12. Bykov, L. V. Vychislitel'naya mehanika sploshnyh sred v zadachah aviacionnoy i kosmicheskoy tehniki [Text] / L. V. Bykov, A. M. Molchanov, M. A. Shherbakov, D. S. Janyshev. – Moscow: LENAND, 2015. – 668 p.
13. Menter, F. R. Two-equation eddy-viscosity turbulence models for engineering applications [Text] / F. R. Menter // AIAA Journal. – 1994. – Vol. 32, Issue 8. – P. 1598–1605. doi: 10.2514/3.12149
14. Jun, A. A. Teoriya i praktika modelirovaniya turbulentnyh techeniy [Text] / A. A. Jun. – Moscow: Librokom, 2009. – 274 p.
15. Svechnikov, V. S. Aerodinamicheskie harakteristiki stupeni osevogo kompressora [Text] / V. S. Svechnikov, A. B. Kirillov. – Moscow: CAGI, 1958. – 94 p.
16. Boiko, A. V. Primenenie vychislitel'noi aerodinamiki k optimizacii lopatok turbomashin [Text] / A. V. Boiko, Ju. N. Govorushhenko, M. V. Burlaka. – Kharkiv: NTU «KhPI», 2012. – 192 p.

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COMPUTER SIMULATION OF HYDRAULIC FLOW IN A MIXING DEVICE WITH A DIAPHRAGM OF SPECIAL DESIGN INSTALLED IN IT

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Наведено результати комп'ютерного моделювання гідравлічного потоку в змішувальному пристрої з діафрагмою спеціальної конструкції. За допомогою пакета програмного забезпечення «FlowVision» (м. Москва, Російська Федерація) отримані віртуальні моделі потоку, показані та змодельовані епюри розподілу тиску, швидкостей і турбулізація потоку. Ці фактори зумовлюють активне і повне перемішування розчину реагенту та оброблюваної води

Ключові слова: статичний змішувач, комп'ютерне моделювання, епюра розподілу тиску і швидкостей, турбулентна дисипація

Приведены результаты компьютерного моделирования гидравлического потока в смесительном устройстве с диафрагмой специальной конструкции. С помощью пакета программного обеспечения «FlowVision» (г. Москва, Российская Федерация) получены виртуальные модели потока, показаны и смоделированы эпюры распределения давления, скоростей и турбулизация потока. Эти факторы обуславливают активное и полное перемешивание раствора реагента и обрабатываемой воды

Ключевые слова: статический смеситель, компьютерное моделирование, эпюра распределения давления и скоростей, турбулентная диссипация

1. Introduction

When coagulating water impurities, a rapid and even distribution of reagents in its volume is necessary. This ensures maximum contact of impurity particles with intermediate products of the coagulant hydrolysis. The formed hydrolysis products exist for a short time. Such short period of time is due to the fact that the processes of hydrolysis, polymerization and adsorption occur within 1 s [1, 2].

Perkinetic coagulation ends when the particles reach size of 1...10 µm, which practically coincides with the period of rapid distribution of the coagulant in the water treated in mixers. Inefficient mixing leads to an over-consumption of coagulant and a low agglomeration rate of water impurities at a given dose of reagent. Therefore, it is necessary to create an optimum operating mode of the mixers in which the coagulant would come into contact with a maximum number of particles of water impurities before hydrolysis and polymerization reactions terminate.

To uniformly and quickly mix reagents with water, one should introduce them in the zones of the greatest turbulence of the flow at several points of its cross section. To mix the reagent with water, it is necessary to provide reagent distributors (reagent injection devices) and mixers. These devices ensure a rapid and uniform distribution in the feed channel or pipeline. A subsequent intensive mixing of the reactants with the treated water takes place in the mixers. Reagent distributors are recommended to be made in a form of perforated tubular systems or inserts in the pipeline, which serve as local resistance.

Mixing of reagents with the treated water is carried out in mixing devices (Venturi nozzles, diaphragms), pipe mixers or in special mixing structures. The mentioned devices must satisfy requirement of fast and complete mixing of reagents with the entire mass of water (i. e., water residence time is 1...3 min.) [1].

