Hydrodynamic characteristics of mixed flow in liquid-gas ejectors

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Abstract

Introduction. The aim of this study is to identify the regularities governing mixed-flow formation and to determine the influence of ejector design elements on hydrodynamic characteristics.

Materials and methods. Ejection processes in ejectors with a cylindrical mixing chamber and active nozzles (jet and centrifugal-jet nozzles) are studied experimentally on a hydraulic stand and using numerical modeling tools in the academic version of the ANSYS 2020 R2 program with a maximum number of calculation cells of 512,000.

Results and discussion. It was found that the vacuum generated in a conventional jet sulfitator with a geometric characteristic of 126 and a standard jet nozzle is relatively low, reaching only 20–25 Pa. In contrast, replacing the standard nozzle with a centrifugal jet nozzle markedly increased rarefaction: at a distance of 20 mm from the nozzle outlet, the vacuum reached 425–555 Pa. Replacing the jet nozzle with a centrifugal jet nozzle while maintaining the same geometric characteristic of the ejector resulted in stable operation of the sulfitation station. Further analysis identified a rational range of the ejector geometric characteristic of m = 25–40 when using a centrifugal jet nozzle, which ensured stable rarefaction in the range of 78–100.4 kPa and reliable gas-phase ejection. Under a liquid pressure of 0.225 MPa at the nozzle, the ejection coefficient reached 2.5, which is sufficient to achieve the required technological pH of the liquid during the diffusion process.

At a liquid pressure in the nozzle channel of the nozzle of 0.25 MPa, its maximum speed reaches 20 m/s along the ejector axis. Due to the loss of energy for dispersion and resistance to the movement of droplets in a gas environment in the mixing chamber, the liquid speed at the ejector outlet decreases to 13.8 m/s. Two zones of mixed flow formation in the ejector have been established. In the first zone at a distance of up to 1.5 diameters of the mixing chamber, primary formation occurs with the formation of a homogeneous flow. In the second zone at a distance of up to 3 diameters of the mixing chamber, phase redistribution occurs and a ring flow regime is established. Based on these results, a rational design of a sulfitator for sugar production liquids was proposed to improve controllability and process stabilization. The working nozzle must provide sufficient surface area for phase contact, which is achieved using centrifugal-jet type nozzles, and the geometric characteristic of the ejector should remain within the identified range of 25–40 to ensure optimal vacuum generation and ejection efficiency.

Conclusions. Experimental and numerical (CFD) studies of ejection processes in liquid-gas sulfitators allowed us to establish the regularities of mixed flow formation and recommend rational size ratios when designing ejectors.

Introduction

The advantages of ejectors make them widely used in various industries as effective equipment for processes requiring high rates of phase interaction. One such application is the sulfitation of liquids in sugar production. These advantages, however, are realized only when the dimensions of the ejector are appropriately selected, taking into account hydrodynamic behavior and technological requirements; otherwise, the equipment may fail to perform effectively.

In the sugar industry, ejectors have been used as sulfitators without sufficient study of the formation of mixed flows and the influence of key structural elements on hydrodynamic characteristics. In practice, this has resulted in unfavorable environmental conditions during sulfitation, difficulty in maintaining regulated technological parameters of the solutions, increased reagent consumption, and higher energy costs. Therefore, the relevance of the present research is evident.

A mandatory technological process in sugar production is the sulfation of liquids and sugar solutions, the main tasks of which are: (a) disinfection of water from microorganisms and lowering its pH for the extraction of sucrose from beet chips in a diffusion apparatus; (b) processing of sugar solutions to reduce the content of non-sugars and improve the color of the final product to normalized values (Saska et al., 2010). This process is carried out in classical sulfitators of irrigation or bubbling types and jet (ejection) sulfitators.

Jet sulfitators consist of a liquid-gas ejector and a cyclone separator for phase separation (Ponomarenko et al., 2014). They offer several advantages over irrigation- and bubbling-type devices, including more intensive mass transfer between components, significantly lower specific metal content, simpler design, and reduced sulfur dioxide emissions into the atmosphere. However, during their operation, a number of design shortcomings were identified, which are explained by inadequate research of ejection processes. Such shortcomings are: lack of gas phase ejection in some operating modes, insufficient quality of liquid processing, SO_2 emissions into the production premises and into the atmosphere.

The practical limitations of ejector equipment can be addressed through a comprehensive scientific study of the ejection processes occurring in the mixing chamber and by determining the optimal hydrodynamic and design parameters. The choice of nozzle type is particularly relevant: in a typical jet sulfitator, a perforated disk is used as the working nozzle to disperse the liquid, effectively functioning as a jet nozzle (compact liquid jet) (Cramers et al., 2001). Since sulfitation is a heat and mass transfer process that requires a large interfacial area for efficient operation, such a nozzle proves to be inefficient.

For such processes, the use of centrifugal-jet type nozzles is recommended, which are characterized by a sufficiently high flow rate (0.7-0.9) and a spray torch filled with liquid droplets (Kandakure et al., 2005; Sliusenko and Ponomarenko, 2021). However, despite the fact that such nozzles have been studied experimentally (Balamurugan et al., 2007; Chen et al., 2019), transient processes during droplet formation have been described (Dos Santos et al., 2019), and data on determining their diameters have been provided (Balamurugan et al., 2007; Dos Santos et al., 2019), there is no unified idea of the mechanism of spray torch formation.

