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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
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NEWS

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OF THE REPUBLIC OF KAZAKHSTAN
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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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jiboj@mail.ru, sbeglerova@mail.ru, bahit12@mail.ru**INTERNAL CORROSION PROPAGATION
IN CURVED SECTIONS OF STEEL PIPES**

Abstract. In the world, the protection of metals from corrosion is one of the urgent problems requiring an integrated approach to their solution. The main task of research in this area is to reduce the economic losses due to corrosion of pipelines, equipment, machinery, structures, machine parts, etc., to increase the reliability of equipment that comes into contact with aggressive media and to preserve the metal stock. Every year around the world there is an increase in the production of metals and the requirements for the conditions of their operation are becoming higher. This is due to the fact that more and more metallic equipment works in aggressive environments. Therefore, the issues of protecting metal equipment from corrosion become more relevant. It is impossible to completely prevent corrosion in metals, but you can find ways to slow down the development of corrosion. For this it is necessary to explore the development of corrosion in metal structures. This article discusses the development of corrosive processes in various parts of the steel pipeline. Studies on the development of corrosion have shown that the development of corrosion on curved sections of steel pipes for various purposes occurs more intensively than on straight sections.

Keywords: corrosion; steel pipes; Lorentz force; internal corrosion.

Introduction. In the history of construction and maintenance of steel pipes, there are accidents and failures due to corrosion damages [1-11]. The problem of corrosion is very urgent and is one of the main factors that cause major catastrophes and accidents on pipelines in various industries.

The main type of corrosion of pipes, which leads to damages, is internal corrosion. Corrosion prevention in steel pipes used in various industrial facilities is in application of insulating coatings both inside the pipes and outside. At that, attention is not paid to the corrosion propagation behavior in the curved sections of steel pipes.

Review. The main internal corrosion studies were carried out in oil and gas and chemical industries, where the transportable medium rapidly leads to the internal corrosion [9-12]. Also, these studies are well developed in the studies of water and heat supply systems [13]. A lot of research has been carried out to this day and being carried out at the moment on the corrosion propagation in these industries, but these results cannot be generalized and used in hydraulic engineering structures due to the difference in the transportable media properties.

In [14] the author studies irrigation pressure pipe systems' life aging by means of forecasting the corrosion propagation danger of metal pipes transporting waste waters. In the work the emphasis is made on waste waters. It does not consider effect of corrosion propagation on the constructional metal pipe features.

The work [15] considers operation conditions of "Astrakhan-Mangyshlak" main internal surface conduit and properties of corrosion formation on it. The corrosion propagates due to water composition, temperature fluctuations and changes along the conduit length. The work does not consider effect of corrosion propagation on the constructional metal pipe features.

The work [16] notes that after long-term operation, localized corrosion damages occur on the oil and gas pipe pitches due to the transportable medium composition and movement influence, which can lead to the pipe rupture.

The works [17-19] present results of experiments on the study of corrosion in the internal cavity of pipes, where the transportable medium flow regime and composition affect the pipe corrosion.

As the review of sources in this direction has shown, investigations of internal corrosion in hydraulic engineering structure pipes have not been adequately conducted, and there are practically no works on the study of the corrosion propagation on the curved sections of steel pipes.

Proposals and differences in methodology. Our investigations [16-20] showed that corrosion propagation occurs more intensively on the curved sections of steel pipes for various purposes than on the straight sections.

We have proposed corrosion propagation mechanism in steel structure elements in aqueous medium taking into account their ferromagnetic properties [18-20]. These studies showed that on the straight sections, ions of the transportable medium attracting by the Lorentz force to the walls of cracks start chemical process of steel elements' corrosion. Existing cracks on the outside are covered with oxide film forming iron hydroxides. Cracks filled with corrosion products on the straight sections are less susceptible to mechanical influences on the transportable medium. Therefore, here the corrosion propagation velocity is less than in the curved sections of steel pipes.

