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EFFECT OF CHANGING THE SHAPE OF THE RAREFACTION CHAMBER OF A DEVICE FOR REMOVING WATER FROM THE ROPE SURFACE ON AIR FLOW PARAMETERS: A TECHNICAL NOTE

Abstract. The study of the interaction of air flow with a water film is an under-researched topic, and therefore this study is relevant for the academic community. The analysis and modelling results complement existing knowledge and expand the understanding of processes in this area. The purpose of this study was to compare the parameters of the air flow generated in the device for removing water from the surface of the mine hoist rope when changing the shape of the rarefaction chamber, which can increase the efficiency of the device. In the study, a computer experiment was performed to create models of the rarefaction chamber of the device for removing water from the rope surface with different shapes of the device surface. The experiment itself was conducted in SolidWorks Flow Simulation software. The study found that changing the shape of the rarefaction chamber substantially affects the air flow parameters in the device for removing water from the rope surface. At a ratio of $D/D1=1.6...2.5$, flow stability and effective water removal along the entire length of the rope were observed. Specifically, it was found that the value $D/D1=1.6$ is particularly optimal, as this pressure is as close as possible to the intensity of water removal, ensuring an even flow distribution and minimal energy consumption. This allows the device to operate at high efficiency, reducing the risk of uneven water removal and increasing the reliability of the lift. The resulting uneven air flow has a negative impact on the integrity of the water film on the rope surface and, as a result, on the removal of water from the surface of the mine hoist rope. The study of this problem allows expanding the understanding of the effect of air flow on the water film on the rope surface and contributes to the development of more efficient water removal devices, which is the practical value of this study.

Keywords: water film; mine hoisting unit; intensity of water removal; efficiency

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Introduction. The study of the design of devices for removing water from the surface of the rope is an important and relevant problem since a series of technical and operational problems constantly arise during the operation of a mine hoisting unit due to the influence of external and internal factors. One of these problems is the increase in air humidity in the mine, which is caused by the influence of precipitation on the surface and groundwater in the mine. Increased humidity leads to the formation of condensation, which settles on various surfaces in the mine, including the surfaces of mine hoists. Condensation on the surface of the ropes in a shaft hoist is particularly dangerous, as moisture from the shaft gets onto the brake pulleys and other essential elements of the hoist. This can lead to corrosion of metal parts, impaired brake pulley adhesion, and a reduction in the overall efficiency and safety of the hoist. As a result, there is a risk of frequent malfunctions and emergency shutdowns, which negatively affects the mine's profitability and the feasibility of its operation in general. Considering that a mine hoist is an essential and indispensable element of a mine's technological process, it is imperative to ensure its uninterrupted and efficient operation.

The principle of operation of the device is based on the interaction of air flow with a film of water on the rope. The water carried out of the rope is in the form of microscopic water droplets, which are transported by the air flow in the rarefaction chamber to the outlet nozzles. R. Peeters *et al.* (2021) covered the topic of the interaction between air flow and water film. Specifically, the paper discussed the production of water from air, and of particular interest was the Water from Air technology, which includes three phase transitions of water, including the condensation process, as water vapour interacts with the air flow, but unlike the device for removing water from the surface of a rope, the task here is to absorb water from the air rather than remove it from a particular object.

There is no method for simulating the interaction between air flow and a water film, and therefore it is necessary to resort to simplifications and replace them with corresponding mathematical models. SolidWorks Flow Simulation uses the finite volume method, which depends on the correct choice of mesh accuracy in the finite volume. J. Tan (2019), investigating the finite volume upwind method for solving convection and diffusion equations with the Dirichlet boundary on a rectangular grid, provided a detailed mathematical analysis of this issue. Furthermore, S. Salmat *et al.* (2023) investigated the

accuracy of grid use on the example of centrifugal fans. The findings of these studies were used to determine the optimum simulation parameters.

The operating mode of the device for removing water from the rope surface is under the condition of laminar air flow, and therefore the values at which laminar flow turns into turbulent flow are a significant component of this study. Thus, N. Agarwal & G. Bhutani (2021) investigated and analysed the use of adaptive and fixed meshes for two models, and then determined the most effective mesh parameters for turbulent flow modelling. Furthermore, the researchers paid special attention to alternative computing methods.

The purpose of this study was to determine the best air flow parameters and its effect on the intensity of water removal from the rope surface when changing the shape of the rarefaction chamber.