One of the most effective solutions ensuring mixing wastewater with reagents was realized in static mixers. This is due to a number of technical and economic advantages of static mixers in comparison with the conventional capacitive mixing devices.

Application of modern technologies and computer modeling makes it possible to develop new and improve existing designs of static mixers. Such approach will ensure theoretical preconditions for explaining the processes taking place in hydrodynamic flows. Visualization ability of the obtained models of fluid flows makes it possible to confirm results of field experiments.

2. Literature review and problem statement

Available sources contain a rather large number of different solutions on this subject. One of the most common types of mixers is a static mixer in two variants:

– static mixers without mixing diaphragms;

– static mixers with mixing diaphragms.

Authors of work [3] assert that the decrease in the efficiency of wastewater treatment in the dairy industry is associated with a number of reasons:

– introduction of expired dairy products (concentrated waste water) directly into the wastewater treatment line;

– anaerobic reactions in the system because of existence of underground reservoirs;

– absence of preliminary cleaning and aeration elements;

– use of low-quality coagulants and flocculants, etc.

However, one of the most important causes of reduction in efficiency of purification of this wastewater is the lack of a qualitative mixing of effluents with reagents.

Materials of work [4] show advisability of sewage treatment at dairy industry enterprises by biological methods, in particular, in anaerobic bioreactors. In doing this, preliminary physical-chemical purification is carried out with the help of a flotator. The flotation scum collected from this flotator is a source for producing an energy carrier. Therefore, intensive and proper mixing of effluents and reagents in the flotator promotes more full cycle of production of an energy carrier (biogas).

The paper [5] presents the results of studies in flotation scum after physical-chemical purification of wastewater from three dairy enterprises. According to the conducted experiments, the amount and quality of the formed sediment (flotation scum) depend on the initial quality of wastewater, the reagent dose and completeness of mixing the flow with the reagent.

The experiments presented in [6] confirmed that with the use of a static flow mixer, the pressure drop depends on the form factor of the elements of the packed bed and the characteristics used. In general, it is observed that with a decrease in the size of the pack, hydraulic resistance increases which can be explained by a decrease in the size of the channels formed in the packed bed and an increase in tortuosity.

Materials of work [7] include and discuss the types of mixing devices for mixing various types of liquids. A comparative analysis of efficiency of these mixers under laminar and turbulent flow regimes was made. Recommendations were given concerning the use of various types of mixers in engineering practice. Publication [8] examined approach to the estimation of efficiency of static flow-type pack mixers based on using the analogy of turbulent momentum and mass transfer. From the expressions obtained, calculations of mixers with various packs were made for determining the effective mixing ratio.

The authors of [9] simulated hydrodynamic flow in a static centrifugal mixer with the help of a computer program which allowed them to obtain a complete information on the processes taking place and improve the mixer.

Visualization and modeling of the process of mixing wastewater and reagent will enable a more complete substantiation of the design of the mixer to be used. Computer simulation of the process will provide an opportunity to study basic hydrodynamic flow parameters in mixers.

3. Research goal and objectives

The objective of this study was a theoretical justification of intensification of the process of mixing wastewater of a milk processing enterprise with a coagulant in a static mixer with a specially designed diaphragm installed in it. This will make it possible to confirm results of the actual experiments, shorten time for the experiment and obtain a visual representation of the main hydrodynamic flow parameters of mixers.

To achieve this goal, it was necessary to solve the following main tasks:

– perform computer simulation of the process of mixing the coagulant with treated wastewater using a special design of the mixing diaphragm in the reagent mixing unit with the help of FlowVision software (Moscow, Russian Federation);

– obtain virtual flow models using various types of mixers and present a comparative characteristic in three main parameters: distribution of pressure, velocity and flow turbulization;

– study the obtained diagrams of distribution of pressure and velocities in order to determine an optimum type of mixer, which would ensure mixing of wastewater with the reagent as fully as possible and quickly.

4. The materials and research methods used in computer simulation of hydraulic flow in mixers

FlowVision software package (Moscow, Russian Federation) [10] was used to simulate the process of mixing the treated wastewater with a reagent in a mixer with a diaphragm of a special design.