In the curved sections of steel pipes, a centrifugal force acts on moving particles (gases, mechanical impurities, water or other liquids) having a certain mass [21]. In the curved sections the corrosion propagation velocity depends on the liquid motion velocity, on the number of ions, and also on the centrifugal force effect equal to:

$$F = \frac{m \cdot v^2}{R}, \quad (1)$$

where m – particle mass; v – particle motion velocity; R – radius of deformation.

These particles, acting mechanically, open cracks of steel pipes closed by the primary corrosion products and contribute to the further intensive corrosion propagation in them.

In the straight sections the corrosion propagation velocity depends only on the liquid flow velocity and on the number of ions, as $\frac{m \cdot v^2}{R} \rightarrow 0$, at $R = \infty$.

In the curved sections, where the turning angle equal to 90° , the corrosion propagation velocity depends on the liquid flow velocity, on the number of ions, as well as on the kinematic energy action, as $\frac{m \cdot v^2}{R} \rightarrow \max$, at $R \rightarrow 0$. In this situation, the corrosion propagates several times more than in other curved sections, as the liquid motion before the angle changes and the number of ions increases. If previously on the straight sections, ions on the wetted perimeter of the pipe could act on the corrosion propagation velocity, then at turns to 90° , ions on the cross sectional area of the liquid can affect the corrosion propagation velocity.

To test the proposed mechanism for the corrosion propagation, we have conducted experiments to measure thickness of the steel pipes walls on the curved sections. The purpose of the experiment is to determine the turning angles, which have the greatest influence on the corrosion propagation velocity.

To this end, we have developed an apparatus for determining metal corrosion on the curved sections in steel pipes (figure 1). The apparatus consists of a pump welded at various angles of pipes $\varnothing 32 \times 3.0$ in diameter, a filter, an air valve and supports. The apparatus developed by us, where the liquid is circulated by the pump, has sections of steel pipes: straight, curved and with turn by 90° .

The experiment was conducted for one year. As is known, river water, fresh water have very weak ions, therefore, in order to obtain comparatively fast results in the role of a corrosive fluid, we took the salt solution, generally accepted in such experiments (NaCl 3.5%) [9, 23].

It should be noted that in similar works [12, 22], the salt solution (NaCl 3.5%) is used to study the corrosion propagation.



Figure 1 – The distance from the rotation axis to the center of gravity of the current r and peripheral R section

In the work [23], the salt solution (NaCl 3.5%) is also used for the experiment, but the work deals with the corrosion propagation in welded joints of pipes.

The thickness of the steel pipes walls was measured by ultrasonic thickness gage UT-301 according to GOST 28702-90. The converter is of 5B12/2-5.0 MHz type. The main material of the pipe with $\text{Ø}32 \times 3.0$ diameter is (Steel 10, GOST 1050-88). When measuring, the “echo” principle is used, i.e. the searcher and receiver are combined in one tester. The activated ultrasonic signals reach the internal pipe surface and are reflected by the receiver, knowing the propagation velocity and the time of passage of ultrasound on the metal, we have determined the wall thickness.

The layout of the measurement points in the apparatus is shown in figure 2. The apparatus is made of a 32 mm pipe, its wall thickness is 3mm, two angles of 90° , one angle is 135° , one angle is 120° , the sharp angle is 35° . The length of the upper pipe is 120 cm, the height is 35 cm, the lower length of the pipe is 36 cm, the angle from this segment is 135° . The apparatus consists of five pipe sections. Its perimeter is 296 cm.