Establishing the patterns of mixed flow formation is necessary when designing ejectors, since the efficiency of their operation significantly depends on the design. The main elements of ejectors that affect the hydrodynamic characteristics are: (a) the design of the receiving chamber, which is manifested in the hydraulic resistance of the ejected (passive) flow entering the mixing chamber (Bergman et al., 2011); (b) the ratio of the main structural dimensions (Lefebvre and McDonell, 2017) (the value of its main geometric characteristic m is the ratio of the area of the mixing chamber to the area of the nozzle).

Thus, in Ashgriz et al. (2011) and Kandakure et al. (2005) it is noted that the highest ejection coefficient (k, the ratio of the passive flow rate to the active flow rate) for an ejector with a compact liquid jet is achieved at m = 4. Balamurugan et al. (2007) and Jain et al. (2014) experimentally demonstrated that the maximum k is at the value of the main geometric characteristic m = 10, while Chen et al. (2019) and Liu (2014) noted that optimal mixing of components in the ejector is achieved at m = 20-25. It should be emphasized that in a typical sulfitator, the geometric characteristic is m=126, which is significantly higher than these optimal values and may explain its insufficient operational efficiency.

Materials and methods

A comprehensive study of the ejection processes of jet devices with a cylindrical mixing chamber and a compact (jet nozzles) and dispersed liquid jet (centrifugal jet nozzles) was carried out by conducting full-scale experiments on a hydraulic stand and numerical modeling of processes in the academic version of the ANSYS 2020 R2 program with a maximum number of calculation cells of 512,000.

Nozzle designs

The studies used jet-type nozzles (Figure 1), which are typical in industrial sulfitators (Allauddin et al., 2024).

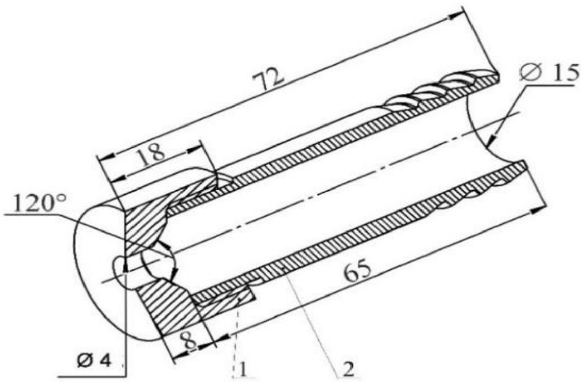


Figure 1. Jet nozzle: 1 – nozzle; 2 – body

The jet nozzle provides a compact liquid jet with a spray angle of 2-4 degrees, is the working nozzle of a classic ejector. The dimensions of the experimental nozzle are indicated in the drawing. The roughness of the nozzle opening is Ra = 0.16, which corresponds to the grinding operation. The flow rate of such a nozzle is quite high and is in the range of 0.93-0.98, which is its advantage.

Another type of nozzles that were studied are centrifugal jet type nozzles (Ponomarenko et al., 2024) (Figure 2).

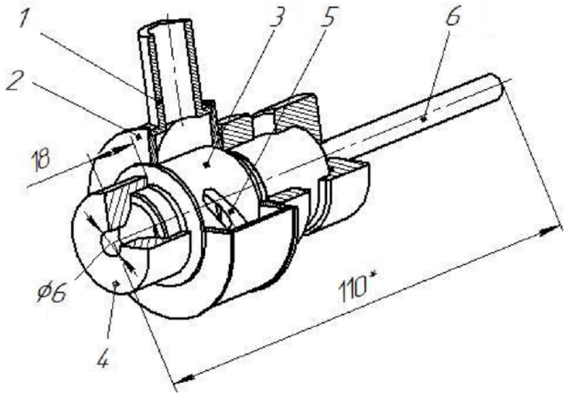


Figure 2. Centrifugal jet nozzle:
1 – inlet pipe; 2 – housing; 3 – twisting chamber;
4 – nozzle; 5 – inlet channel; 6 – plunger with rod

The spray torch lies in the range of 20–600, and is formed by liquid droplets that are formed when it exits the nozzle opening at a short distance. A feature of the nozzle is that the slotted inclined channels 5 for supplying liquid to the swirl chamber of the nozzle 3 are placed so that both edges of the channel adjoin it tangentially, but on different sides of the axis. Such an entry of liquid into the swirl chamber contributes to the formation of a turbulent flow that moves in the direction of the nozzle 4 and flows out of it in the form of a dispersed jet.

Ejector design

Ejection processes were studied in jet devices of two types: with a compact and dispersed liquid jet. In the first case, the ejector had a geometric similarity with the ejector of a typical water sulfitator for the diffusion process. The criterion for the similarity of ejectors is the equality of the value of their main geometric characteristic m. The main dimensions of the studied ejector: nozzle diameter d_c = 4 mm, mixing chamber diameter D = 45 mm, which corresponds to the geometric characteristic of the water sulfitator ejector m = 126. An ejector with d_c = 4 mm and mixing chamber diameter D = 22 mm was also studied. Geometric characteristic m = 30.25.

The design of the ejector and the receiving chamber is shown in Figure 3.