To construct hydrodynamic models of fluid flows, three types of mixers were imported into the program in a three-dimensional image. Then pipeline parameters were set. The point of reagent entry in the mixing line and the mixer location were set. The entire system was represented in the program by a three-dimensional image.

The next step was to enter the flow parameters:

– density, temperature and consumption of the wastewater model;

– density, temperature and consumption of the reagent model.

According to the parameters, which were set, the program calculated basic hydrodynamic parameters of the flow: velocity, pressure, and turbulent dissipation in a given system. Based on the calculation results, diagrams of these hydrodynamic flow parameters were constructed. The program functions have made it possible to obtain three-dimensional visual images of flow hydrodynamics.

5. Results of the computer simulation of hydraulic flow in mixers

A special design of static mixer (diaphragm) was used in the conducted studies to intensify the process of mixing the reagent solution and its more full contact with the treated wastewater of the milk processing enterprise (Fig. 1) [11, 12].

The mixing diaphragm, which creates differential pressure was mounted in a pipe. A part of the stream was directed into the bypass pipeline ahead of the diaphragm. A concentrated coagulant solution was injected into the pipeline wherein the solution was mixed with the part of the wastewater flow. The taken part of the flow with the coagulant was returned to the main pipeline immediately after the exit from the diaphragm into the zone of intense vortex formation.

Computer simulation of the mixing process was performed in this work using this diaphragm of a special design (Fig. 1) and mixing devices of the most common designs: pipe and orifice mixers. To study parameters of the obtained streams, the pressure and velocity changes in the flow were taken in front and behind the mixers. Turbulent dissipation of the flow was studied in its passage through the mixers of various designs.

The FlowVision software package (Moscow, Russian Federation) was used in computer modeling and construction of diagrams of speed distribution in a mixing device. This software package assures simulation of the liquid and gas flows in real conditions. The program functions enable running of "what if" scenarios and an effective analysis of the influence of fluid flow, heat transfer and associated forces on the immersed or surrounding components. The FlowVision package makes it possible to compare options in making more substantiated decisions and obtain products with improved characteristics [9].

Initial data for modeling:

– dimensions of the computational grid: 50×50×100 (250,000 nodes);

– nominal wastewater discharge rate: 36 m^3/h;

– nominal consumption of coagulant: 0.36 m^3/h;

– pipe mixer: D_y80 W50 K15;

– orifice mixer: D_y80 K15;

– static mixer: D_y80 K20.

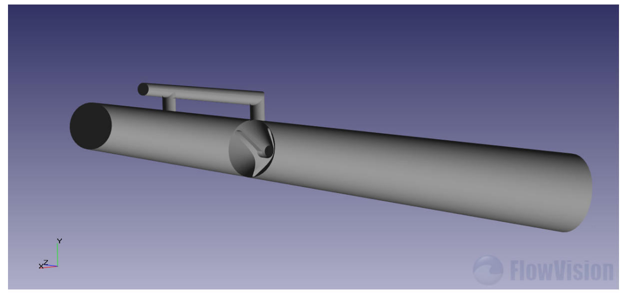


Fig. 1. Static mixer (the model physical appearance) with an installed diaphragm of a special design (a three-dimensional model)

The computer simulation of the mixing process was based on a model having appearance as shown in Fig. 1. In the course of computer modeling, diagrams of distribution of pressure, velocities and turbulent flow dissipation were obtained. Fig. 2–4 present models of flow distribution in a mixing device with a diaphragm of a special design installed in it [12]. The diaphragm design includes the following technical solutions:

– the mixer has an inlet and an outlet openings connected with each other with a channel to form at least two guide vanes and one obstructive vane;

– the obstructive vane has a guide section inclined to the flow and an obstructive section perpendicular to the flow, the obstructive section being located in the flow section center;

