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IMPROVING STRENGTH OF HOT-ROLLED PIPES IN OIL AND GAS PIPELINE TRANSPORTATION SYSTEMS AND HEAT SUPPLY SYSTEMS

A rather significant degree of wearing of pipeline transportation systems constructed using hot-rolled pipes is observed in the oil and gas industry. This raises concerns regarding emerging threats to their operational safety. As to the use of hot-rolled pipes in heat supply systems, where the pipes service life is short, while labor intensity and costs for pipes replacement are high, the situation is unfavorable. Measures are required to increase their reliability. Technologies and equipment have been developed for anticorrosion treatment of pipe surfaces and the solid material, combined with hardening surface deformation processing (SPD) of inner and outer pipe surfaces. Anticorrosive inhibitory treatment of the solid body ensures elimination of inter-crystalline corrosion inside the solid material.

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Introduction

Intensive development of the oil and gas industry gets obvious considering the volume of the metal fund in the industry, which makes up 18 % of the total metal fund [1]. In view of the important role that the industry plays in the economy and the volume of the metal fund, its condition requires special attention. According to the available sources, the situation in the industry cannot be considered favorable. Expired welded constructions account for 55 – 65 % of the total number [2], [3], and oil pipeline networks, require a volume of repair work exceeding the scope of work at newly constructed facilities. The technical condition of oil and gas production equipment and pipelines, considering their degree of wear, have made them objects of increased danger [4]. In view of the role that the industry plays in the economy, the ever-increasing tasks of hydrocarbon production, measures are required to increase the service life and reliability of technical equipment.

Methodology

General condition of technical equipment in the industry

Given the specifics of pipeline transportation systems operation, one of the effective measures may be increasing their durability. Often used in systems, hot-rolled pipes have major technological deficiencies like surface scale and coarse-grained decarburized surface layers, and there are no technologies and technological equipment to eliminate such deficiencies. Both factors are initiators and intensifiers of corrosion processes development, as they initiate and intensify development of fatigue processes. The consequence of the factors is low corrosion resistance, which reduces fatigue properties, thus creating the threat of emergency situations. The situation is aggravated by the fact that, due to the specifics of operation with pipelines laid underground, control over the state of structures is difficult or impossible.

Corrosion processes develop on pipeline surfaces and inside the wall material in form of inter-crystalline corrosion. Surface corrosion often develops in local form with premature failure of the structure. No less dangerous is the corrosion that occurs in the solid body – inter-crystalline corrosion. When it occurs, despite the fact that the metal surface externally remains intact, "adhesion between individual grains in steel can be broken over the entire cross-section of the part and lead to destruction" [5, p. 100].

Development of inter-crystalline corrosion inside the solid material is also relevant for welded structures made of plate metal and pipes. In welded structures, significant heating causes complex processes of residual stresses redistribution in the weld zone, which are of high significance for durability and reliability of structures. In addition to residual stresses redistribution, as a result of heating carbides are precipitated near the weld, along the grain boundaries, which decreases grain boundary stability, creating favorable conditions for occurrence of inter-crystalline corrosion [5].

The situation is also unsatisfactory in another area of hot-rolled pipes use – in heat supply, where heat carrier transportation is accompanied with high chemical aggressiveness of water at temperatures of 75 – 85 °C, that reduces the service life of pipes in heating systems to 4 - 6 years. Therefore, increasing pipe products corrosion resistance is of great practical importance.

Articulation of the problem

From the previous provision it follows that the hazard to pipeline systems lies in both external corrosion occurring on outer surfaces and internal inter-crystalline corrosion. While certain measures have been developed with respect to external corrosion to combat it, the same cannot be stated about inter-crystalline corrosion that generates inside the solid material. Given its high importance, no significant measures have yet been developed to counteract it, and therefore new approaches are required. The task is to increase the inter-crystalline corrosion resistance inside the solid material. One of the directions of research is to find ways of anti-corrosion inhibitory treatment of structural crystalline surfaces inside the solid material, which can be achieved by introducing an inhibitor to the surfaces of elements of crystalline structures. A prerequisite for the possibility of the inhibitor entering the crystalline structure surfaces is the very fact of inter-crystalline corrosion occurrence that generates as electrochemical corrosion, i.e. with participation of an electrolyte – an

aqueous medium. The fact indicates the possibility of the moisture penetration and presence in the solid material. Electrochemical corrosion is a type of heterogeneous corrosion involving two phases – liquid (aqueous) and solid. The surfaces of the crystalline structure elements inside the solid material act as the solid phase. Only one molecular layer of moisture can act as the aqueous medium [5]. Inter-crystalline corrosion presence inside the solid material indicates the possibility of moisture presence in the solid material. And if this is so, then there are mechanisms for moisture ingress into the solid material, therefore, inhibitors can enter the solid material in a similar way, providing anti-corrosion inhibiting treatment of the crystalline formation surfaces. Understanding of how these mechanisms work is needed.