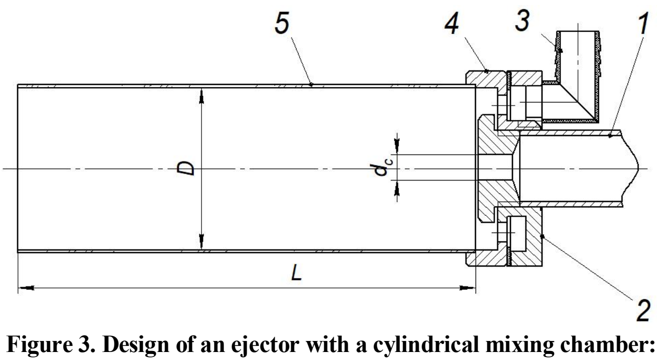


Figure 3. Design of an ejector with a cylindrical mixing chamber:
1– nozzle, 2 – cover, 3 – gas supply pipe,
4 – receiving chamber body, 5 – mixing chamber

This design of the ejector allows you to change the type of nozzle and install glass-mixing chambers of different diameters, which allows for experimental studies of ejection processes and visualization of the hydrodynamics of flows in ejectors with different geometric characteristics while maintaining the design of the receiving chamber. Table 1 shows the characteristics of the investigated ejectors and pressure ranges.

Table 1

Parameters of the investigated ejectors

Description of the ejector	Nozzle diameter, d_c, mm	Mixing chamber diameter, D, mm	Geometric characteristic m	Mixing chamber length, l, mm	Range of tested pressures, P, MPa
Compact liquid jet ejector	4	45	126	152	0.05–0.25
Ejector with dispersed liquid jet	4	45	126	152	0.05–0.25
Ejector with dispersed liquid jet	4	22	30.25	152	0.05–0.2

Design of an experimental setup for studying ejection processes

The design of the experimental setup is shown in Figure 4. The setup consists of a pump, a pipeline system, a liquid tank, shut-off and control valves, and control and measuring instruments. The liquid (water) flow rate was determined using a rotary flow meter (accuracy class 1.5). A sample pressure gauge (accuracy class 1.5) was used to control the liquid pressure in the nozzle. The gas (air) flow rate was measured using a rotary meter (accuracy class 1.5). A differential pressure gauge was used to determine the vacuum in the ejector receiving chamber.

The studies were conducted in a water-air environment at a phase temperature of 20 °C and a relative humidity of 85%. Changes in the ejector operating modes were carried out by adjusting the liquid pressure in the nozzle, which was controlled by a pressure gauge. During the studies, the readings of the liquid and gas flow meters at the beginning and end of the experiment, the liquid pressure in the nozzle and the vacuum in the receiving chamber were recorded.

Methodology and conditions of CFD modeling of ejection processes

For CFD modeling of ejection processes in ejectors with compact and dispersed liquid jets and different values of the main geometric characteristic m, the ANSYS CFX software package (ANSYS 2020 R2 with a maximum number of computational cells of 512,000) was used.

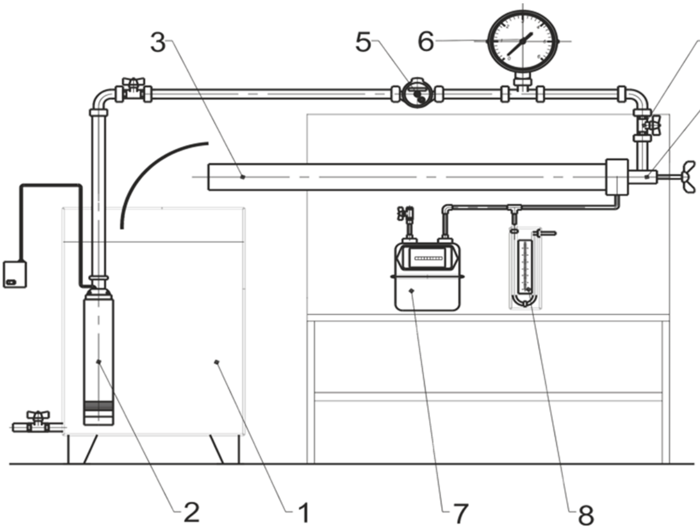


Figure 4. Design of the experimental setup: 1 – tank with liquid; 2 – pump; 3 – mixing chamber; 4 – nozzle with receiving chamber; 5 – liquid flow meter; 6 – pressure gauge; 7 – gas flow meter; 8 – differential pressure gauge

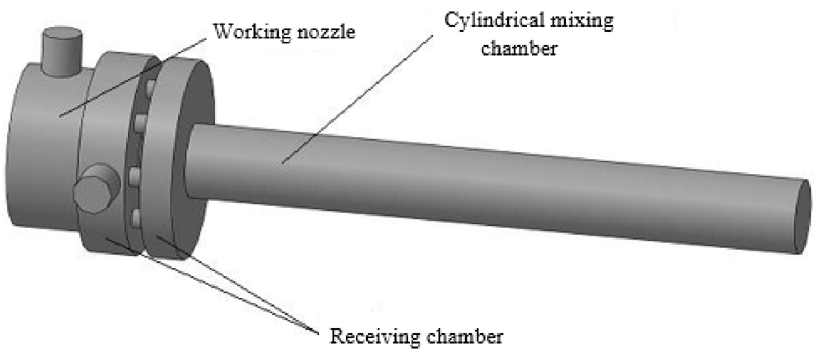


Figure 5. 3D model of the ejector

Figure 5 shows a 3D model (computational domain) of the investigated ejector. The boundary conditions for the simulation are (Figure 5): liquid inlet into the nozzle "Inlet_liquid", gas inlet into the receiving chamber "Inlet_gas", wall "Solid_wall" and outlet of the two-phase mixture from the mixing chamber "Mixture_Outlet".