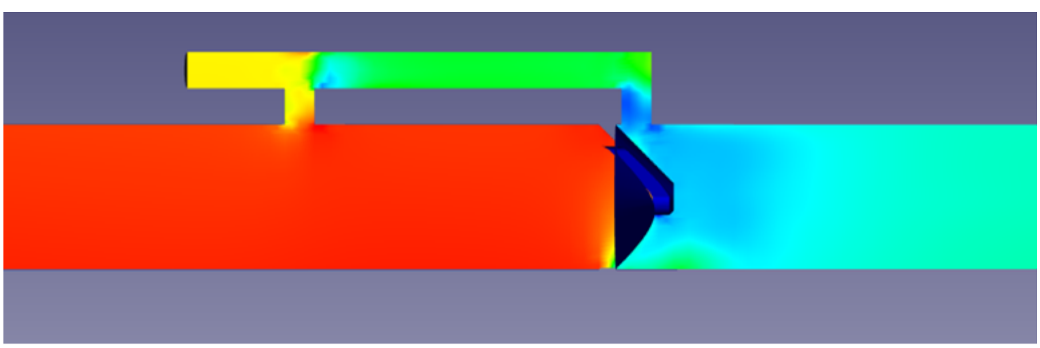
– the coagulant injection zone is located immediately behind the obstructive vane;

– the diaphragm has an aperture for receiving the bypass pipeline;

– both ends of the bypass pipeline are connected with the waste water supply pipeline, one of the ends being fixed in front of the diaphragm and the other is fixed in the diaphragm aperture;

– the inlet aperture of the diaphragm narrows in the direction of waste liquid flow.

The same models were calculated and constructed for using pipe (Fig. 5–7) and orifice (Fig. 8–10) mixers. This made it possible to compare the mixing process with various mixer designs.



Name	Value
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Block	Movement
Phase	All phases
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Local minimum	-12211.5029
Global maximum	21513.2188
Global minimum	-36535.0273

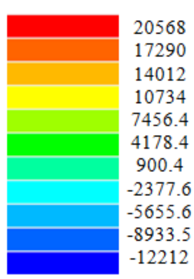
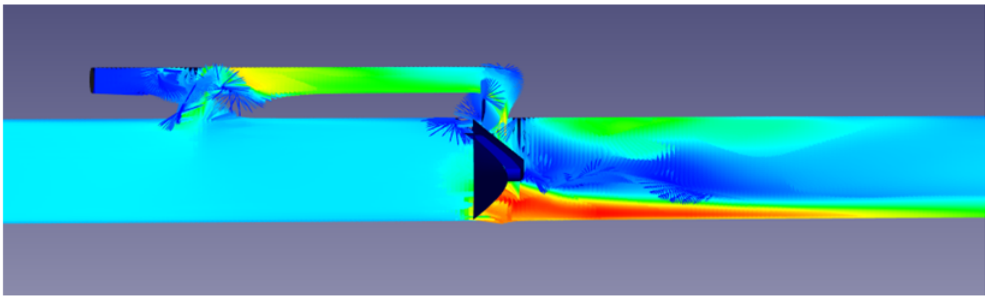


Fig. 2. Diagram of pressure (Pa) distribution in a static mixer in the case of installing the diaphragm of a special design: longitudinal section



Name	Value
Addit. variable	VEL
Block	Movement
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Component	Length
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Local minimum	0.0528591909
Global maximum	10.671275139
Global minimum	0

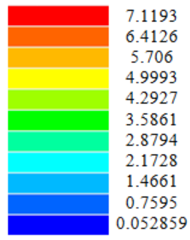
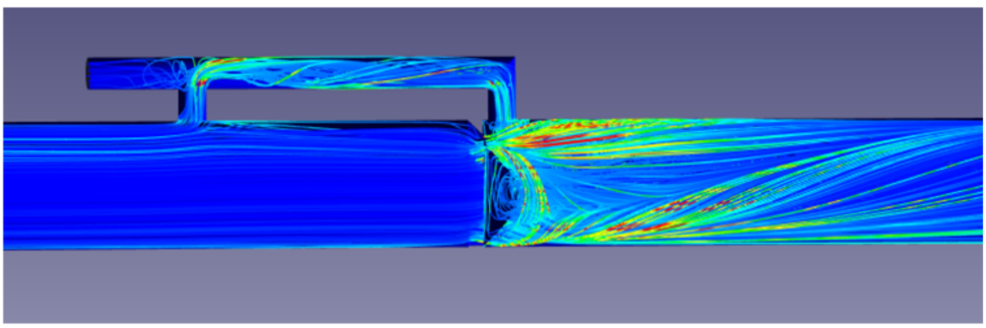