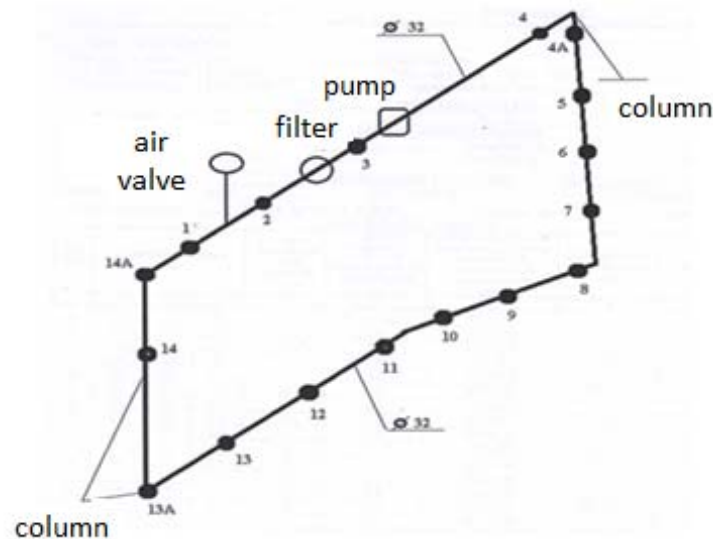


Figure 2 – The layout of the measurement points in the apparatus

Results and discussion. The apparatus was switched on in May 2017. There is a pump in the middle of the upper part that distills the salt solution. The pump is switched on via the time relay, it works continuously for 1 hour, stops for 20 minutes. The thickness of the pipe wall at 17 points was measured after 3 months (table 1), 8 months (table 2) and 1 year (table 3). The thickness of the pipe wall was measured in the laboratory of ultrasonic testing (Testing laboratory of PKF FAN LLP, Taraz, Accreditation certificate N° KZ.I.08.1791).

Table 1 – The results of measuring the thickness of the steel pipes walls subjected to internal corrosion (August, 2017)

N	Measurement value (mm)			Mean value of three measurements (mm)	Thickness of the wall taking into account measurement errors (mm)	Initial thickness of the wall and diameter of measured elements (mm)	Retirement size (mm)	Notice
1	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	pipe
2	3.1	3.0	3.1	3.1	3.0	Ø32x3.0	δ = 1.53	- // -
3	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
4	3.0	3.1	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
4A	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
5	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
6	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
7	3.1	3.0	3.1	3.1	3.0	Ø32x3.0	δ = 1.53	- // -
8	2.7	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
9	2.7	2.8	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
10	2.9	2.8	2.9	2.9	2.9	Ø32x3.0	δ = 1.53	- // -
11	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
12	3.1	3.0	3.1	3.1	3.0	Ø32x3.0	δ = 1.53	- // -
13	2.7	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
13A	2.7	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
14	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
14A	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -

Table 2 – The results of measuring the thickness of the steel pipes walls subjected to internal corrosion (February, 2018)

N	Measurement value (mm)			Mean value of three measurements (mm)	Thickness of the wall taking into account measurement errors (mm)	Initial thickness of the wall and diameter of measured elements (mm)	Retirement size (mm)	Notice
1	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	pipe
2	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
3	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
4	2.9	2.9	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
4A	2.2	2.3	2.2	2.2	2.1	Ø32x3.0	δ = 1.53	- // -
5	2.4	2.3	2.3	2.3	2.2	Ø32x3.0	δ = 1.53	- // -
6	2.9	3.0	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
7	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
8	2.4	2.3	2.4	2.4	2.3	Ø32x3.0	δ = 1.91	- // -
9	2.7	2.8	2.7	2.7	2.6	Ø32x3.0	δ = 1.91	- // -
10	2.8	2.9	2.8	2.8	2.7	Ø32x3.0	δ = 1.91	- // -
11	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.91	- // -
12	3.0	2.9	3.0	3.0	2.9	Ø32x3.0	δ = 1.53	- // -
13	2.7	2.6	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
13A	2.4	2.5	2.5	2.5	2.4	Ø32x3.0	δ = 1.53	- // -
14	2.4	2.5	2.4	2.4	2.3	Ø32x3.0	δ = 1.53	- // -
14A	2.3	2.3	2.4	2.3	2.2	Ø32x3.0	δ = 1.53	- // -

Table 3 – The results of measuring the thickness of the steel pipes walls subjected to internal corrosion (May, 2018)