The main directions of increasing corrosion resistance

Examples of atoms and molecules penetration and movement inside the solid materials are known from practice. History knows examples of moisture penetration into the sealed cavities of equestrian sculptures with their subsequent rupture due to water freezing, whereafter it was decided to make drainage holes in sculptures. At that time and even much later, appearance of large water quantities in sealed cavities of the solid material was not explained. An unexplained phenomenon of segregation is also known, consisting in the "instantaneous" movement of atoms of certain elements in the solid metal towards surfaces [6]. Successful use of lubricating and cooling fluids in the spots with extreme conditions is also known. When cutting, the pressure in the cutting spot develops up to 50 MPa, and the temperature locally can rise to several dozens of thousands of degrees. In these conditions, successful use of coolants is noted, despite inconsistency of their use in such conditions. A positive effect is explained by the ability of the active substance (coolant) – polarized dipole molecules of surface-active substances (surfactants) – to penetrate into the spots with extreme conditions. When cutting, such spots are localized in the contact zone of chips separated from the solid body with the front surface of the cutter. The joint of the chip material with the front surface of the cutter, despite abnormal pressures, is not tightly sealed. Electrically polarized surfactant molecules can penetrate into it, preventing self-healing of numerous microcracks in this zone, thereby reducing the level of the supplied energy dissipation and, accordingly, the temperature. To ensure penetration into the area with extreme conditions, "penetration channels" and driving forces are required to stimulate movement of surfactant

molecules. Creation of "penetration channels" at the joint is ensured by the presence of contacting surface micro-irregularities, their shapes geometry deviations, mechanical, chemical, and other features of the surfaces state that appear due to oscillatory phenomena. The driving forces are electric forces, the presence of electric dipoles in surfactant molecules, the presence of electric charges on the walls of microcracks. In bibliographic sources [6], the fact of detecting charges on microcracks walls inside the solid material is noted, however, the reason for their formation stays unknown. It can be suggested that this reason is associated with formation of double electric layers, which is typical for breaking of any contacts. Some features of the coolant application identified – mechanisms of movement through the "penetration channels", etc. – can be taken as the basis for the task development.

Practical experience of obtaining high anticorrosion properties from the action of NaNO_2 inhibitor during intense deformation was considered. The result was obtained in the process of surface treatment by a waterjet jet under pressure with adding the inhibitor into the waterjet suspension composition. It was revealed that the anticorrosion effect was absent during separate treatment with the surface inhibitor apart from hydroabrasive treatment, which allowed to conclude that the anticorrosion effect is related to the surface strain hardening effect of the hydroabrasive jet on the surface. At the same time, appearance of intense glowing during treatment was noted, which was explained by electrostatic discharges from double electric layers upon breaking contact between the abrasive particles and the material [7]. It was suggested that the increased anticorrosive effect is associated with the surface layer structural elements mobility under external deformation, including grain crushing and grinding. Mobility of the elements created conditions for deep penetration of the inhibitor, providing a reliable anti-corrosion effect. Based on this experience and respective conclusions, a detailed study was conducted on the use of certain inhibitors in conditions of their use in course of surface plastic deformation (SPD) and without it [8]. The processed samples were subjected to long-term tests for corrosion resistance to the action of climatic factors ac-

cording to DSTU ISO 9227:2015 in a salt spray chamber. The test duration was 120 hours. The medium used was a sprayed 5 % NaCl solution at the temperature of 35 °C.

The conducted detailed study, which in the main features duplicates hydroabrasive treatment, where a high anti-corrosion effect was obtained, confirmed high results on one of the types of inhibitors and their absence on the other two. The search for explanations is difficult – chemical formulas, composition of the inhibitors stay unknown. One of the inhibitors that did not show positive results during the test – the inhibitor being a water-miscible synthetic anti-corrosion concentrate. As judged from the definition, it can be assumed that its complex shape makes it difficult to get to structural elements even in conditions of their mobility during surface plastic deformation (SPD).

