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The Effect of Perforation Diameter and Number of Elements on Hydraulic Resistance

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Abstract: In this article, the influence of the perforation diameter and the number of arcuate elements on the hydraulic resistance in the working bodies of the rotor-filter apparatus is studied. In the course of research, the pressure losses occurring in the apparatus when the conditions of the gas-liquid flow, the size of the perforation holes and the number of working elements are changed were analyzed. It is also determined how the increase in the diameter of the perforation and the change in the number of arc elements affects the level of turbulence of the flow and the interaction of phases. The obtained results serve as an important scientific basis for reducing the hydraulic resistance, increasing the efficiency of the apparatus and optimizing the dust gas cleaning process. The results of the research are of practical importance in improving the design of the rotor-filter apparatus and increasing the efficiency of gas cleaning devices used in industrial enterprises.

Keywords: Rotor-filter apparatus, perforation diameter, arc-shaped elements, hydraulic resistance, gas-liquid flow, turbulent regime, spray dynamics, droplet dispersion, dust removal efficiency, liquid consumption, Reynolds number, hydrodynamics, wet gas cleaning, industrial gas purification.

INTRODUCTION:

The rotor-filter device is an improvement over traditional filter devices, equipped with a perforated filter and a modified special rotor with a contact spring profile. Such a constructive solution can change the mechanism of interaction between the dusty gas flow and the working fluid, intensifying mass exchange processes, increasing cleaning efficiency, and reducing energy consumption under certain operating conditions.

At the same time, the design and operating mode of the rotor affect the gas flow of the working fluid, as well as the change in the concentration of dusty gas entering the apparatus.

Determining the liquid flow rate, flow regime, and velocity in a rotor-filter apparatus is one of the most important stages of the study, since the efficiency of dusty gas purification in the device is directly dependent on the liquid spray intensity, the dispersion of the resulting droplets, the wetting surface, and the gas-liquid contact time.

First, determining the fluid flow rate allows you to determine the amount of working agent supplied to the device. As the flow rate increases, the flow impulse through the nozzles increases, resulting in the formation of finely dispersed droplets, a thickening of the water film, and an increase in the degree of wetting of the filter active surface. This increases the efficiency of dust particle capture based on inertial, diffusion, and adhesion mechanisms.

Fig. 1. General view of the experimental setup.

Based on the above, the fluid flow rate to the rotor-filter apparatus was experimentally determined and the parameters were evaluated.

When conducting experiments, calculations were made for water (t≈20 °C) based on the following data: ρ_w = 1000 kg/m³, $\mu_w = 1.0\times10^{-3}$ Pa·s. The pump was assumed to be operating at maximum flow rate (Q_p= 40 l/min = 0.000667 m³/s N_e=0.37 kW; h_{max}=38m; V=220V; n_r=3000 rpm according to GOST-2757030-91). A rotometer was installed in the apparatus (RS-5 scale indicators in the range 0÷100 according to GOST-13045-81). The fluid flow rate, speed, flow regime and water dispersion angle, as well as the diameter of the resulting water curtain were determined for the diameter of the nozzle hole d_{sh}=2 and 3 mm. In this case, the number of connectors installed on the device is 3. It was taken into account that the resistance of the nozzle hole is equal to 1.41 when the diameter of the hole is 2 mm and 1.32 when it is 3 mm.

The flow rate in the rotometer increases proportionally to the scale. In practice, 3–5 points are usually taken. Since the process under study required that the fluid flow rate during the purification of 1 m³ of dusty gas be not less than 0.15 liters, the following points on the rotometer scale were selected to determine the water flow rate: Rc = 25; 50; 75 and 100 and calculated using the following formula: m³/hour;

$$Q_{sh} = Q_{um}\frac{Rc}{100} \qquad (1)$$

where Q_{um}=40 l/min; Rc is a scale indicator.

Consumption of one nozzle is determined according to the following equation, m³/hour;

$$Q_{sh} = \frac{Q_{um}}{3} \qquad (2)$$

The cross-sectional area of the nozzle hole is determined according to the following equation, m²;

$$F_{sh} = \frac{\pi d_{sh}^2}{4} \qquad (3)$$

The calculated cross-sectional area for d_{sh} = 2 mm is $F_2 = 3.14\times10^{-6}$ m² and for d_{sh} = 3 mm is $F_2 = 3.14\times10^{-6}$ m². The experimental results are presented in Figures 2 and 3.

