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https://doi.org/10.26906/znp.2018.50.1076

УДК 622.7

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STATIC MIXERS IN FLUSHING FLUID CIRCULATION SYSTEMS OF DRILLING RIGS

The work of three static mixer designs in flushing fluid circulation systems of drilling rigs was studied taking into account the basic parameters of drilling mud. Modelling was carried out, and parametric slurry fields were obtained in the pipe work area, that is in a static mixer installation site and in the area of pipeline behind it. The following models were obtained: velocity fields, vorticity fields, turbulence intensity fields, scale turbulence fields along the travel path. Graphs of the parameters changes regarding the tube axis were plotted. The comparative analysis of patterns and curves was carried out. The rational design of static mixer for obtaining of optimum mud mixing technology features is grounded.

Keywords: *static mixer, mud, modelling, vorticity field, turbulence intensity, turbulence scale.*

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СТАТИЧНІ ЗМІШУВАЧІ В ЦИРКУЛЯЦІЙНИХ СИСТЕМАХ ПРОМИВАЛЬНОЇ РІДИНИ БУРОВИХ УСТАНОВОК

Досліджено роботу трьох конструкцій статичного змішувача в циркуляційній системі промивальної рідини бурових установок, ураховуючи основні параметри бурового розчину. Виконано моделювання та отримано параметричні поля гідросуміші у робочій зоні труби, а саме в місці установки статичного змішувача і в зоні трубопроводу за ним. Отримано моделі: поля швидкостей, поля завихреності, поля інтенсивності турбулентності, поля масштабу турбулентностей по довжині шляху перемішування. Побудовано графіки зміни досліджуваних параметрів відносно осі труби. Виконано порівняльний аналіз моделей та кривих. Обґрунтовано раціональну конструкцію статичного змішувача для отримання оптимальних технологічних характеристик перемішування бурового розчину.

Ключові слова: *статичний змішувач, буровий розчин, моделювання, поле завихреності, інтенсивність турбулентності, масштаб турбулентності.*

Introduction. In recent times static mixers are widely used in a number of industries, due to their advantages, including a large number of possible options for design solutions, the lack of moving parts, drive units, power consumption, possibility of hydro and pneumatic-transport networks combination, as well as a variety of technological features, which they are able to perform: gaseous, liquid and loose solidphase components mixing, dispersing of solidphase components in poor and immiscible liquids, solidphase flocculation in fluid flows, intensification of the reagents dissolving in liquids, etc. [1].

In the flushing fluid circulation systems we use different designs of mechanical agitators, such as blade, rotary, ball ones and others. Static mixers are seen to be promising [2]. However, their design should meet the requirements of effective drilling mud mixing with reagents, to integrate into existing hydrotransport communications of the drilling rig circulation system of the surface complex. To attain this purpose it is important to perform the study of the static mixer effect on slurry parametric fields, including speed and vortacity.

Analysis of recent research and publications of sources. Development of technical solutions and active static mixers research starts in 1980 – 90 [1, 3, 4]. In [1] it is emphasized that the construction of static mixers of the first generation was based mainly on intuition with the following empirical approbation of options. The best of them was chosen on the basis of comparative analysis. Instead, modern technology widely uses slurry flow modelling. In [5], numerous tools for analyzing complex mixing devices were developed, 3D. Calculations are based on the finite elements method. In [6], the author using methods of computational dynamics of fluid for modelling showed that the static mixer forms a complex vorticity system which includes a stationary longitudinal vortex flow and transient (secondary) flows (vortexes) that, according to V. G. Levich [7], can be considered as a developed turbulence.

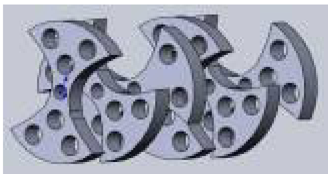
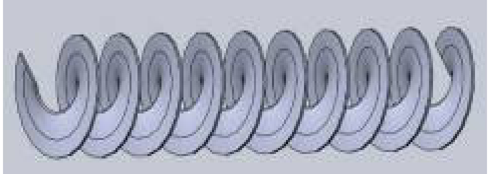
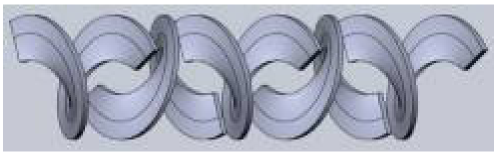
In [8], the dependence of pressure drops in turbulent flow (Re = 1000 – 5000) created in a static mixer, away from the number Re, was studied. In [9], the Kenics static mixer in a wide range of turbulent flow (Re = 1 – 25000) was examined. The picture of the velocity field and pressure difference for three modifications of the Kenics-mixer and flow of liquid and air was obtained by a picture of the velocity field and pressure difference for three modifications Kenics-mixer and flow of liquid and air was obtained by numerical modelling. In [10], the authors use «mixing efficiency» as the description of the static mixer and show its dependence on power spent on mixing, and the difference in pressure in the mixer. Using the method of mirror images the calculations of parametric mixer fields were carried out. On the base of their comparative analysis is was shown that different designs of static mixer determine different models of mixing, which are called «global» and «local». Optimization of the mixer geometry to provide the necessary process parameters was carried out.

Accentuation of unsolved before aspects of the problem. However, in domestic and foreign practice studies of static mixer in flushing fluid circulation systems of drilling rigs are unknown.