Table 2 and Table 3 provide a list of parameters for CFD modeling of ejection processes.

Table 2

Basic parameters of CFD modeling of ejection processes

Indicator	Value
Calculation grid	Unstructured with a seal in the nozzle area and annular gap at the gas phase inlet to the mixing chamber. Maximum cell size is 4 mm, minimum size is 2 mm.
Task type	Non-stationary (Ansys, 2020)
Duration of computer calculation	0.5 s
Step between iterations	0.001
Criterion for convergence of results	0.0001
Calculation accuracy	Double precision
Work environments	Water and air
Turbulence model	*k-ε* (Dos Santos et al., 2019)
Multiphase flow model	Euler's "Mixture" model (Ansys, 2020; Ishii and Hibiki, 2011)
Initial simulation conditions	Zero speed components, Pressure P = 101325 Pa, Temperature t = 20 ºC The volume fraction of air is 1, i.e. 100% in the entire calculation area

Table 3

Boundary conditions of CFD modeling of ejection processes

Boundary condition name	Type of boundary condition	Parameters
Inlet liquid	Inlet	Mass flow rate of liquid: M = 0.2 kg/s Turbulence model parameters: k = 0.05, ε = 10 Volume fraction of component: water – 1, air – 0
Inlet gas	Inlet	Pressure P = 0 Pa Turbulence model parameters: k = 0.05, ε = 10 Volume fraction of component: water – 0, air – 1
Solid wall	Wall	No-slip wall
Mixture_Outlet	Outlet	Pressure P = 0 Pa

Results and discussion

Rarefaction in jet sulfitator

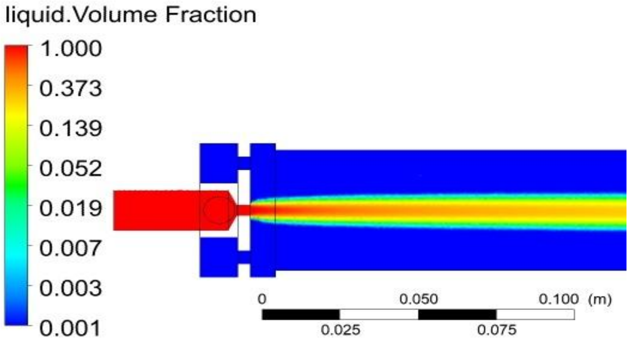
Comprehensive studies of ejection processes in a jet apparatus with geometric characteristics m = 126 (d_c = 4 mm, D = 45 mm) and a jet nozzle (compact liquid jet), which corresponds to the operation of a typical water sulfitator ejector for the diffusion process, were carried out. Figure 6a shows the liquid distribution in the ejector in the form of a compact jet along the ejector axis obtained using CFD modeling.

Confirmation of such liquid distribution is visual observation of the operation of an experimental ejector with the same geometric dimensions and a transparent mixing chamber (Figure 6b).

It should be expected that when an ejector with such geometric dimensions operates, the vacuum in the receiving chamber will be minimal or absent. This statement is based on the fact that to create an ejection effect, it is necessary to create a closed geometric region bounded by the walls of the mixing chamber and the outer contour of the spray torch (Zheng et al., 2017). If this condition is not met, then only the gas phase circulates within the mixing chamber (Mifsud et al., 2019). This conclusion is confirmed by the practice of operating a jet sulfitator (Ponomarenko et al., 2022), which shows that the wrong choice of geometric dimensions of the main elements of the ejector leads to loss of equipment performance. An unsuccessfully implemented idea of an ejector device can lead to the abandonment of this type of equipment.

Flow hydrodynamics modeling in the ANSYS CFX software package allows obtaining both a quantitative and qualitative picture of the pressure distribution in the cross-section of the mixing chamber (Kuś et al., 2024). Such data were obtained at a distance of 20 mm from the injector nozzle (Figure 7).

The calculations performed for this ejector show that the vacuum in this cross section is only 20–25 Pa. Such a vacuum is not enough for the equipment to operate effectively.



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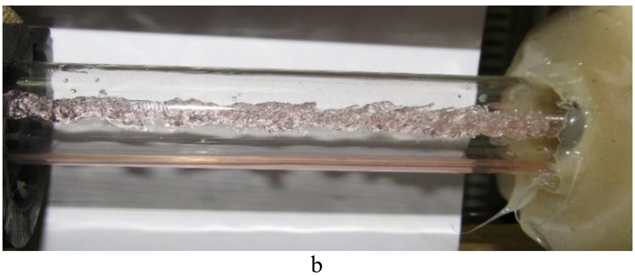

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Figure 6. Liquid distribution in an ejector with a jet nozzle and m = 126:
a – CFD modeling; b – experiment

