotating mechanism was assumed to be proportional to the cube of the rotor rotation speed, and expressed in watts (W) as:

$$P_{rotor} = k_{rot} n^3 \tag{3}$$

Here P_{rotor} is the power consumed to rotate the rotor, in watts (W); k_{rot} is a coefficient dependent on the rotor's design, accounting for rotor geometry, friction forces, and hydrodynamic resistance; and n is the rotor rotation speed in revolutions per minute (rpm).

The total energy consumption was determined as the sum of the fan and rotor powers. The energy required to clean 1000 m³ of gas was calculated by multiplying this power by the gas processing time and then converted to kilowatt-hours (kWh).

In the third stage, the efficiency of the apparatus under various operating conditions was evaluated through parametric analysis. For example, the liquid-to-gas ratio (L/G) was varied from 0.5 to 2.0 L/m³, and the rotor rotation speed was changed from 500 to 1200 rpm.

In the fourth stage, energy consumption was calculated, taking into account both the fan and rotor power. The energy required to process 1000 m³ of gas was determined in kilowatt-hours (kWh).

In the fifth stage, the Multi-Criteria Decision Analysis (MCDA) method was applied. This considered criteria such as cleaning efficiency, energy consumption, reliability, and ease of maintenance.

RESULTS

According to the MATLAB modeling results, the overall cleaning efficiency of the vertical apparatus was approximately 89%, resulting in an outlet dust concentration of 0.88 g/m³. For the horizontal apparatus, the cleaning efficiency reached 93%, with an outlet concentration of 0.56 g/m³.

The energy consumption analysis showed that the fan power for the vertical apparatus was approximately 5384 W, while for the horizontal apparatus it was 4615 W. The energy required to clean 1000 m³ of gas was 0.62 kWh for the vertical apparatus and 0.54 kWh for the horizontal apparatus.

To evaluate the results, correlation graphs were plotted. Figures 1, 2, and 3 illustrate the relationships between cleaning efficiency and particle diameter, cleaning efficiency versus liquid-to-gas ratio, and energy consumption, respectively.

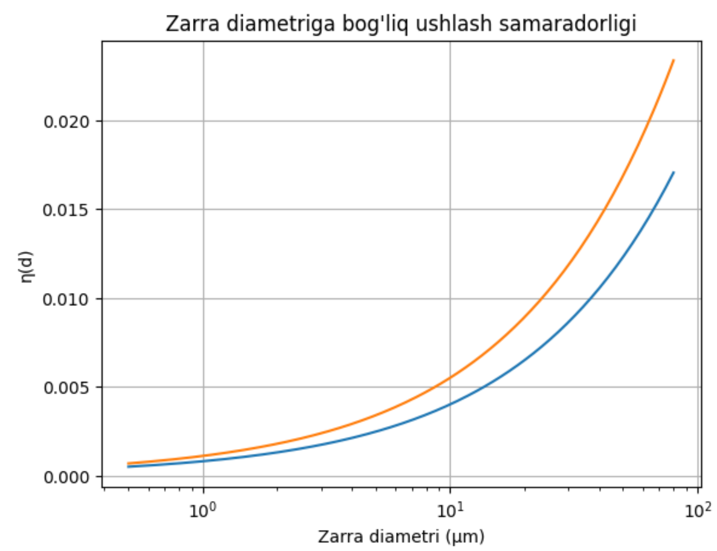

Figure 1. Cleaning efficiency as a function of particle diameter.