Setting objectives. The aim of this research is to study the design of three non-newtonian fluid static mixers with the following parameters of mud: density – 1250 kg/m^3, dynamic viscosity – 0.02 cPs with the use of the Flow Simulation module of Solid Works software environment.

Basic material and results. The study is provided for the design of three static mixers belonging to different classes of devices (Table 1).

Table 1 – Investigated objects «pipeline – static mixer»

Number of the experiment	Design description	3D-model mixer
1	Pipe Ø114x9 mm	Without mixer
2	Pipe Ø114x9 mm, with an additional set of static mixer № 1	
3	Pipe Ø114x9 mm, with an additional set of static mixer № 2	
4	Pipe Ø114x9 mm, with an additional set of static mixer № 3	

To obtain models of the above-mentioned parametric fields we use the Flow Simulation module of the SolidWorks software environment [12, 13]. The results of the research are presented in Table 2. The graphs of the mud velocity changes along the length of the pipeline (curves *v(L)* are given in Fig. 1. The graphs of the vorticity changes *I (%)* regarding the pipe axis *L (m)*, (curves *n(L)*) are shown in Fig. 2. The graphs of turbulence intensity changes l_m *(m)* regarding the pipe axis *L (m)* (curves *I (L)*) in Fig. 3. Schedules zoom l_t turbulence (*m*) tube axis *L (m)* (curves l_m *(L)* are shown in Fig. 4.

We calculate the following parametric fields of the slurry in the pipe work area, which covers the mixer itself and a section of pipe behind it up to 20 pipe diameters long:

– slurry velocity field *v* (*m/s*);

– vorticity field n (c^{-1}) (average circular velocity of the fluid in vortex flow);

– turbulence intensity field (%) I [11]

$$I \equiv \frac{u'}{U} \ , \tag{1}$$

where the mean-square velocity of turbulent fluctuations is

$$u' \equiv \sqrt{\frac{1}{3}u_x'^2 + u_y'^2 + u_z'^2} = \sqrt{\frac{2}{3}k} \ ; \tag{2}$$

and the average turbulent flow speed is

$$U \equiv \sqrt{U_x^2 + U_y^2 + U_z^2} \ ; \tag{3}$$

– turbulence scale field along mixing length l_m *(m)*.

Table 2 – Results of static mixer modelling with the help of flow simulation module

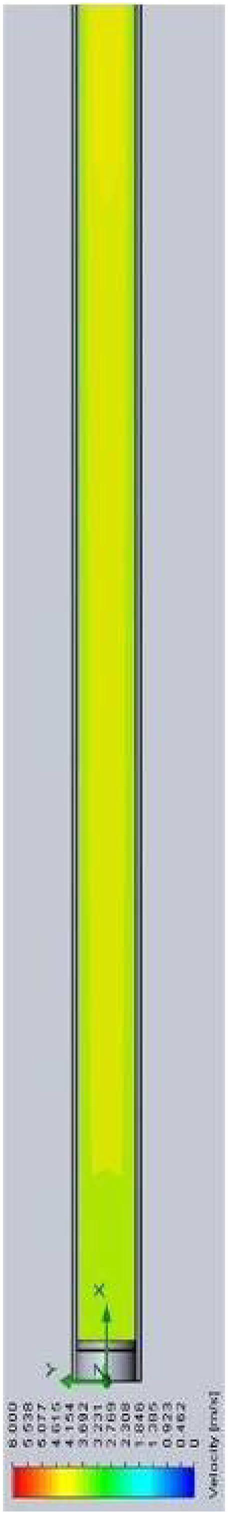
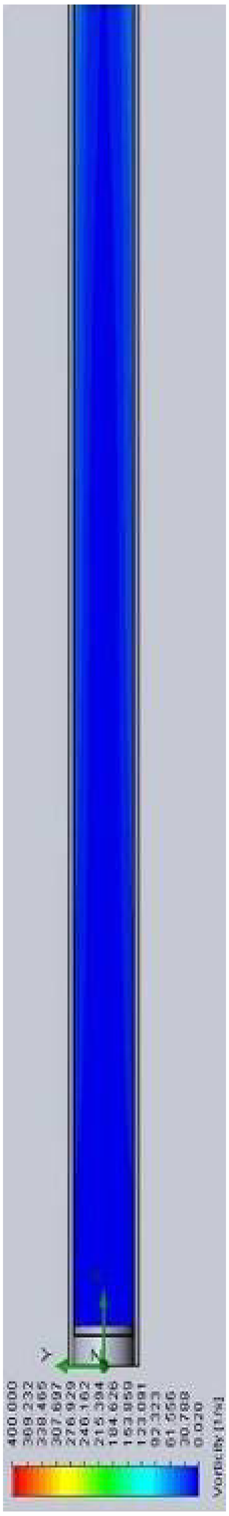
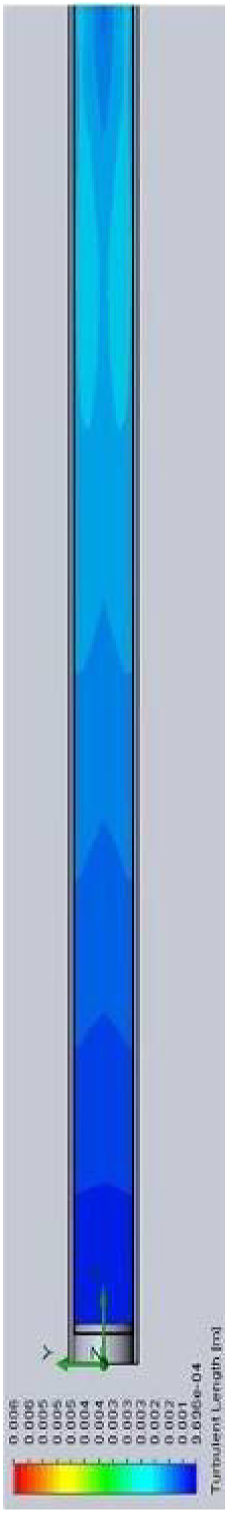
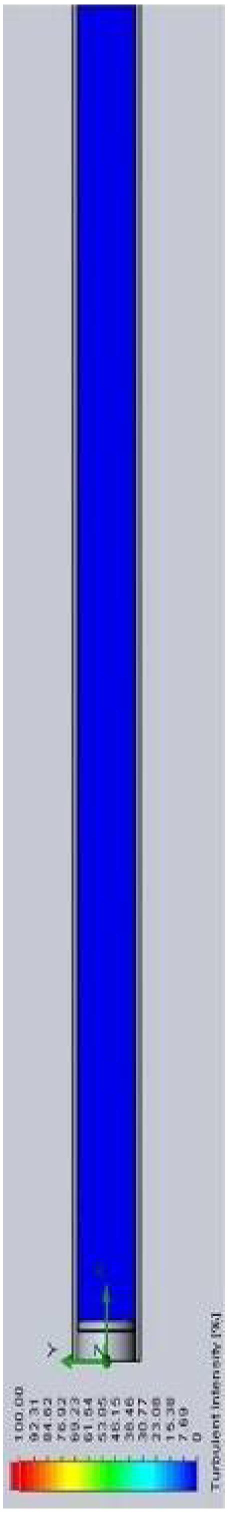
Experiment number	Experiment 1 – Pipe Ø114×9 mm with out static mixer			
Model of parametric experiment	Velocity field model	Vorticity field mode	Turbulence intensity model	Turbulence scale model
				