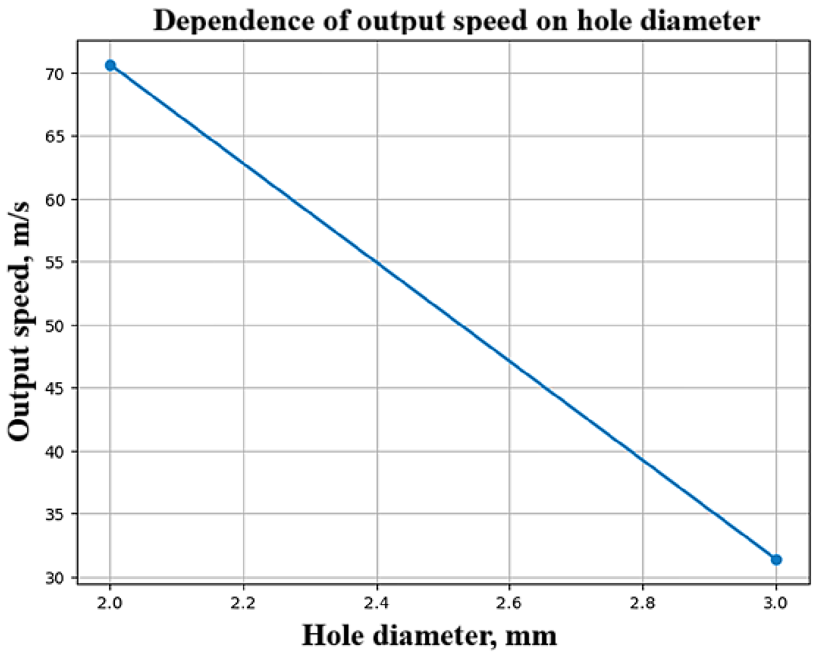

Figure 2. Variation of the speed of the working fluid depending on the nozzle diameter.

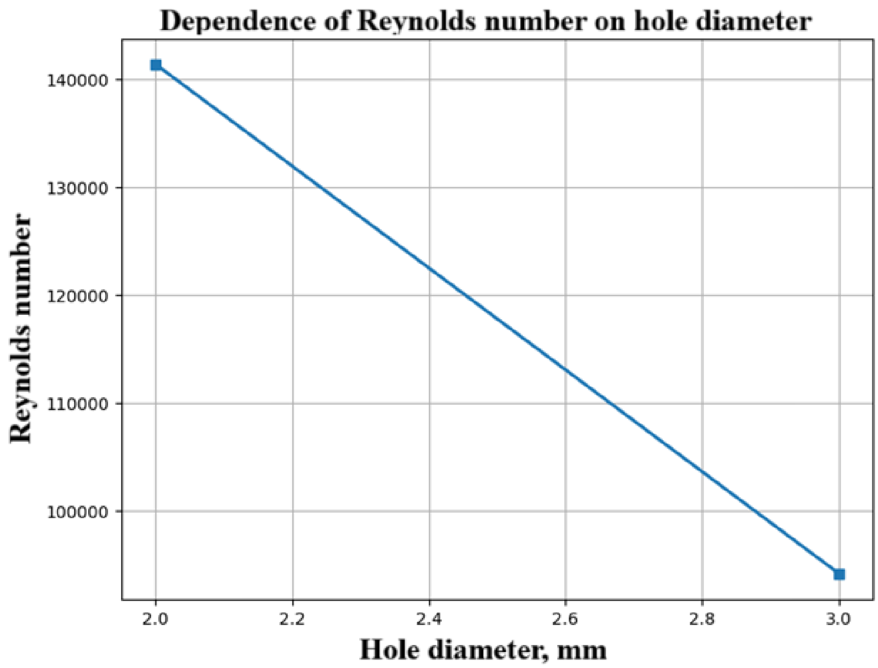

Figure 3. Variation of the working fluid flow regime depending on the nozzle diameter.

At the next stage of the research, the liquid scattering mechanism was determined experimentally. The angle of dispersion of the spray water jet generated by the liquid-dispersing nozzles in the device is mainly formed depending on the geometry of the nozzle, the diameter of the outlet hole and the dynamic pressure of the flow. Experimental and computational analysis showed that the spray angle does not change dramatically in direct proportion to the variable consumption values through the rotometer scale, under the condition that the local hydraulic resistance coefficient z is assumed for the nozzle hole to have a constant value.

This situation is explained as follows: when the scale of the rotometer changes in the range of 0-100, the amount of consumption increases in a certain range, but the hydrodynamic structure of the flow is preserved due to the fact that the coefficient of local resistance, which affects the flow formation in the nozzle hole, remains constant. As a result, the spray water jet geometry, including the spray angle, is relatively stable.

The following equation was recommended and used to calculate the splash angle (α) for a centrifugal pump and an experimental connection for a conical vane:

$$tng\left(\frac{\alpha}{2}\right) \approx \frac{1}{\sqrt{\xi_{sh}}} \quad (4)$$

where ξ_{sh} is the nozzle resistance coefficient.

When determining the diameter of the water curtain in the rtor-filter devicethe distance from the nozzle to the wall was taken as approximately ≈ 25 mm = 0.025 m and determined according to the following equation, m; A graph of the dependence of the diameter of the water curtain on the diameter of the nozzle hole was constructed. Figure 4.

$$D = 2Ltng\left(\frac{\alpha}{2}\right) \quad (5)$$

The conducted computational and experimental analyses showed that the diameter of the nozzle hole has a significant effect on the hydrodynamics of the spraying process. When the hole diameter was increased from 2 mm to 3 mm, the outlet cross-sectional area increased by approximately 2.25 times. The increase in the cross-sectional area led to a decrease in the flow velocity under the same flow conditions, and according to calculations, it was found that the outlet velocity decreased by approximately 2.2 times. This phenomenon is explained by a decrease in the kinetic energy of the spray water jet.