Materials and methods. Various technological solutions are used to reduce the impact of air humidity, one of which is a device for removing water from the surface of mine hoist ropes. This device is designed to remove water from the surface of ropes using the energy of rarefied air, which eliminates the need for rope centring and facilitates the maintenance of the device.

The principle of operation of the device is to remove the water film from the rope surface using compressed air in the rarefaction chamber. The rarefaction chamber is created by a fan unit that removes air from the system. A pipeline connects the rarefaction chamber and the fan unit, to which water separators are connected. The device diagram is presented in Figure 1.

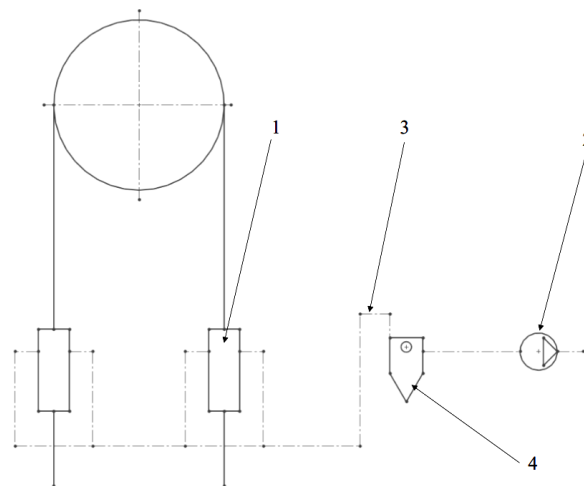


Fig. 1. Diagram of the device for removing water from the rope surface Source: developed by the author of this study

In existing devices, design imperfections were identified due to the instability of air flow during operation. This results in zones with values that are considerably higher or lower than the fan dispersion value. Several ways to improve the design have been proposed to address this problem (Zinoviev & Zinovieva, 2010):

1. Changing the shape of the rarefaction chamber. Using a computer parametric study, it is possible to find the optimum chamber model wherein the air flow is stable and the fan dispersion at all points of the rope is minimal. This will ensure an even distribution of air flow along the entire length of the rope, which will contribute to the effective removal of moisture.

2. Changing the equipment parameters. Replacing the fan unit with a more powerful one can improve the uniformity of air flow. However, this leads to an increase in energy consumption, which is not always economically feasible (Temchenko, 2024).

The first option, albeit requiring a rarefaction chamber with a complex surface, is better in terms of energy consumption. Improving the efficiency of the structure can significantly increase the reliability of the mine hoist and prevent frequent breakdowns. This is the most promising way to improve the design, unlike the second, where improving the device's parameters involves replacing the fan with a more powerful one. It is advisable to find the required design using parametric design systems, which allow exploring variable design parameters such as nozzle or rarefaction chamber diameters, different pressure and volume flow rates. These systems include SolidWorks with the Flow Simulation software package. Among the analogues of this package is ANSYS, which has high accuracy in calculations. However, considering all the advantages of this product, SolidWorks Flow Simulation is more

suitable for performing design research and optimisation tasks, and therefore this tool was used in the present study (Biletskyi, 2021). The experiment was based on an existing device that was used at the Kozacha mine, with known technical characteristics (Zinoviev, 2004). Two models were built based on this device: one with a straight inclined surface and the other with a parabolic surface.

Results. The experiment involves finding the relationship between the shape of the rarefaction chamber and the required airflow parameters. For this, the diameters of the end and central part of the model with a parabolic surface (Fig. 2) were changed. The surface shape is defined by a regular parabola and is bounded by the rim of the central $y = ax^2 + b$ part of the chamber and its end.

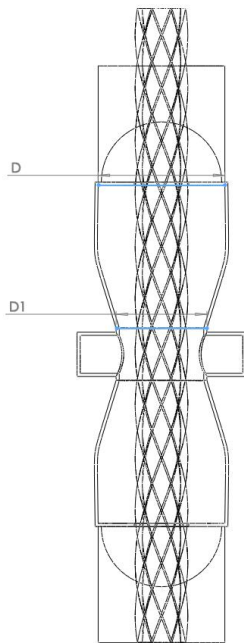


Fig. 2. Model of a rarefaction chamber with a parabolic shape Source: developed by the author of this study

A chamber with a straight inclined surface was considered as a special case of a chamber with a parabolic surface. Since the parabola is bounded by the end and the rim, changing their parameters changes the parabola itself. The internal diameters of the end face and rim were taken as parametric changes. The simulation (Fig. 3) is intended to approximate the real operating conditions of the device, and therefore a model of the dome was built to help simulate the environment. The initial parameter “ambient pressure” was applied to its surface. Furthermore, an external volume per flow rate tool was applied to the outlet plugs, which was 0.23 m³/s. The selection of the grid accuracy involves considering the specifics of the model and the method of grid construction and calculation. Thus, the finite volume method has difficulties in constructing a finite volume mesh in places bounded on both sides by curved surfaces. For this model, a particularly problematic area is the central part, which is bounded by a parabolic surface and a rope. The grid in this experiment was built automatically, without any changes, and its accuracy level was 4. This accuracy allows the mesh to adapt to the curved surface of the device (Barth *et al.*, 2017).