Table 2 ctd

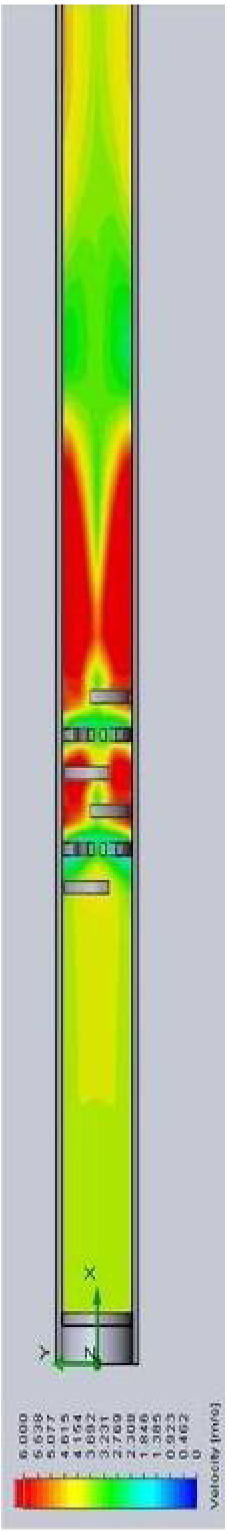
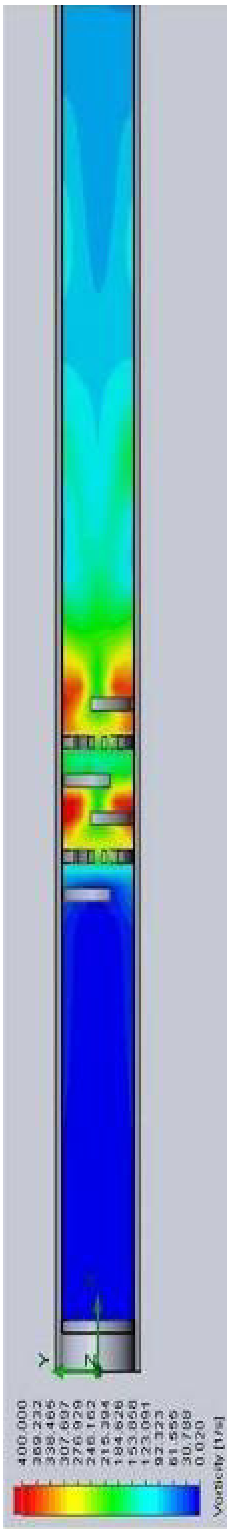
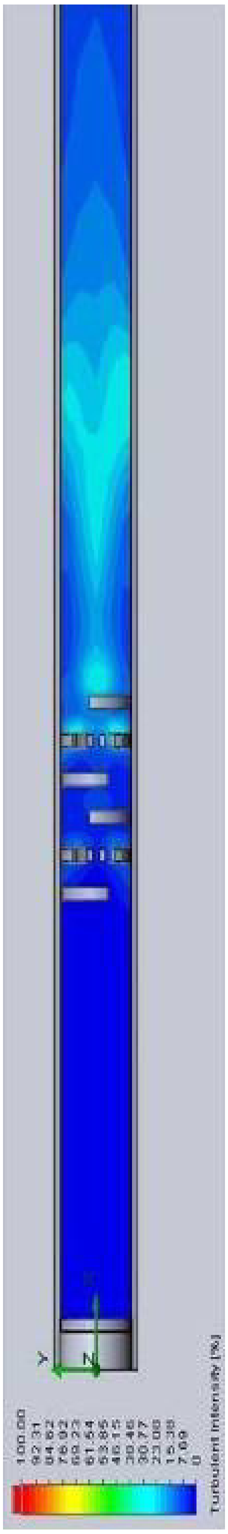
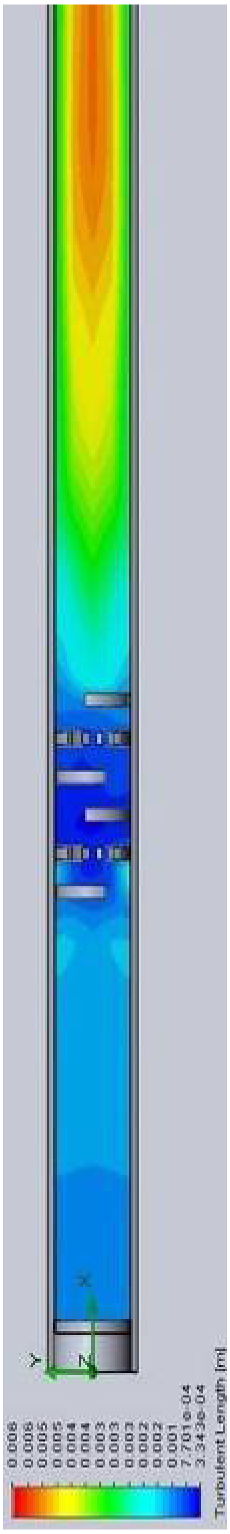
Experiment number	Experiment 2 – Pipe Ø114×9 mm with an additional static mixer № 1			
Model of parametric experiment	Velocity field model	Vorticity field mode	Turbulence intensity model	Turbulence scale model
				