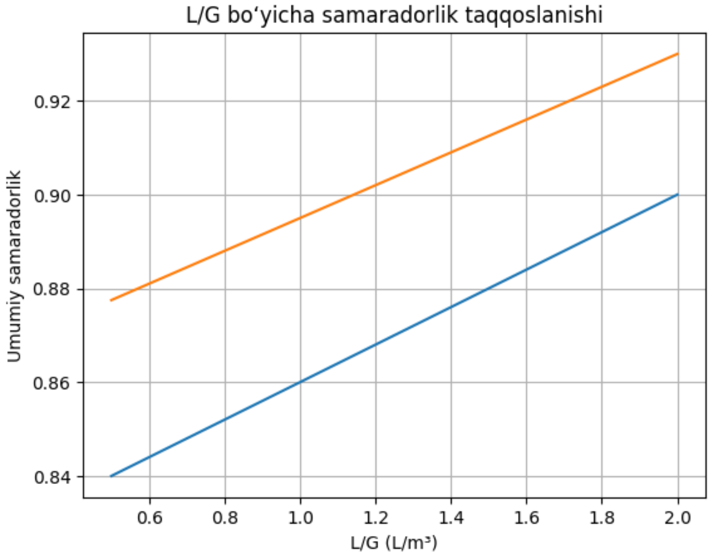

Figure 2. Overall cleaning efficiency as a function of the L/G ratio.

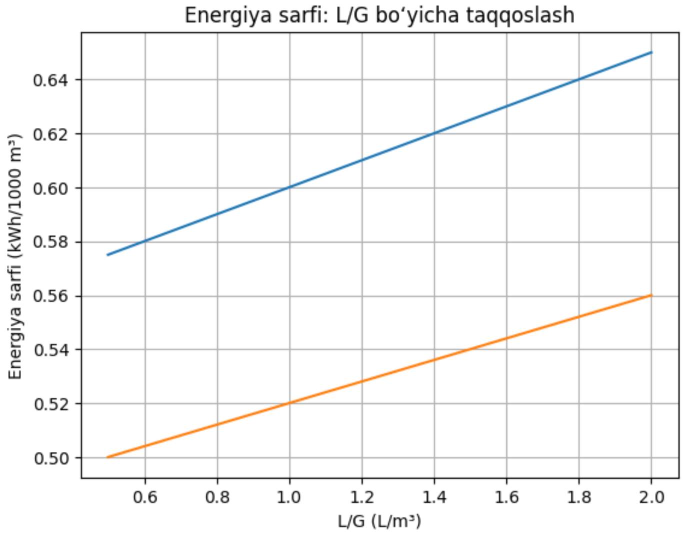

Figure 3. Comparison of energy consumption.

The analysis of efficiency versus particle diameter showed that particles larger than 10 micrometers were captured with over 95% efficiency in both apparatus types. However, in the 2–5 micrometer range, the horizontal apparatus demonstrated significantly better performance.

According to the analysis based on the L/G ratio, the optimal operating range is 1.0–1.3 L/m³. Within this range, the cleaning efficiency is high while energy consumption remains relatively low.

The multi-criteria evaluation results showed that the overall process efficiency (utility coefficient) of the vertical apparatus was 0.78, whereas for the horizontal apparatus it reached 0.86.

DISCUSSION

The obtained results indicate that the horizontal apparatus design provides more stable contact between the gas and the liquid. This leads to more effective capture of dust particles. Additionally, in the horizontal apparatus, sludge is collected in a special tank, which reduces the likelihood of particle re-entrainment.

In the vertical apparatus, particle re-entrainment may occur under high dust loading, which leads to a decrease in cleaning efficiency.

From the perspective of energy consumption, the horizontal apparatus also has an advantage. Its relatively lower pressure drop requires less fan power.

Parametric analysis showed that increasing the gas velocity and L/G ratio improves cleaning efficiency, but also raises energy consumption. Therefore, selecting the optimal operating mode is crucial.

CONCLUSION

The five-stage systematic analysis model developed in the MATLAB environment has proven to be an effective method for evaluating gas–dust mixture cleaning apparatus in asphalt-concrete production.

The study results showed that the horizontal apparatus demonstrates high efficiency under asphalt-concrete production conditions. Its cleaning efficiency reached 93%, and its energy consumption was approximately 15% lower compared to the vertical apparatus.

Therefore, the use of horizontal-type apparatus for gas–dust mixture cleaning in asphalt-concrete plants is considered the most appropriate.

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