Fig. 3. Diagram of velocity (m/s) distribution in a static mixer in the case of installation in it the diaphragm of special design: longitudinal section



Name	Value
Addit. variable	OMEGA
Block	Turbulence
Phase	All phases
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Local minimum	1.000009
Global maximum	101813.8692
Global minimum	1

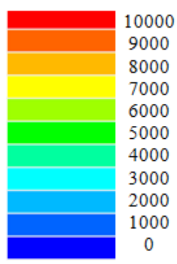
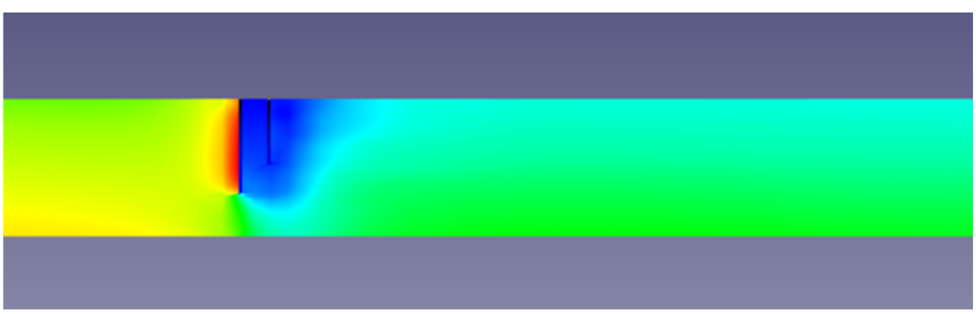


Fig. 4. Simulation of the process of turbulent dissipation (s^{-1}) in a static mixer in the case of installing in it the diaphragm of a special design: top view and longitudinal section



Name	Value
Addit. variable	PRES
Block	Movement
Phase	All phases
Local maximum	20568.2617
Local minimum	-12211.5029
Global maximum	21513.2188
Global minimum	-36535.0273

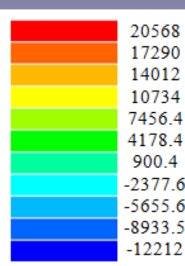
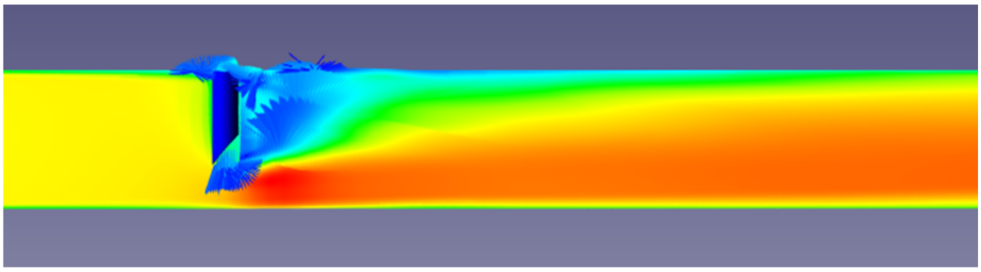


Fig. 5. Diagram of pressure (Pa) distribution in a pipe mixer: longitudinal section



Name	Value
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Block	Movement
Phase	All phases
Component	Length
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Global maximum	3.199871
Global minimum	0