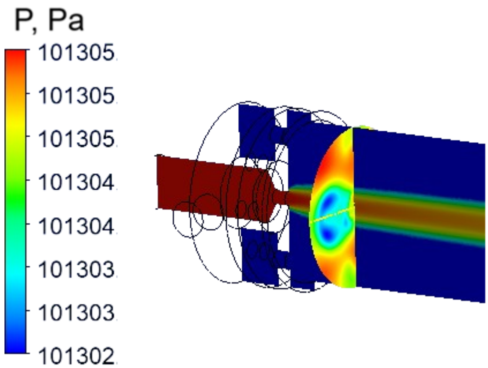


Figure 7. Gas phase pressure across the cross section of the mixing chamber

Eector with centrifugal jet nozzle

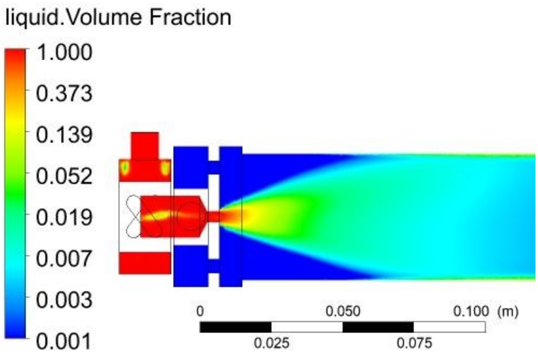
It should be noted that sulfitation is a heat and mass transfer process for the effective course of which requires a sufficient interfacial contact surface of the phases (Balamurugan et al., 2007), and according to Fick's law (Mauro, 2021), the amount of transferred substance is directly proportional to the size of this surface.

The jet nozzle does not provide the creation of a significant area of phase contact (Lyons et al., 2010), since mass exchange processes occur only on the outer side of the liquid flame (Zhou and Prosperetti, 2020). Therefore, it is proposed to change the type of nozzle from jet to centrifugal-jet. This will improve the course of the sulfitation process by significantly increasing the contact surface due to liquid dispersion. There are extremely few studies on the impact of such a replacement in the design of the ejector on ejection processes, they need to be clarified and deepened. The implementation of these tasks will allow solving the practical problem of optimizing the design of an industrial jet-type sulfitator.

Replacing the jet nozzle with a centrifugal jet nozzle with a dispersed liquid jet allowed us to radically change the pattern of liquid distribution in the ejector mixing chamber (Figure 8).

The liquid spray torch reaches the walls of the mixing chamber, which ensures the formation of a guaranteed zone of reduced pressure, and therefore the ejection of the gas phase. The results of CFD modeling and experimental research, shown in Figure 8, are in good agreement.

Figure 9a presents a visual picture of the pressure distribution in the cross section at a distance of 20 mm from the nozzle opening of the jet nozzle, and Figure 9b shows its graph. The results of the numerical experiment show the presence of rarefaction along the axis of the spray torch within 20-30 Pa, which decreases along the cross section of the torch, and on its surface the pressure is equal to the pressure in the ejector mixing chamber. This result is confirmed by experimental data (Chegini et al., 2025). It should also be noted that the rarefaction along the axis of the spray torch decreases with distance from the nozzle and disappears at a distance of about 150 mm. The obtained data on rarefaction in the spray flame near the nozzle explain the ejection of the gas phase into it.



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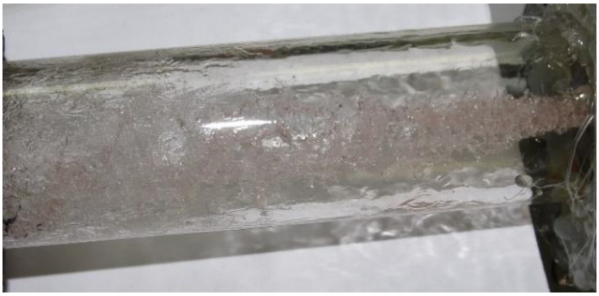

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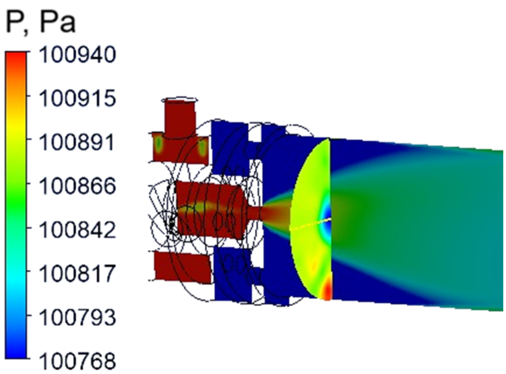
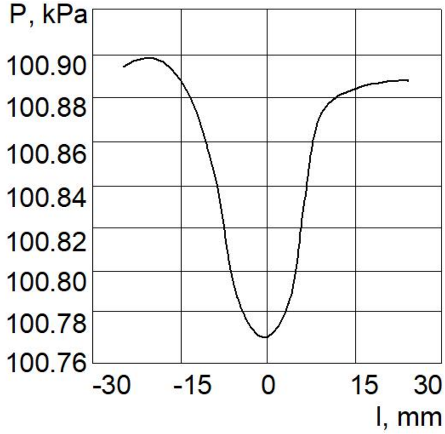
Figure 8. Liquid distribution in an ejector with a centrifugal jet nozzle and geometric characteristic m = 126: a – CFD modeling; b – experiment





a b

Figure 9. Gas phase pressure across cross section of the mixing chamber:
a - visualization of pressure distribution during CFD modeling at a distance of 20 mm;
b – pressure distribution in radial direction