N	Measurement value (mm)			Mean value of three measurements (mm)	Thickness of the wall taking into account measurement errors (mm)	Initial thickness of the wall and diameter of measured elements (mm)	Retirement size (mm)	Notice
1	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	pipe
2	2.9	2.9	2.8	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
3	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
4	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
4A	2.2	2.1	2.1	2.1	2.0	Ø32x3.0	δ = 1.53	- // -
5	2.1	2.2	2.2	2.2	2.1	Ø32x3.0	δ = 1.53	- // -
6	2.6	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
7	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
8	2.4	2.3	2.3	2.3	2.2	Ø32x3.0	δ = 1.91	- // -
9	2.7	2.8	2.7	2.7	2.6	Ø32x3.0	δ = 1.91	- // -
10	2.7	2.7	2.6	2.7	2.6	Ø32x3.0	δ = 1.91	- // -
11	2.8	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.91	- // -
12	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
13	2.8	2.7	2.7	2.7	2.6	Ø32x3.0	δ = 1.53	- // -
13A	2.4	2.5	2.4	2.4	2.3	Ø32x3.0	δ = 1.53	- // -
14	2.9	2.8	2.9	2.9	2.8	Ø32x3.0	δ = 1.53	- // -
14A	2.2	2.2	2.3	2.2	2.1	Ø32x3.0	δ = 1.53	- // -

Analysis of tables 1–3 shows that at the points of measurement – N°. 4A, 8, 13A, 14A, where the turning angles are sharp or equal to 90°, the wall thickness has significantly decreased. This shows that on the curved sections of steel pipes, corrosion propagates more strongly than on the straight sections, which in turn confirms the corrosion propagation mechanism proposed by us.

Corrosion inside steel pipes begins, as we established earlier [21, 22], in the damaged areas. These areas with defects, non-uniformities, dislocations and cracks in steel structures, damage the ferromagnetic properties of steel. They, in turn, damage the domain structure of steel, and between the domains Cl⁻ ions are attracted to the south poles, and Na⁺ ions are attracted to the north poles, and thus corrosion begins, i.e. chemical process.

The pipe thickness in the first section decreased by 0.1 mm at the first measurement and the corrosion propagation velocity was equal to $\frac{0.1}{0.25} = 0.4 \text{ mm / year}$. The corrosion propagation velocity in the second measurement was equal to zero. The corrosion propagation velocity in the third measurement was equal to $\frac{0.1}{0.353} = 0.3 \text{ mm / year}$. The average corrosion propagation velocity in the steel pipes with the

straight section was equal to $\frac{0.2}{1} = 0.2 \text{ mm / year}$. After mathematical processing of thickness measurement results, we determined the corrosion propagation velocities in the steel pipes of the experimental apparatus on its straight sections, which are shown in figure 3.

At first straight sections of the steel pipes, the corrosion first developed actively, and then its propagation velocity slowed down. Then after a certain time, the corrosion propagation resumed. The resulting phenomenon is explained by the fact that when the ions passed through the cracks of domains after the first measurement, products of chemical reaction – micelles (chemical corrosion product) [23] formed and filled the cracks of domains, thereby reducing the corrosion propagation velocity.

The average corrosion propagation velocity on the curved sections of the steel pipes of hydraulic engineering structures (figure 4) equal to 0.375 mm/year.