Table 2 ctd

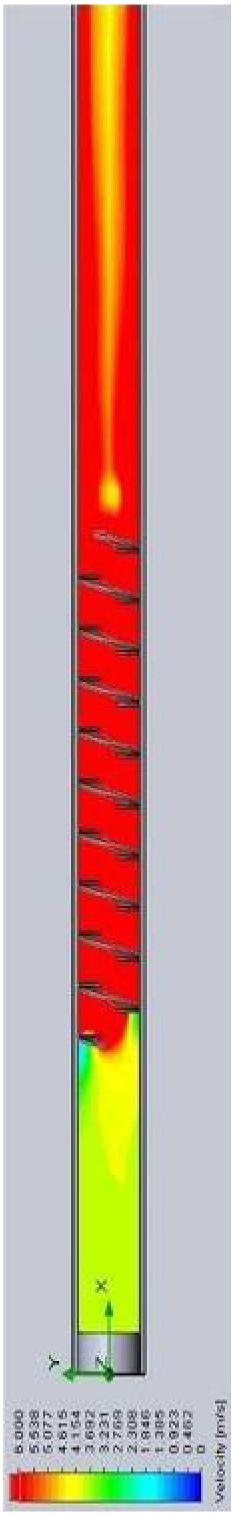
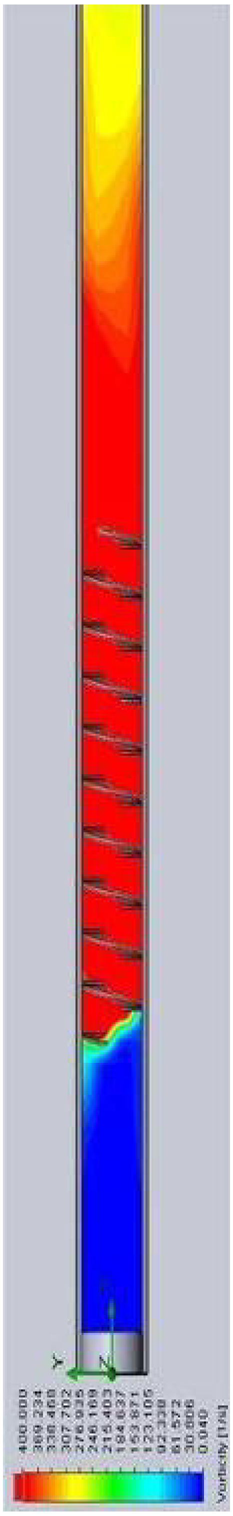
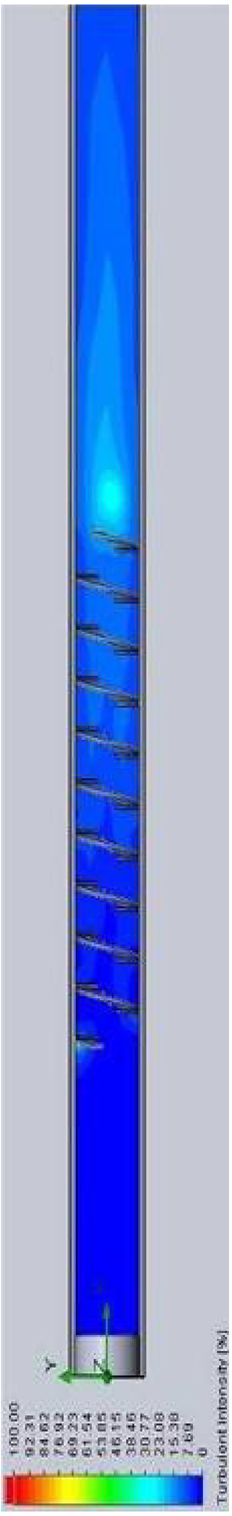
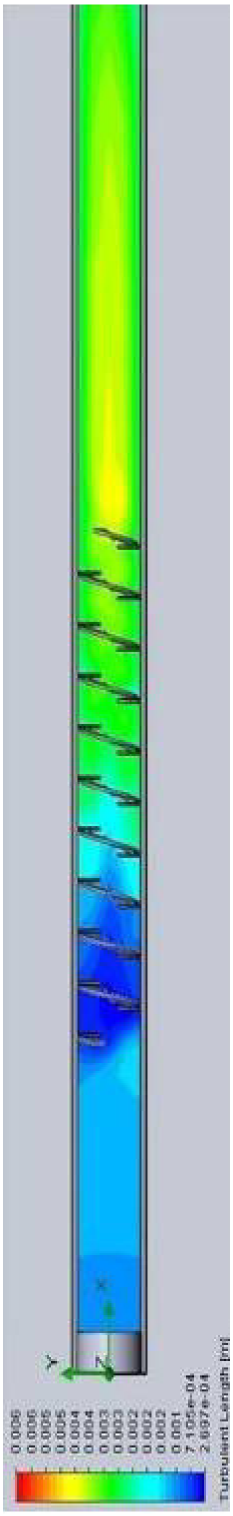
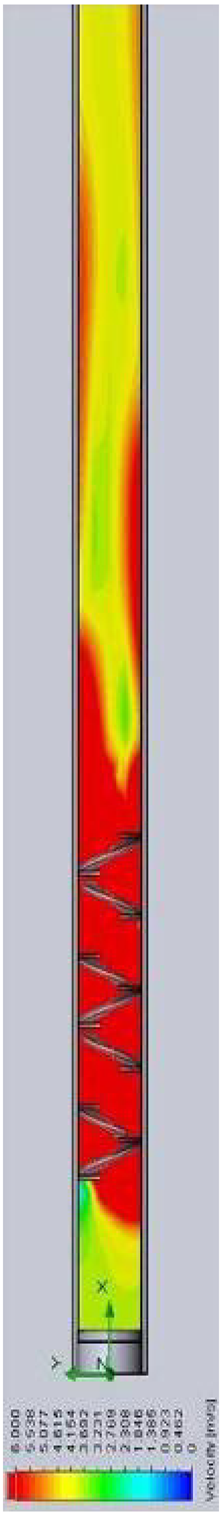
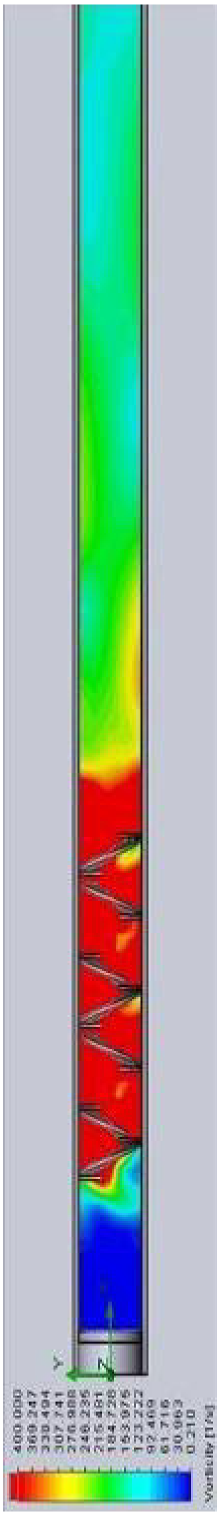