Comparative characteristics of ejectors with jet and centrifugal jet nozzles

Comparison of the rarefaction along the axis of the spray jet for the jet and centrifugal-jet nozzles is presented in Figure 10. The obtained numerical values of the rarefaction in the cross section for the centrifugal-jet nozzle lie in the range of 425-555 Pa, which exceeds the rarefaction indicators for the jet nozzle (20-25 Pa) by an average of 20 times. The explanation for such a significant difference in the rarefaction along the axis of the spray jet lies in the features of its formation. During the centrifugal-jet outflow of liquid from the nozzle, there are two liquid flows: axial and centrifugal, which, when interacting, form a common flow. The second feature of such interaction is the rapid expansion of the spray jet and the formation of liquid droplets at a close distance from the nozzle (Vambol et al., 2020). In this case, the liquid droplets attach the corresponding part of the gas phase, and since the axial flow velocity is higher than the velocity of the liquid droplets moving along the peripheral trajectory, this results in a rarefaction, and it is greater along the axis of the torch. It is possible to predict that the higher the liquid spray pressure, the greater the axial velocity and the greater the rarefaction will be achieved.

When the liquid flows out of the nozzle in a jet, the spray angle is within 2-5°, i.e. the entire liquid moves almost at the same speed, dispersion on the drop occurs at a greater distance from the nozzle, which leads to the creation of a much smaller rarefaction.

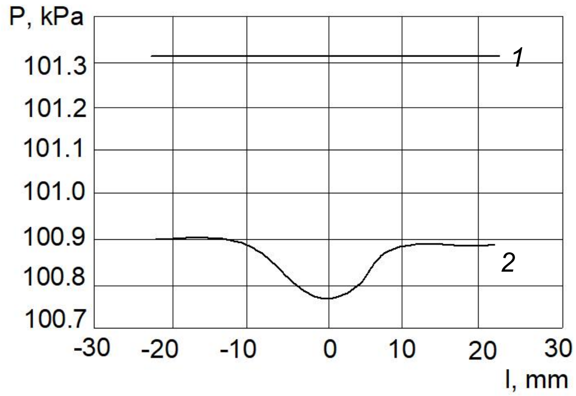


Figure 10. Comparative values of rarefaction for jet (1) and centrifugal jet (2) nozzles in radial direction

Thus, replacing the jet nozzle with a centrifugal jet nozzle with the same geometric characteristics of the ejector allowed stabilizing the operation of the sulfitation station.

Determination of rational characteristics of ejectors

As our research has shown (Figure 11), the value of the main geometric characteristic of the ejector m of the water sulfitator for the diffusion process in the sugar industry (m = 126) does not correspond to the optimal value at which the operation of the jet apparatus with the highest ejection coefficient is achieved. It was found that its rational value is in the range of 25–40.

Therefore, studies of ejection processes in ejectors with a centrifugal jet nozzle were continued in the zone of optimal values of geometric characteristics. At the same time, thanks to CFD modeling, results were obtained that are quite difficult to obtain experimentally.

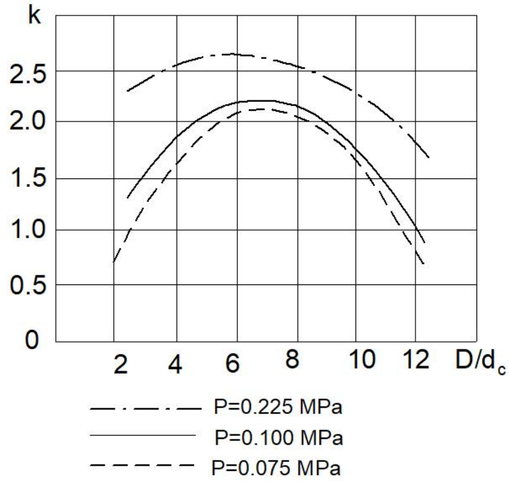


Figure 11. Dependence of volumetric ejection coefficient k on geometric dimensions of ejector D/d_c at different liquid pressures P

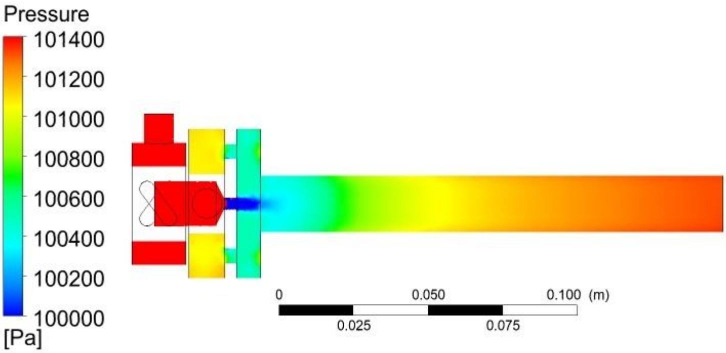
Patterns of mixed flow formation

Figure 12 shows the distribution of static pressure in the ejector at a mass flow rate of 0.2 kg/s, which corresponds to its pressure in the nozzle of 0.25 MPa with a nozzle diameter of 4 mm and a mixing chamber diameter of 22 mm (m = 30.25).

Under the conditions of the experiment, the static pressure in the nozzle is 250 kPa. When the liquid exits the nozzle, the static pressure drops sharply (Figure 12b) because of the conversion of potential compression energy into kinetic energy of the flow.