In view of the foregoing, it is expedient to use inhibitors having a relatively simple chemical formula and corresponding molecular sizes. Literature sources on corrosion recommend the use of inhibitors acting as anode passivators belonging to the class of nitrites, phosphates, alkali metal silicates. In particular, sodium nitrite NaNO_2 is especially recommended, applied in the ratio of 1 – 2 %; this particular substance was applied during hydroabrasive treatment [7]. Passivators of the nitrite class form $\gamma\text{-Fe}_2\text{O}_3$ protective films, and, to a lower extent, $\gamma\text{-FeO}\cdot\text{OH}$. The inhibitor NaNO_2 has a molecule with a molecular weight in atomic units of 48 units, which is comparable with the molecular weight of water in the same units; the sizes of NaNO_2 ions are even more comparable in size with water molecules. Comparable sizes create the same conditions for penetration. To fulfill the task of increasing the inter-crystalline resistance inside the solid material, it is anticipated to carry out anti-corrosion inhibitor treatment of crystalline structural elements within the solid body. This can be ensured by the entry of the inhibitor in ionic form into the solid body in the type of water molecules penetration into the solid body. For this purpose, it is necessary to identify "penetration channels", transportation mechanisms. Dimensions of the structural elements of materials are presented below [9].

Table 1. Dimensions of materials structural elements

Atoms – 0.1 nm	Microcrystals – 100 - 1000 nm
Atomic clusters – 0.5 - 2 nm	Fine-grained polycrystal – 1.0 - 10 nm
Quasicrystals – 2 - 5 nm	Normal grain size – 10 - 100 μm
Nanocrystals – 5 - 10 nm	Coarse grains – 100 μm
Submicrocrystals – 10 - 100 nm	

Table 2. Classification of polycrystals by grain size

Meso-level	Macrolevel
Large-grained (macro) polycrystal – 0.1 - 10 mm	Ultra-fine-grained (UFG) crystals – 0.2 - 1 μm
Normal (meso) polycrystal – 10 - 100 μm	Submicrocrystals – 5 - 200 nm
Fine-grained polycrystal – 1 - 10 μm	Nanocrystals – 3 - 50 nm
Imperfect crystals and amorphous state – no grains	

Identification of "penetration channels" can be carried out on the basis of modern ideas about the structures of nanomaterials and nanotechnology. The vast majority of engineering materials are metals with a crystalline structure. It was established that during crystallization there is a mismatch in orientation of the crystallographic planes of adjacent crystal lattices, reaching 5° in ordinary materials [10]. In nanomaterials, the mismatch can reach several dozens of degrees [9]. Significant misorientation also takes place when grains are crushed by traditional deformation methods (SPD, etc.).

If there are misalignments in location of crystallographic planes of the neighboring crystals being formed, free volumes will inevitably occur at the joints of the neighboring crystalline formations surfaces. It leads to appearance of some residual porosity, free volumes, and in ordinary materials with a low degree of misalignment up to 5° it increases significantly for nanostructures due to a significant increase in misalignment to several dozens of degrees [9, p. 35]. As the complex shape of crystals is formed, the elements of the crystalline forms of neighboring crystals come into contact with creation of constrained conditions, and mutual influence, up to mutual distortion of forms. Under these conditions, tight surfaces contact of the crystals contacting elements is eliminated, and formation of free volumes is inevitable. The processes are repeated until grains formation, which also occurs in constrained conditions, eliminating the tight contact of grains along their boundaries. As a result, grain-boundary pores are located and the bulk of the excess (free) volume is concentrated along the grains boundaries (GB) and their clusters [9, p. 36]. In monocrystals and coarse-grained polycrystals, the free volume takes the form of point defects, dislocation centers; with grain refining, the free volume of imperfect grain boundaries, GB, is added to them [9, p. 95].

Besides, when crushing grains, their fragmented parts become wedged with acute-angled peaks and ribs of fragments with formation of free volumes, the proportion of which in the deformation zone increases significantly, creating prerequisites for formation of the "penetration channel". Wedging eliminates occurrence of tight packing of fragments corresponding to the lowest content of free volumes.

To the greatest extent it is observed in the immediate crushing zone, creating, together with the available free volumes, the conditions for formation of "penetration channels". Outside the zone of direct deformation, as a result of various oscillatory processes, etc., wedging is eliminated with some compaction of the crushed grains fragments, though with preservation of a significant part of free volumes. While grinding grains, the shape of the free volume moving during deformation changes, its relative fraction increases and the mechanisms of atomic movement become more diverse. They are almost always group-like [9], which predisposes the possibility of movement of inhibitors in ionic form in the solid material.