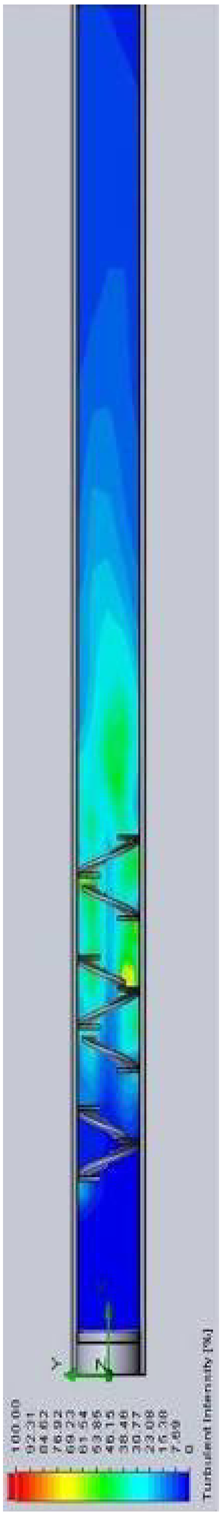
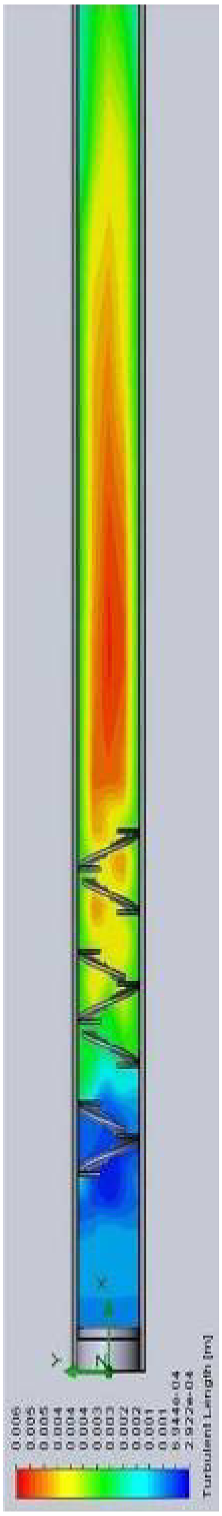
Experiment number	Experiment 3 – Pipe Ø114×9 mm with an additional static mixer № 2			
Model of parametric experiment	Velocity field model	Vorticity field mode	Turbulence intensity model	Turbulence scale model
				