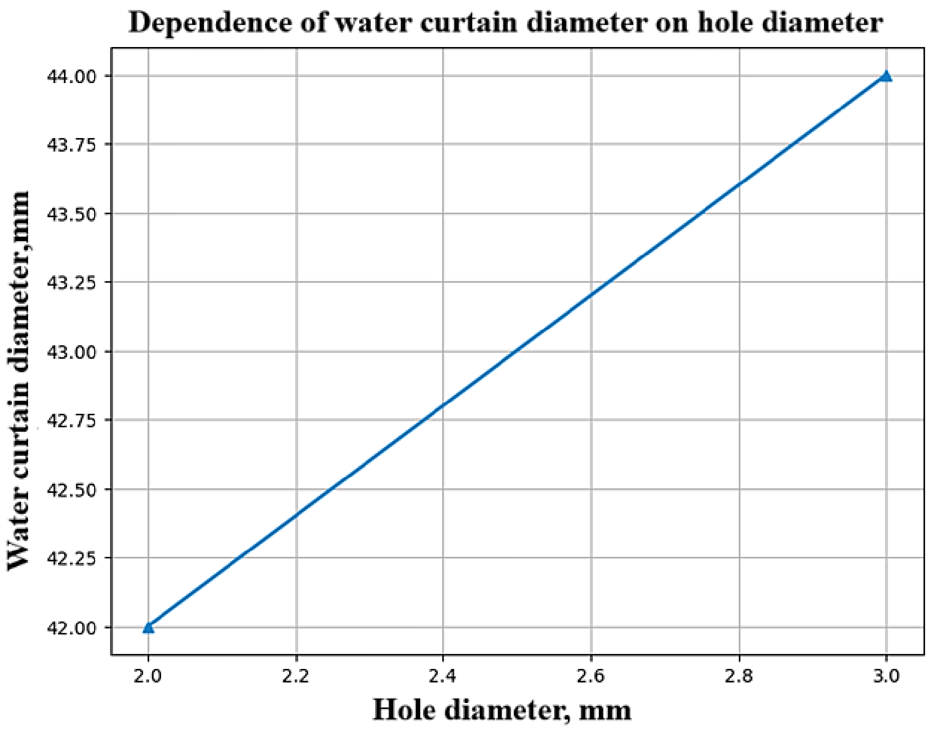

Figure 4. Variation of the diameter of the working fluid membrane depending on the diameter of the nozzle hole.

According to the results of hydrodynamic analysis, in both cases the Reynolds number is higher than 4000, and the flow exiting the nozzle is formed in a strongly turbulent regime. The formation of a turbulent water jet contributes to the intensive fragmentation of droplets, their uniform distribution in the gas medium, and, as a result, an increase in the probability of contact with dust particles. In this regard, the turbulent spray regime was assessed as an important factor in increasing the efficiency of dust capture.

When the pump was operating at a maximum flow rate of 40 l/min, the fluid flow through each nozzle was approximately 0.000222 m³/s. The exit velocity reached 70 m/s in the 2 mm diameter hole, creating a high-energy and strong turbulent spray water jet. In the 3 mm hole, the exit velocity was around 31 m/s, and the water jet spread was wider, but the kinetic energy was lower.

As a result of calculations, it was found that in both cases the scattering angles are in the range of 80–82°, and the diameter of the resulting water curtain is in the range of 42–44 mm. From a technological point of view, the use of a 2 mm nozzle for high-efficiency cleaning of dusty gases gives a favorable result. In order to increase the efficiency of washing walls and overall wetting, it is advisable to use a 3 mm nozzle. Therefore, in the next stage of research, a nozzle with d_{sh}=3 mm and a water flow rate Q_w=0.2÷0.8 m^3/h with a step of 0.2 m^3/h was determined.

CONCLUSION

The conducted experimental and theoretical investigations demonstrated that the diameter of nozzle perforations and the number of arc-shaped elements have a significant impact on the hydraulic resistance and overall performance of the rotor-filter apparatus. An increase in perforation diameter leads to a reduction in flow velocity and kinetic energy of the liquid jet, while simultaneously expanding the spray coverage area.

The analysis confirmed that, under all studied conditions, the flow regime remains turbulent (Re > 4000), which plays a crucial role in enhancing droplet dispersion and improving gas-liquid interaction. This, in turn, increases the probability of particle capture through inertial, diffusion, and adhesion mechanisms. It was found that smaller nozzle diameters (2 mm) produce high-velocity streams with strong turbulence, making them more effective for cleaning fine dust. Conversely, larger diameters (3 mm) produce wider spray patterns with lower jets, which are more suitable for surface wetting and washing processes. The spray angle and liquid film diameter were found to remain relatively stable despite variations in flow rate, due to constant local hydraulic resistance coefficients. This indicates устойчивость hydrodynamic structure of the jet under varying operating conditions.

Overall, the obtained results provide a scientific basis for optimizing конструкция and operating parameters of rotor-filter devices. The findings can be effectively applied to improve energy efficiency, reduce hydraulic losses, and enhance the performance of industrial gas cleaning systems.

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