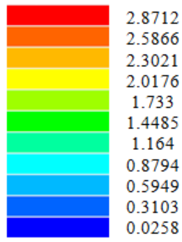
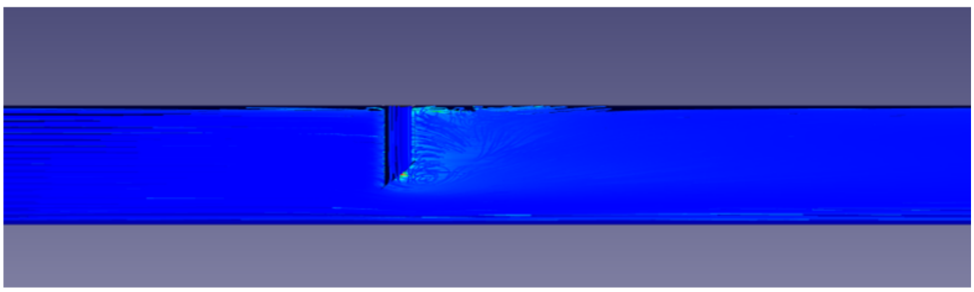


Fig. 6. Diagram of velocity (m/s) distribution in a pipe mixer: longitudinal section



Name	Value
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Block	Turbulence
Phase	All phases
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Local minimum	1.00013
Global maximum	59354.29823
Global minimum	1

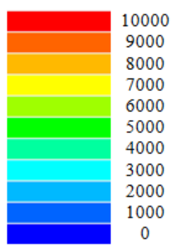
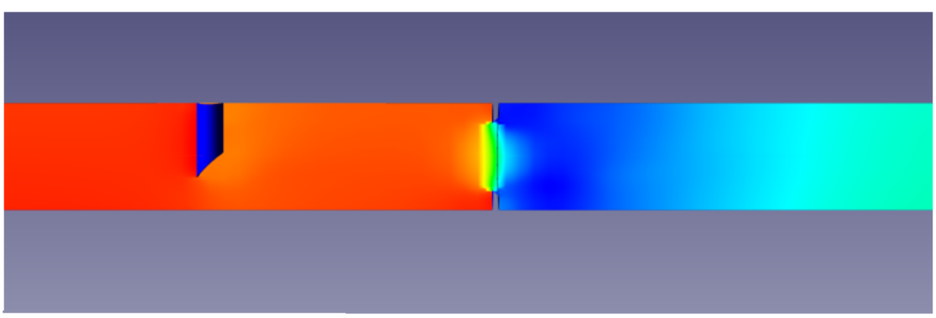


Fig. 7. Simulation of the process of turbulent dissipation (s^{-1}) in a pipe mixer: longitudinal section



Name	Value
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Block	Movement
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Global minimum	-15739.0518

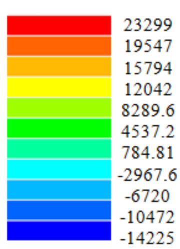
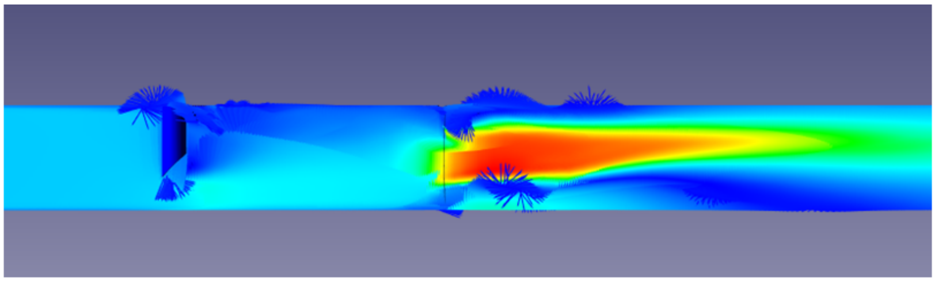
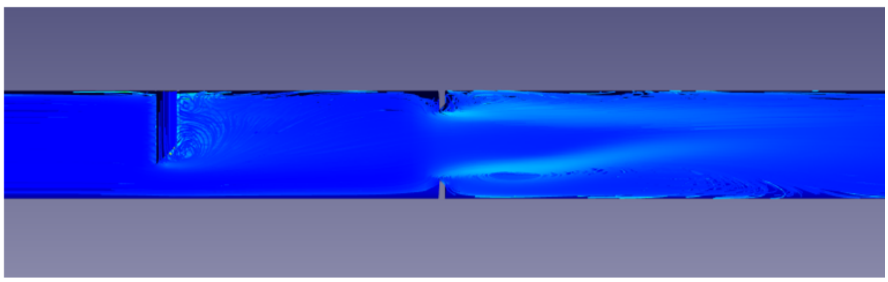