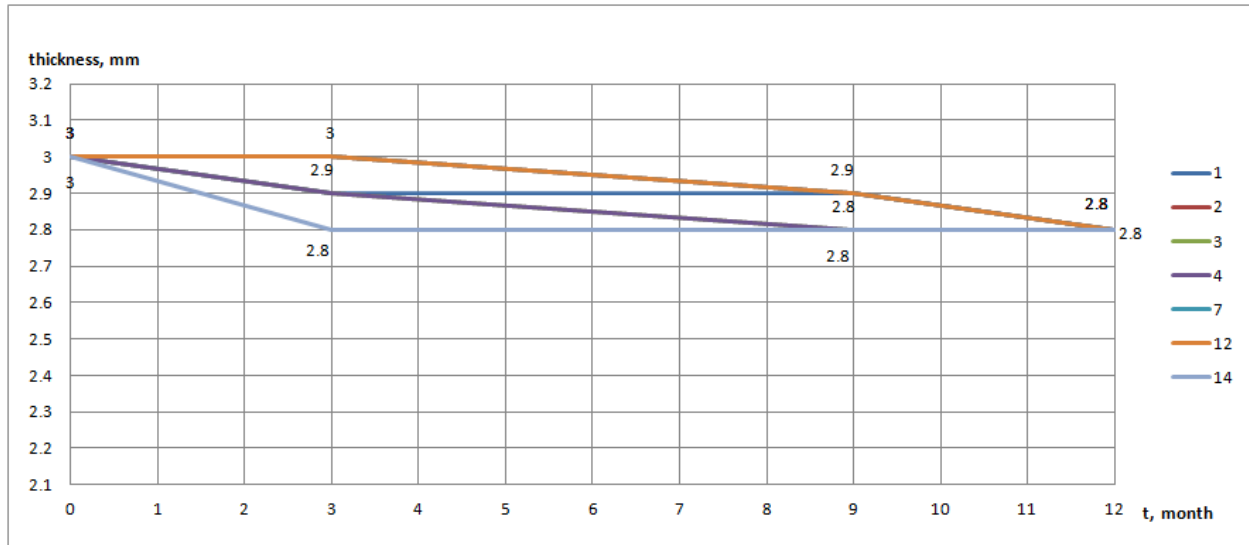


Figure 3 – Dependence of the pipe wall thickness on the residence time in the corrosive medium on the straight sections. The numbers correspond to the measurement points on the experimental apparatus

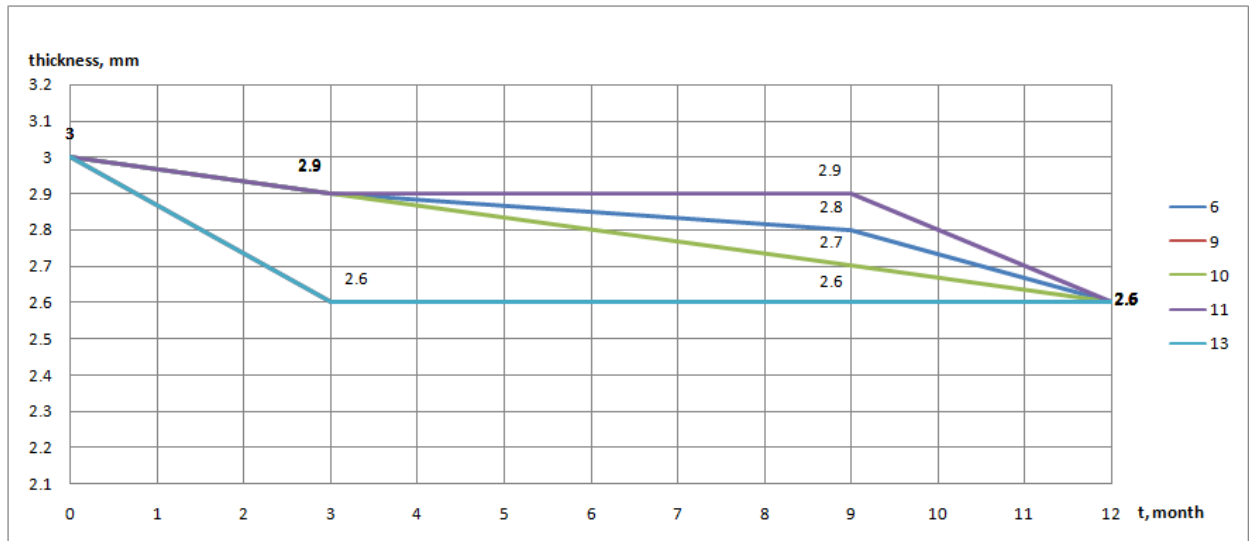


Figure 4 – Dependence of the pipe wall thickness on the residence time in the corrosive medium on the curved sections. The numbers correspond to the measurement points on the experimental apparatus

The obtained value in comparison with the straight section of the steel pipes increased by 80.5%. This phenomenon is explained by the fact that when turning the steel pipes, the liquid under the action of centrifugal forces hits the walls and wash out the micelles, and therefore the physical process does not stop, affecting the corrosion propagation velocity.