Analysis of the results obtained allowed us to establish that a zone of reduced pressure of 78–100.4 kPa appears in the receiving chamber and in the area 1.5D from the beginning of the mixing chamber. This guarantees the ejection of the gas phase and will definitely allow us to achieve stable operation of the sulfidation station (Kiên et al., 2025). This is the zone of primary formation of the mixed ejector flow, when the liquid spray jet expands and reaches the walls of the mixing chamber. A zone of reduced pressure is formed (Figure 9b), which is confirmed by the graph of Figure 12b.

The length of the low-pressure zone along the ejector axis is insignificant, which is the result of the reformatting of the mixed flow due to the impact of the droplets on the ejector wall (Siddiqui and Khan, 2025). Then, some of the liquid droplets move along the wall of the mixing chamber in the form of a liquid film, and the other part of the droplets changes the trajectory of movement, moves to the ejector axis, and again hits the opposite wall. Such a complex liquid flow contributes to the reformatting of the mixed flow, which is confirmed by Figure 13b.



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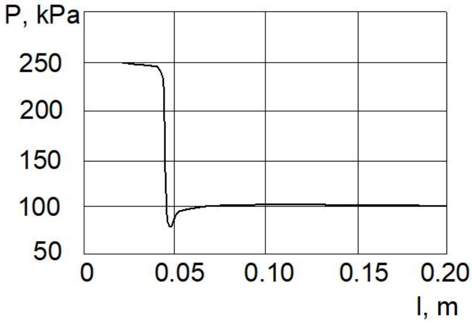
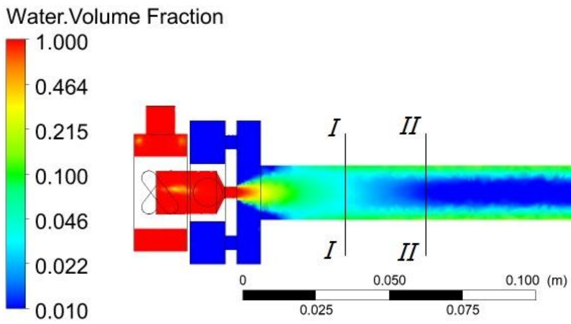


b

Figure 12. Static pressure distribution in the ejector:
a – static pressure on the ejector elements;
b – static pressure distribution graph along ejector axis

Figure 13 shows the distribution of the volume fraction of the liquid along the length of the ejector. At a distance of about 1.5D (section I-I) from the nozzle cut, the liquid droplets are evenly distributed over the cross section of the mixing chamber. Between zones I-I and II-II, the mixed flow is re-formed due to the impact of drops on the wall of the mixing chamber, and after the section II-II, a stable flow formation occurs. Along the axis of the mixing chamber, the volume fraction of the liquid is minimal, and near the wall, it is maximal, which is clearly visible from the graph in Figure 13b. The movement of the liquid in the mixing chamber corresponds to the annular flow regime.

The distribution of the liquid velocity along the ejector axis was obtained (Figure 14). According to the obtained graph, the maximum liquid velocity in the nozzle at the specified nozzle research parameters reaches 20 m/s (distance 0.05 m from the origin of coordinates, which is located on the inner wall of the nozzle). Due to the significant loss of energy for liquid dispersion at the outlet of the centrifugal jet nozzle (Ismailov et al., 2025), gas ejection and the initial formation of a mixed flow, there is a sharp decrease in the liquid velocity to 16 m/s and subsequently, due to the resistance to the movement of droplets in a gas medium (Basmanov et al., 2025) along the length of the mixing chamber, the liquid velocity at the outlet of the ejector decreases to 13.8 m/s.



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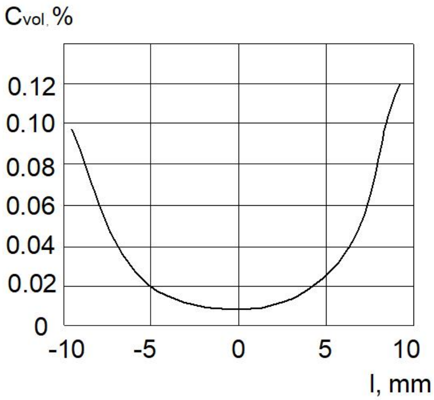


b

Figure 13. Distribution of the volume fraction of liquid in the ejector:
a – longitudinal section;
b – cross-section of mixing chamber at distance of 3D from its beginning

Since the Euler model "Mixture" (Ansys, 2020; Ishii and Hibiki, 2011) allows us to visualize the distribution of each phase, we will use this opportunity and present the distribution of the volume fraction of gas in the ejector (Figure 15).