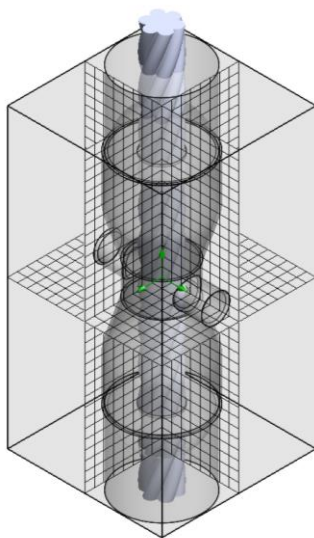


Fig. 3. Computational model of the rarefaction chamber Source: developed by the author of this study

Rope surface water removal devices are characterised by the intensity of water removal from the rope surface

$$In = \frac{8\sqrt{2}\pi^3 B C_p}{3\sqrt{3}} \Lambda d_r \sqrt{\Delta p^*}, \quad (1)$$

where Λ – the effective length of interaction of the air flow with the water film on the rope surface; B – the coefficient characterising the operation of the rope dewatering equipment; C_p – the coefficient of the rope perimeter; ρ – the density of the water film on the rope surface; Δp^* – the fan depression value, which is equal to the difference between the ambient pressure and the pressure at the inlet to the chuck formed by the fan and is equal to $\Delta p = P_{AT} - P_a$; d_r – the rope diameter.

Since this value depends on the geometric shape of the device and the square root of the fan dispersion, the required shape can be searched using the dispersion value, which for the Kozacha mine is 5,000 Pa. This means that the values should be as close to 95,000 Pa as possible, but not exceed it, otherwise water removal cannot take place due to the lack of rarefaction.

The effect of changing the shape of the rarefaction chamber on the air flow was sufficient and meets the necessary requirements for removing water from the rope surface. Specifically, it was found that with a ratio $D/D1=1.6...2.5$, the value of water removal from the rope surface will be approximately the same at any point of the rope. The bar chart (Fig. 4) shows the pressure drop as the shape approaches the cylindrical shape. In this case, the flow is stable, although the air flow is laminar. How-

ever, the disorderly movement creates rarefaction areas, which can lead to a decrease in the efficiency of the device.

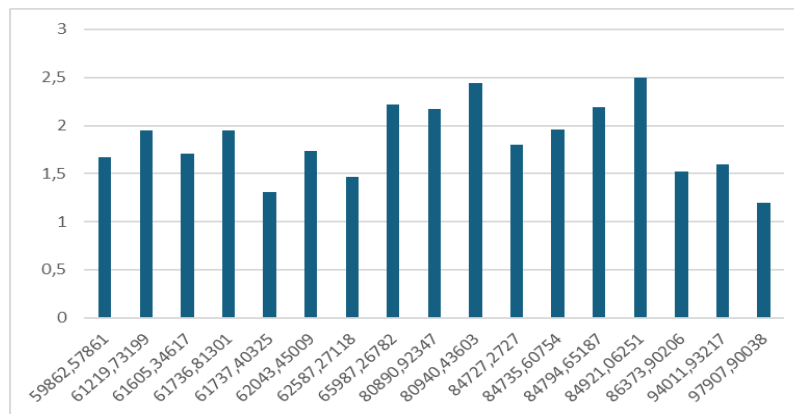


Fig. 4. Histogram of the chamber pressure versus the ratio of its diameters

Source: developed by the author of this study

Re: При макетуванні необхідно замінити кому в дробових числах зліва від діаграми на крапку (згідно правил англ. мови). Крім того, всі числа, що знизу, повинні бути прописані наступним чином: 59,862.57861; 61,219.73199 і так далі. Тобто ціле число повинно бути розділене комою через кожні три символи, починаючи з правої сторони. Коми знову замінюються на крапки

As mentioned above, the change in shape affects the flow stability and the fan dispersion value along the entire length of the rope. Approximation of the parabolic shape to a more spherical shape stabilises the flow, and therefore that the intensity of water removal from the rope surface along its entire length stays approximately the same. Thus, at $D/D1=1.6$ (Fig. 5), the rope pressure value is as close as possible to the value of the intensity of water removal from its surface, while the air flow moves steadily.