The average corrosion propagation velocity at the turns of the steel pipes of hydraulic engineering structures equal to 90° and is shown in figure 5 and equal to 0.833 mm/year.

The obtained value in comparison with the square section of the steel pipes increased by 416.5%. This phenomenon is explained by the fact that when turning by 90°, the liquid completely breaks its structure, and the number of ions in the liquid increases in proportion to the ratio of the cylinder volume to its perimeter.

Thus, we obtained results showing that location of the steel pipes of hydraulic engineering structures affects the corrosion propagation velocity inside the pipes. This phenomenon was not taken into account when designing the steel pipes of hydraulic engineering structures, and reliability of the steel pipes depends on their location in space. In practice, elements of metal structures are designed to be equal in

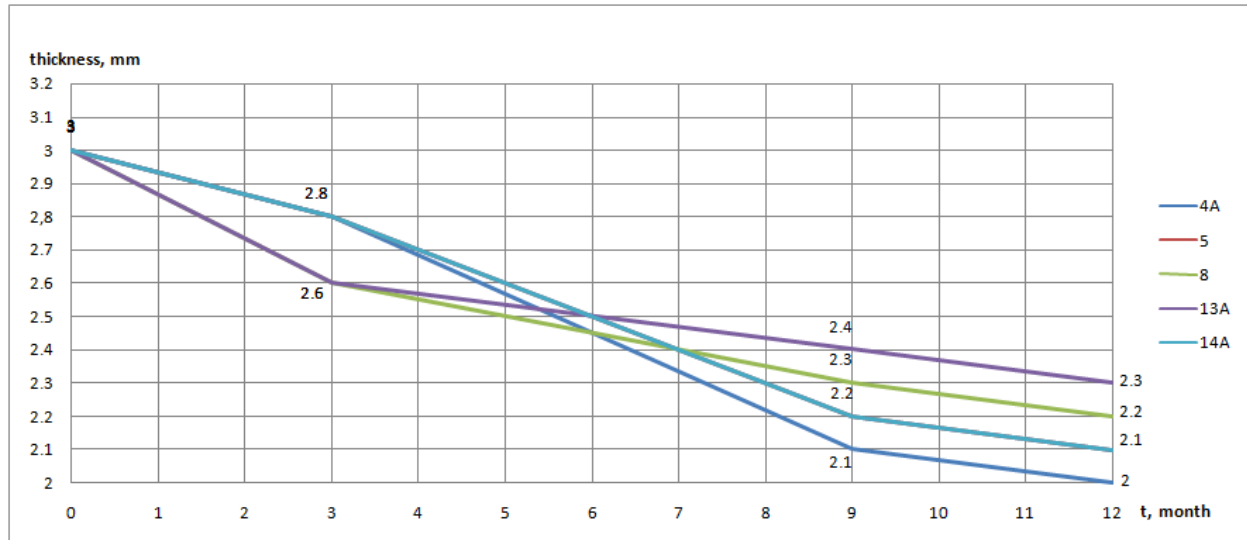


Figure 5 – Dependence of the pipe wall thickness on the residence time in the corrosive medium on the square sections. The numbers correspond to the measurement points on the experimental apparatus

strength, while elements of metal structures of hydraulic engineering structures should be designed to have the same reliability and ensure trouble-free operation.

Calculation of tubular metal structures of hydraulic engineering structures is carried out according to the well-known formula of Laplace [24]:

$$\frac{\sigma_1}{r_1} + \frac{\sigma_2}{r_2} = pt, \quad (2)$$

where σ_1 - meridian stress; σ_2 - circular stress; r_1 - meridian radius; r_2 - radius of curvature in the circular direction; p - pressure inside the pipe; t - thickness of the pipe walls.

The second component stress acting along the meridian direction is also determined for the pipes by the formula [24]:

$$\sigma_1 = \frac{p}{2t}, \quad (3)$$

The pipes are in a plane stressed state, and the strength is tested by the following formula [24]:

$$\sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2} \leq R_y \frac{\gamma_c}{\gamma_n}, \quad (4)$$

where R_y - design strength of the steel, established by the yield point; γ_c - service factor; γ_n - reliability factor.