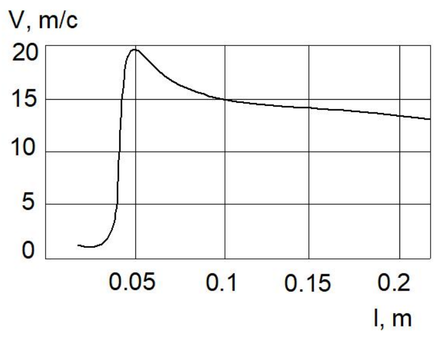
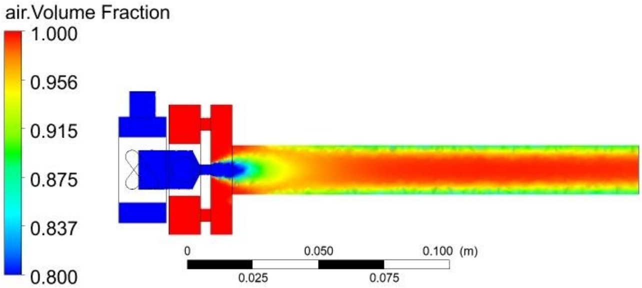


Figure 14. Liquid velocity distribution along the ejector axis



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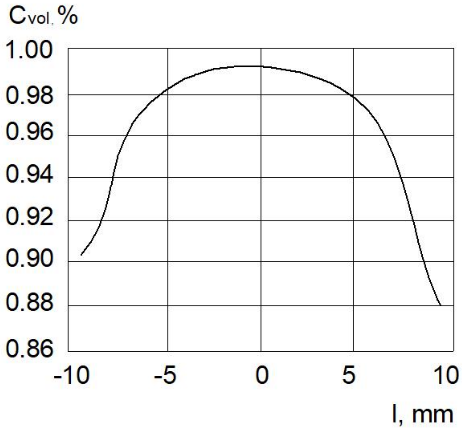

b

Figure 15. Distribution of the volume fraction of gas in the ejector:
a – longitudinal section;
b – cross-section of the mixing chamber at a distance of 3D from its beginning

The obtained results of gas distribution in the ejector correlate with the previously presented results of liquid phase distribution. At a distance of 1.5–3 D, gas ejection into the middle of the liquid flow occurs, and at a distance of more than 3D along the ejector axis, the volume fraction of gas is maximum (~90%), and when approaching the wall it gradually decreases to ~10%. Gas ejection into the middle of the sprayed liquid flow is explained by the presence of rarefaction. Analysis of phase distribution graphs in cross-sections of the mixing chamber shows the presence of a slight asymmetry of the flows relative to the axis, which is explained by the following reasons and can be eliminated by adjusting the dimensions of the ejector structural elements:

– deformation of the liquid jet under the influence of turbulence and rarefaction occurring in the ejector (Bhaduri et al., 2025);
– uneven distribution of the gas phase in the ejector receiving chamber (Jingyang et al., 2023);
– insufficient length of the nozzle swirl chamber, which leads to asymmetric distribution of liquid droplets in the spray jet (Zhu et al., 2014).

The obtained results are confirmed by the results of studies by other scientists. During experimental and theoretical studies of the ejector operation, it was found (Guangming et al.,

2010) that it can operate only in one optimal state with fixed geometric dimensions. We have established such an optimal operating mode for ejectors with a centrifugal jet nozzle in the range of geometric characteristic values 25–40.

As for the studies of mass transfer in the ejector, it was found that the geometric characteristics of the ejector (nozzle diameter, mixing chamber length, ratio of nozzle and mixing chamber diameters) significantly affect mass transfer (Cramers et al., 2001). Mass transfer processes depend on the physical properties of the liquid and the geometric parameters of the ejector, which are interconnected (Cramers et al., 2001). The volumetric mass transfer coefficient increases with an increase in the fraction of the gas phase (volumetric ejection coefficient) and the length of the mixing chamber. When studying the water-air ejector (Balamurugan et al., 2007), the optimal ratio of the area of the ejector throat to the area of its nozzle was established, which is 10. This value of the geometric characteristic is explained by the design features of the ejector. The mass transfer coefficient and the area of the interface surface increase with increasing velocity in the nozzle. The proposed correlation for predicting mass transfer agrees with experimental data ±20%. Ejectors used as mass transfer devices are particularly effective in the case of rapid or instantaneous chemical reactions (Cramers et al., 2001).

Studies of pressure distribution along the mixing chamber (Balamurugan et al., 2007; Li and Li, 2012) showed that a “shock” occurs at the beginning of the mixing chamber. That is, sharp changes in pressure, density and velocity lead to an intensive exchange of impulses of turbulent vortices. For ejectors of the gas-liquid system, the length of the “shock” section can be up to 6 diameters of the mixing chamber, which depends on the design of the ejectors. Such results confirm the presence of a zone of spray flame formation near the nozzle; however, the length of this zone is individual for ejectors of different designs.

Conclusions

A comparison of experimental and CFD studies on the operation of liquid-gas ejectors during the sulfitation of sugar solutions using jet and centrifugal-jet nozzles was carried out, confirming the reliability of CFD modeling for predicting hydrodynamic characteristics. When a centrifugal-jet nozzle was used in a typical jet sulfitator, the vacuum at a distance of 20 mm from the nozzle reached 425–555 Pa, approximately 20 times higher than the 20–25 Pa observed for a standard jet nozzle. This has been demonstrated for the first time under sugar solution sulfitation conditions. The rational range of the ejector geometric characteristic for a centrifugal-jet nozzle was found to be m = 25–40, ensuring stable rarefaction of 78–100.4 kPa and guaranteed ejection of the gas phase; previously, a value of m=126 was used in sugar industry devices, which proved ineffective. These results can be applied to the development of new jet sulfitator designs with increased efficiency, contributing to reduced SO_2 emissions and improved quality of the final product.

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