Table 2 ctd

Experiment number	Experiment 4 – Pipe Ø114×9 mm with an additional static mixer № 3			
Model of parametric experiment	Velocity field model	Vorticity field mode	Turbulence intensity model	Turbulence scale model
				

The results describe the changes of mud turbulence along the pipeline in the site of static mixer installation and in the area of pipeline behind it. As you can see, turbulence evaluations are represented by curves *n (L)*, and *(L)* and l_t *(L)* which correspond each other (Figure 1 – 4). The average circular velocity of the fluid in the vortex flow *n*, the turbulence intensity *I* and turbulence scale l_m attain their maximum at the site of static mixer installation and then decrease along the pipe at the distance up to 10 pipe diameters (*10D*). Similar experimental data on the Re character were obtained in [11, 14]. However, each of the studied types of the static mixer affect individual characteristics of turbulence in different ways.

The maximum and minimum values of velocity *v*, vorticity *n*, turbulence intensity *I* and turbulence scale l_t are shown in Table 3.

The comparative analysis of the velocity curves *v (L)* shows that the mixers № 2 and № 3 differ favorably from the mixer № 1, and give close values of characteristics of the flow field in the pipe. The maximum flow velocity for them is at 15 – 16 m/s, minimum – 3.5 – 3.6 m/s, that is vastly larger than the indexes of the mixer № 1 (respectively 4.9 and 1.8 m/s) and 3.5 times more than the maximum flow velocity without mixer.

The analysis of vorticity curves *n (L)* shows that best data demonstrates mixer № 2 (maximum 786.5 s^{-1}), a little worse – mixer number 3 (706.4), next lower order are characteristics of mixer № 1 (108, 5). However, mixer № 2 delivers stable high vorticity in the pipeline on the section of 0.5 m long. For other mixers the curve *n (L)* has an unstable pulsating character.

The comparative analysis of turbulence intensity curves changes l_m *(L)* shows a significant advantage of mixer № 3 (maximum 43.53%) and the practical parity rate of results of mixer № 1 and 2 (respectively 28.13 and 27.01%).

The analysis of the changes of curves of the turbulent vorticity scale along the pipeline *n (L)* shows almost the same picture for all three mixers – the diameter of vortexes in turbulent flows naturally reduces at the site behind the mixer. The rate of turbulence scale changes is the same for mixers № 1, 2 and 3.

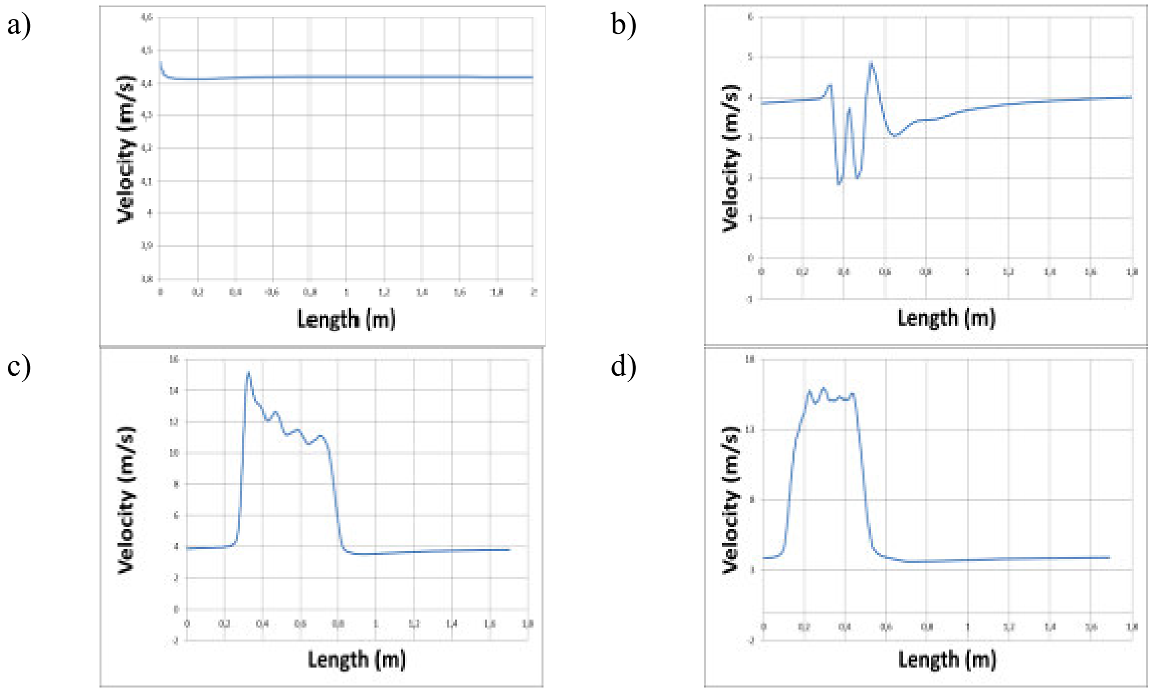


Figure 1 – The schedules of velocity changes *v* (m/s) relatively to the tube axis *L* (m) (curves *v(L)*):
a) experiment 1 (pipe without static mixer); b) experiment 2 (mixer № 1);
c) experiment 3 (mixer № 2); d) experiment 4 (mixer № 3)