Fig. 8. Diagram of pressure (Pa) distribution in the orifice mixer: side view and three-dimensional image



Name	Value
Addit. variable	VEL
Block	Movement
Phase	All phases
Component	Length
Local maximum	8.814197
Local minimum	0.023616
Global maximum	8.97735
Global minimum	0

Fig. 9. Diagram of velocity distribution in the orifice mixer: longitudinal section



Name	Value
Addit. variable	OMEGA
Block	Turbulence
Phase	All phases
Local maximum	30474.2383
Local minimum	1.0001
Global maximum	60204.9578
Global minimum	1

Fig. 10. Simulation of the process of turbulent dissipation (s^{-1}) in the orifice mixer: longitudinal section

Application of the FlowVision software package has made it possible to create hydrodynamic flow models for three types of mixers: a mixer with the proposed diaphragm design, a pipe mixer and an orifice mixer. Information was obtained on the hydrodynamic processes, which took place. At the same time, design and technological parameters of these types of mixers were taken into account.

In the long run, computer simulation of flows in the mixing devices of various types has made it possible to significantly reduce time for conducting studies (inconcrete statements are unacceptable) and confirm the results of field experiments [11].

6. Discussion of the results of computer simulation of hydraulic flow in mixers

As a result of study of the obtained visual models, one can distinguish the following features of pressure distribution:

– when the flow passes through the diaphragm of the proposed design, pressure change across the entire cross section of the pipeline was observed. Hence, the whole flow was stirred (Fig. 2);

– only a small area where pressure change was observed in the tube mixer in an immediate vicinity of the point where the coagulant solution was injected but pressure changes were insignificant in the main flow (Fig. 5);

– with the use of an orifice mixer in an immediate vicinity of the washer orifice, vacuum formation zones were noticeable which is an indication of intensive agitation of the flow (Fig. 8). However, there were greater hydraulic resistances than when using the diaphragm of a special design.

Analysis of the diagrams of velocity distribution when various types of the mixing device designs were used has resulted in observation of the following distinctions:

– when using the diaphragm of special design (Fig. 3), maximum velocity reached 7.12 m/s. More or less uniform distribution of equal flow velocities was noticeable over the entire perimeter of the pipeline at a small distance from the mixer. The latter indicates a complete and intensive mixing of the and coagulant solution flows;

– velocity reached only 2.87 m/s in the pipe mixer (Fig. 6). Immediately near the point of introduction of the reagent solution, mixing takes place only in the lower section of the pipeline. Velocities distribution was extremely uneven indicating a non-uniform and incomplete mixing of the treated water with the coagulant solution;

– when the orifice mixer was used, the flow rate reached 8.81 m/s (Fig. 9). The core of velocity was in the center of the flow, which indicates intense mixing at the center of the pipeline section. However, a part of the flow at the walls of the pipeline (at its periphery) will be mixed less intensively at speeds from 0.02 to 0.9 m/s. The flow will be mixed incompletely and unevenly.

When studying the turbulent flow dissipation when using various types of mixing devices (Fig. 4, 7, 10), it can be noted that the maximum vortex formation was achieved by using the diaphragm of a special design. An intensive mixing of practically entire volume of the mixture was noticeable in the pipeline in an immediate vicinity of the mixer. When using a pipe mixer, vortex formation was negligible and concentrated at the coagulant injection point. When using an orifice mixer, one could notice intensive mixing only at the center of the flow but the zones at the walls of the pipeline, where there was practically no turbulence and mixing were observed.

7. Conclusions

1. Virtual models of hydraulic flows were obtained with the help of the FlowVision software (Moscow, Russian Federation). The flow was formed during coagulant and waste water mixing. Virtual flow models were obtained for three types of mixers: a mixer with a diaphragm of special design, a pipe mixer and an orifice mixer.