The calculation made by this formula does not ensure trouble-free operation of the pipes of hydraulic engineering structures, since it does not take into account the corrosion propagation inside the pipe [25].

Conclusions. The results of the above studies carried out by us in laboratories of M.Kh. Dulati Taraz State University showed that the pipes can lose their performance due to the corrosion. Pipes having turning angles, especially when they turn at the angle of 90° , may lose their trouble-free operation earlier than the pipe sections having straight sections.

To eliminate this phenomenon, it is necessary to take measures ensuring equal reliability of all sections of tubular steel structures of hydraulic engineering structures, thus ensuring their trouble-free operation.

In our opinion, the following measures should be taken:

- thicken pipes at the turning points;
- periodically paint pipes at the turning points;
- use in the turning points of pipes, steel of corrosion-resistant properties grades;
- continue to study the corrosion propagation on the curved sections of the steel pipes.

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БОЛАТ ҚҰБЫРЛАРДЫҢ БҰРЫЛЫСТАРЫНДАҒЫ ІШКІ ТОТЫҒУДЫҢ ДАМУ ЕРЕКШЕЛІКТЕРІ

Аннотация. Дүниежүзінде металларды тоттанудан қорғау кешенді шешімдерді талап ететін өзекті мәселелердің бірі. Осы саладағы зерттеулердің басты мақсаты металл құбырларының, жабдықтардың, құрылымдардың машина бөлшектерінің және т.б. механизмдердің тоттығу салдарынан келетін экономикалық шығындарды төмендету, агрессивті ортада жұмыс жасайтын қондырғылардың сенімділігін арттыру және металл қорын сақтау болып табылады. Жыл сайын бүкіл әлемде металдар өндірісінің өсуі байқалады және олардың жұмыс істеуіне талаптар жоғарлауда. Бұл көп металдық жабдықтардың агрессивті орталарда жұмыс жасауында. Сондықтан металл жабдықтарды коррозиядан қорғау мәселелері өзекті болып табылады. Металлдардың тоттануына жол бермеу мүмкін емес, бірақ коррозияның дамуын бәсеңдету жолдарын табуға болады. Ол үшін металл конструкцияларындағы коррозияның дамуын зерттеу қажет. Бұл мақалада болат құбырдың түрлі бөліктеріндегі коррозиялық процестердің дамуы қарастырылады. Коррозияның дамуы туралы зерттеулер түрлі мақсаттағы болат құбырлардың қисық бөліктеріндегі коррозияның түзу бөліктеріне қарағанда қарқынды өсуін көрсетеді.

Түйін сөздер: тоттану, болат құбыр, Лоренц күші, ішкі тоттану.

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ОСОБЕННОСТИ РАЗВИТИЯ ВНУТРЕННЕЙ КОРРОЗИИ НА УГЛАХ ПОВОРОТОВ В СТАЛЬНЫХ ТРУБАХ

Аннотация. В мире защита металлов от коррозии является одной из актуальных проблем, требующих комплексного подхода по их решению. Основная задача исследований в этой сфере – это уменьшение экономических потерь в результате коррозии трубопроводов, оборудования, механизмов, конструкции, деталей машин и т.д., повышение надежности оборудования, которое соприкасается с агрессивной средой и сохранность металлического фонда. С каждым годом во всем мире наблюдается рост производства металлов, и требования к условиям их эксплуатации становятся выше. Это связано с тем, что все больше металлическое оборудование работает в условиях агрессивных сред. Поэтому вопросы защиты металлического оборудования от коррозии становятся более актуальными. Полностью предотвратить коррозионные процессы в металлах невозможно, но можно найти способы замедления развития коррозии. Для этого надо исследовать пути развития коррозии в металлических конструкциях. В данной статье рассматривается развитие коррозионных процессов на различных участках стального трубопровода. Исследования за развитием коррозии показали, что на криволинейных участках стальных труб различного назначения развитие коррозии происходит более интенсивнее, чем на прямолинейных участках.

Ключевые слова: коррозия, стальные трубы, сила Лоренца, внутренняя коррозия.

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