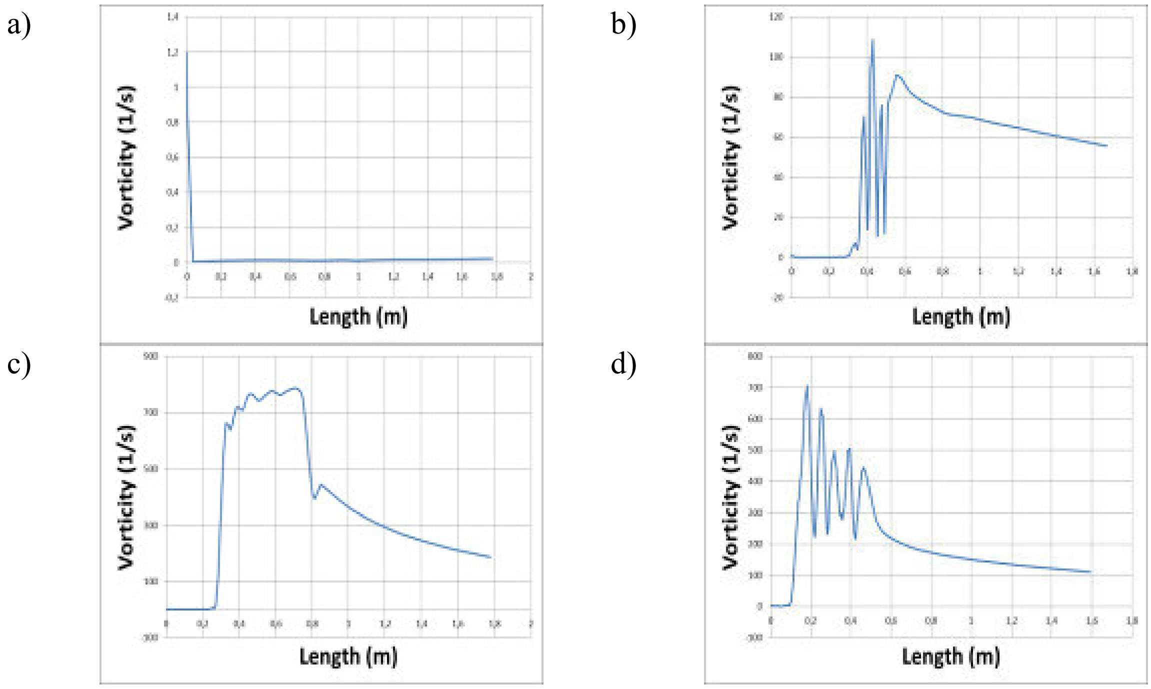


Figure 2 – The schedules of vorticity changes *n* (c^{-1})
relatively to the tube axis *L* (m), (curves *n(L)*):
a) experiment 1 (pipe without static mixer); b) experiment 2 (mixer № 1);
c) experiment 3 (mixer № 2); d) experiment 4 (mixer № 3)

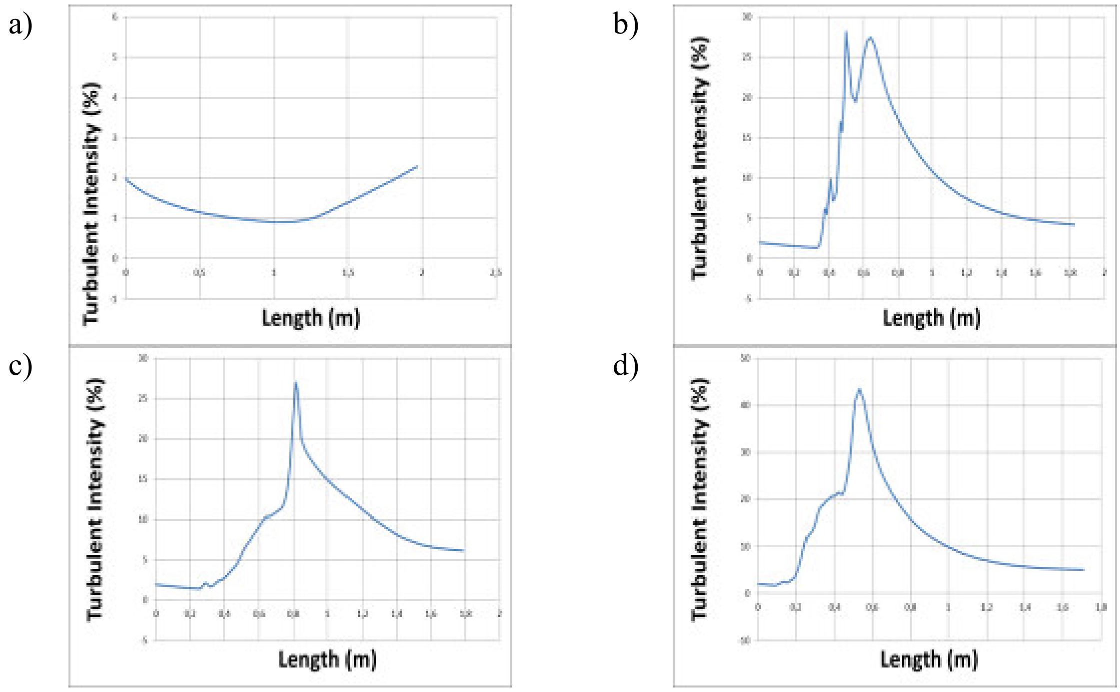


Figure 3 – The schedules of turbulenceintensity changes *I* (%)
relatively to the tube axis *L* (m) (curves *I (L)*):
a) experiment 1 (pipe without static mixer); b) experiment 2 (mixer № 1);
c) experiment 3 (mixer № 2); d) experiment 4 (mixer № 3)