2. Of the above virtual models, the best results of intensive flow mixing were obtained when using a mixer with a specially designed diaphragm and with an orifice mixer. This was evidenced by the diagrams of distribution of pressure and velocities in these mixers. However, when using an orifice mixer, intensive mixing could only be noticed in the center of the flow and zones were observed at the walls of the pipeline where there were practically no turbulence and mixing respectively. In the pipe mixer, only a small region was observed where pressure and velocity varied. This region is located in the immediate vicinity of the point of injection of the coagulant solution. These parameters change insignificantly in the main flow.

3. The study of the obtained diagrams of distribution of pressures and velocities enables a conclusion that the proposed diaphragm design provides more effective mixing of waste water with the reagent as compared to the pipe and orifice mixers. This diaphragm makes it possible to mix wastewater with the reagent as fully and quickly as possible.

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References

1. Mixing of coagulants with water [Electronic resource]. – Pology chemical plant "Coagulant". – Available at: http://coagulant-producer.com/
2. Shevchenko, T. A. The Intensification of the flotation unit in a wastewater treatment of dairy industry [Text] / T. A. Shevchenko, A. A. Shevchenko // Visnyk Odes'koyi derzhavnoyi akademiyi budivnytstva ta arkhitektury. – 2015. – Issue 59. – P. 151–156
3. Babatola, J. O. Failure Analysis of a Dissolved Air Flotation Treatment Plant in a Dairy Industry [Text] / J. O. Babatola, K. T. Oladepo, S. Lukman, N. O. Olarinoye, I. A. Oke // Journal of Failure Analysis and Prevention. – 2011. – Vol. 11, Issue 2. – P. 110–122. doi: 10.1007/s11668-010-9430-z
4. Wastewater treatment in the dairy processing industry – recovering energy using anaerobic technology [Electronic resource]. – Available at: http://envirochemie.com/cms/upload/downloads-en/fachbeitraege/Whitepaper_Wastewater_treatment_in_the_dairy_processing_industry_.pdf
5. Boruszko, D. Research on the Effectiveness of the Flotation Process and Properties of Flotation Sludge from Dairy Wastewater Pretreatment [Text] / D. Boruszko, W. Dabrowski // Inzynieria i Ochrona Srodowiska. – 2014. – Vol. 17, Issue 2. – P. 269–280.
6. Alekseev, K. A. Experimental study of the hydraulic characteristics of flow static mixer Packed [Text] / K. A. Alekseev, A. G. Muhametzyanova, A. V. Klinov, M. I. Farahov, S. M. Kirichenko // Vestnik Kazanskogo tekhnologicheskogo universiteta. – 2013. – Vol. 16, Issue 7. – P. 212–216.
7. Mixing and Reaction Technology. Pace Setting Technology [Electronic resource]. – Available at: http://www.sulzer.com/lv/-/media/Documents/ProductsAndServices/Mixpac_Cartridges_Applications_Static_Mixers/Static_Mixers/Brochures/Mixing_and_Reaction_Technology_e_23270640.pdf
8. Laptev, A. G. The Efficiency of turbulent mixing of media in a Packed flow-through mixers [Text] / A. G. Laptev, M. I. Farakhov, O. G. Todorovska // Electronic scientific journal "Oil and gas business". – 2012. – Issue 4. – P. 387–408.
9. Tishin, O. A. Analysis of the mixer in the "FlowVisison" [Text] / O. A. Tishin, V. N. Kharitonov // News of Volgograd state technical University. – 2012. – Vol. 1, Issue 5. – P. 80–83.
10. FlowVision. User's manual (Version 3.09.0.) [Text]. – Moscow: LLC "TESIS", 2015. – 1294 p.
11. Shevchenko, T. A. Experimental investigation of intensification of the process of dissolved-air flotation in wastewater treatment of milk processing enterprises [Text] / T. A. Shevchenko, A. A. Shevchenko // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 1, Issue 6 (79). – P. 4–12. doi: 10.15587/1729-4061.2016.60121
12. Pat. No. 147134. Device for coagulation waste liquid [Text] / Shevchenko A. A. et. al.; Federal service for intellectual property (ROSPATENT). Patent of "EKOTON". – declareted: 10.07.2014; published: 26.09.2014.