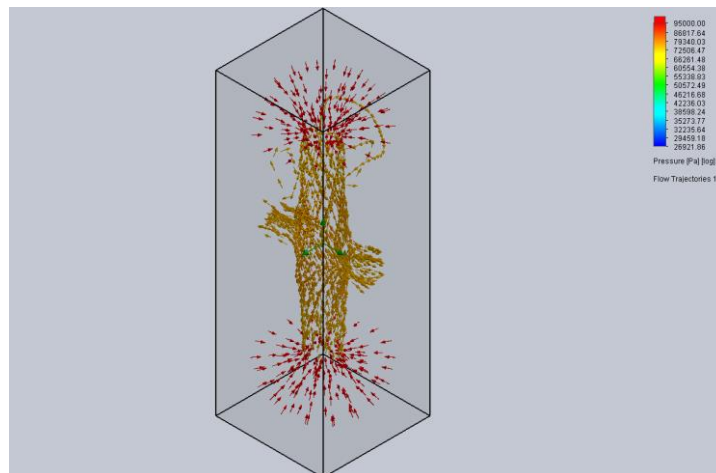


Fig. 5. Air flow trajectory. **Source:** developed by the author of this study

Notably, the most favourable conditions are observed at values from $D/D1=1.6...2.5$, but only with the optimum shape of the chamber itself and with sufficient distance of the nozzles to the rope. Their proximity to the rope causes a pressure drop on the graph and goes beyond the optimum design of the device for removing water from the rope surface, even with optimum $D/D1$ ratios.

Discussion. There is almost no research on removing water from the rope surface. The only researcher in this area was S. Zinoviev (2004), who developed a device for removing water from the rope surface and the methodology for its construction. It was he who proposed a formula for removing water from the surface of the rope. Considering this, the proposed change in the shape of the rarefaction chamber does not affect its operation parameters, while stabilising the air flow.

The principle of operation of the device is based on the interaction of air flow with a film of water. Y. Liu *et al.* (2017) investigated the effect of airflow on water droplets on an aircraft wing, which allowed them to extrapolate to a device for removing water from the surface of a rope and select the correct parameters for simulation. This study is close to the present one and describes the behaviour of

the air flow. Even though the presented study employed a computer experiment to simplify the process of water film rupture and its removal by air flow, the parameters of this process coincide with the findings from the practical experiment.

F. Touron *et al.* (2015) investigated horizontal straightforward layer-by-layer two-phase flow in a channel with a rectangular cross-section, using the Reynolds number as parameters. Considering this, in some cases the results of the research do not coincide with the stated ones. Considering the behaviour of the water film at certain parameters of this study, as well as the fact that the device for removing water from the rope surface operates at Weber number parameters greater than 3 but less than 10, it can be assumed that the inaccuracies are conditioned by the parameters falling outside this range.

F. Piscaglia *et al.* (2013) evaluated the SGS models for modelling internal combustion engines. Although the principle of operation of the engines is fundamentally different compared to the water removal device, the behaviour of the topological grid of finite volumes is analogous to that in the present study.

Thus, research related to the removal of water from the rope surface is extremely limited. However, the conducted analysis suggests that the parameters of the device can change depending on the conditions, such as the Weber number. Comparison with other studies, specifically, studies of two-phase flow and topological mesh modelling, indicates the possibility of inaccuracies due to parameters going beyond certain limits.

Conclusions. The experiment showed that changing the shape of the rarefaction chamber affects the air flow. At a ratio $D/D1=1.6...2.5$, the value of water removal from the rope surface stays stable at any point of the rope. At a value $D/D1=1.6$, the pressure is as close as possible to the intensity of water removal from the rope surface. Thus, the findings of this study showed that optimising the shape of the rarefaction chamber is the most promising way to increase the efficiency of water removal from the surface of mine hoisting ropes. This ensures a stable air flow and minimal energy consumption, which contributes to the reliability and safety of the lifting system. Notably, this study had to simplify the process of water film breaking and consider this as the movement of air flow with an increased humidity parameter, which can affect the accuracy of the results. The prospects for further research on this subject are to conduct experiments with real objects and to theoretically substantiate the processes that occur in the system. The interaction of fluid flows and the water film is particularly noteworthy, as this topic is understudied.

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