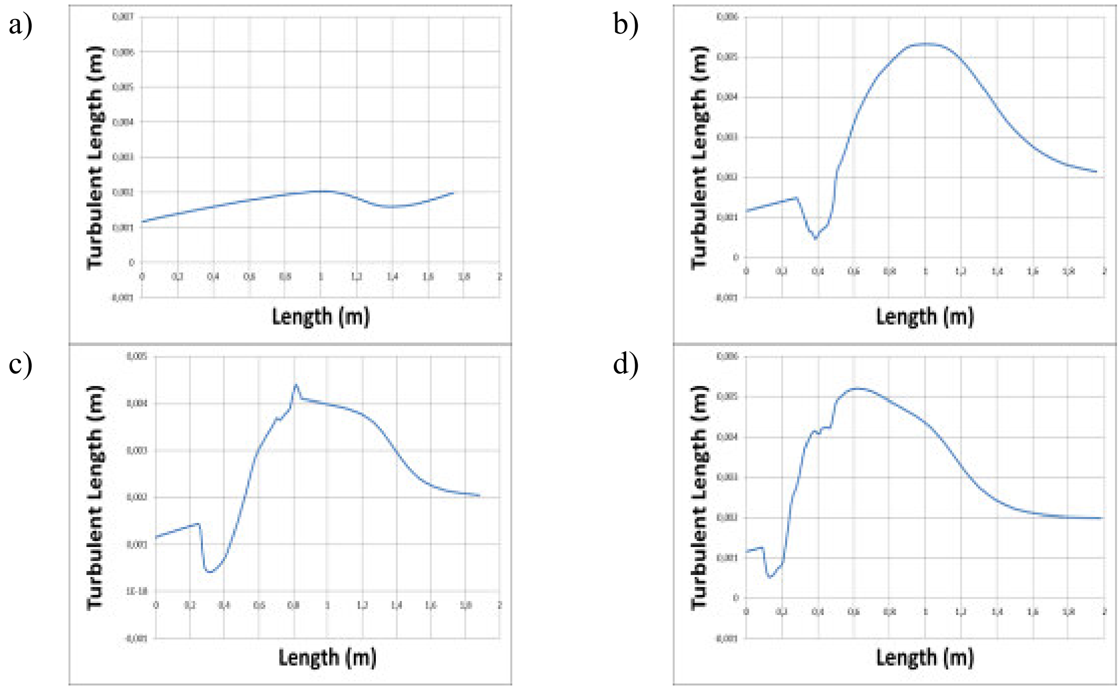


Figure 4 – The schedules of turbulence scale changes l_m (m) relatively to the tube axis L (m) (curves l_m (L)):
a) experiment 1 (pipe without static mixer); b) experiment 2 (mixer № 1);
c) experiment 3 (mixer № 2); d) experiment 4 (mixer № 3)

Table 3 – Maximum and minimum parameter values

Parameter	Experiment No	Design description	Max value	Min value
Velocity *v (m/s)*	1	Pipe without static mixer	4,43	4,41
	2	Pipe with mixer № 1	4,88	1,83
	3	Pipe with mixer № 2	15,19	3,53
	4	Pipe with mixer № 3	15,99	3,59
Vorticity n, c^{-1}	1	Pipe without static mixer	1,19	0,01
	2	Pipe with mixer № 1	108,5	0,01
	3	Pipe with mixer № 2	786,5	0,01
	4	Pipe with mixer № 3	706,4	0,97
Turbulence intensity I (%)	1	Pipe without static mixer	2,27	0,89
	2	Pipe with mixer № 1	28,13	1,28
	3	Pipe with mixer № 2	27,01	1,41
	4	Pipe with mixer № 3	43,53	1,73
Turbulence scale l_m, *m*	1	Pipe without static mixer	0,0020	0,0011
	2	Pipe with mixer № 1	0,0053	0,0005
	3	Pipe with mixer № 2	0,0044	0,0004
	4	Pipe with mixer № 3	0,0052	0,0005

Conclusions:

1. Static mixers are efficient devices that can increase the slurry turbulence and thus have several advantages, including a large number of possible options for design solutions,

such as the absence of moving parts, drives and power consumption, the possibility of combining with hydro and air-transport network.

2. The investigation of functioning of three static mixer designs of Non-Newtonian Fluid with the following mud parameters: density – 1250 kg/m^3, dynamic viscosity – 0.02 cPs with the use of Flow Simulation module of SolidWorks software environment made possible to obtain slurry parametric fields in the pipe work zone, including the mixer and a pipe section behind it up to 20 pipe diameters long: slurry velocity field v *(m/s)*; vorticity field n $(c^{-1})$and turbulence intensity field $I(\%)$,turbulence scale field along the length mixing l_m *(m)*.

3. According to the obtained data, the best technological mixing specifications of mud are provided by mixers № 2 and № 3, which are recommended for carrying out in the system of mud preparation at the site of its mixing with the reagents. For them, the maximum pulp velocity is 15.2 – 16 m /s, vorticity is 786 – 706 c^{-1}, the turbulence intensity is 27 – 43.5%, the turbulence scale is 4.4 – 5.2 × 10^{-3} meters.

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