But, in addition to the free volumes in the structures, the regions of grains directly adjacent to GB, having a special structure and properties, deserve special attention. It concentrates impurities, free volumes, dislocations, excess, versus equilibrium, free volume. The grain boundaries, GB, are sources of dislocations and drains for them. An increased diffusion permeability along the grain boundaries and in the absence of grain-boundary pores is noted. It is also noted that nanomaterials are characterized by extremely high diffusion mobility of atoms, which is 5 to 6 orders of magnitude higher than that in ordinary polycrystals [9, p. 30]. This is noted not only in nanostructures. In study [6], an unexplained phenomenon of segregation was noted, consisting in the "instantaneous" movement of atoms of certain elements in to solid metal towards surfaces. "Instantaneous" nature of movements should be explained by the extremely high fluidity of microlevel processes amounting to $10^{-6} - 10^{-11}$ s [11] and by the presence of "free volumes" in the structures that came into view only owing to nanomaterials development [9].

Formation of transport channels - "penetration channels"

The noted features are key in the issue related to deformation grinding of grains and the behavior of inhibitor ions – possibility of their penetration into the solid material. It can be seen from the foregoing that during plastic deformation of the surface layer with grain crushing, conditions are created for for-

mation of "penetration channels" in the material from the complex of free volumes in the solid body in combination with free volumes of mobile deformable layers. From the practice of conducting surface hardening treatment with deformation, examples are known where the crushing-deformation action extends to a depth of 35 – 40 mm [12]. This corresponds to wall thicknesses of hot-rolled pipes, and therefore, the experience can be used for anti-corrosion treatment of pipes in the solid material over the entire wall thickness. Equipment has been developed for similar treatment of outer and inner surfaces of pipes. As a result, the pipe wall can be treated from two sides. The penetrating ability of inhibitor ions, in addition to the free volumes of "penetration channels", increases, due to the specific properties of the material of grains adjacent to their boundaries. The specific nature of these zones with a large number of dislocations, concentration of impurities, and even interlayers in an amorphous state, provide conditions for plastic deformations, as a result of which new free volumes are generated. As a result, under conditions of the material structural elements mobility during surface plastic deformation with grains crushing, they are supplemented by new free volumes. Due to the arbitrary forms of free volumes, they are able to form a chain of separate larger volumes, forming "chambers", and volumes with smaller sizes, forming "connecting channels". Under the conditions of poly-frequency oscillations taking place in the solid material (as a result of a discrete multi-level structure of the material), the "chamber - connecting channel" systems are capable of playing the role of a peristaltic pump known from biology and technology. The essence of its action is to move the objects through the system "chamber - connecting channel" under the influence of volumes of "chambers" changing during oscillatory processes, in the presence of a "driving force". Electric forces act as the driving force.

Taking into account the high brevity of the microlevel processes ($10^{-6} - 10^{-11}$ s), the time of crushing and grinding of grains corresponding to the direct crushing effect is incommensurably long (it can be taken, to a first approximation, within 0.01 – 1 s). This is several orders of magnitude longer than the duration of the microlevel processes and means that a large number of microlevel acts can occur during the material deformation consisting in penetration of inhibitor ions into the solid body, their transportation through the "penetration channels", and formation of protective passivating films on the crystal structure elements. In addition to the "penetration channels" of free volumes, transportation of

inhibitor ions can be carried out due to the diffusion conductivity noted above at the grain boundaries, where, due to misorientation of the crystal lattices, interlayers of 1 to 5 nm with high content of dislocations (see above) are formed. These layers, under conditions of mobility and vibrational phenomena of a wide spectrum of oscillations, can also contribute to solving the problem. The observed ultrahigh diffusion permeability of nanomaterials should be associated with grain refinement, which can be compared with the common practice of hardening treatment with grain crushing. During strain hardening crushing of grains, both large fragments and small ones are formed that are comparable in size to nanograins. At the moment of grain destruction, new activated surfaces are formed, from which one should also expect initiation, along with other diffusion processes.

The role of vibrational phenomena in the transportation of an inhibitor in an array of material

The course of all previously described processes can be intensified to a large extent by oscillatory processes specific to discrete-level structures of materials. Since there are several levels of discreteness in the structure, there are the same number of oscillatory systems with their own oscillation frequencies. Each of the systems can come into oscillatory motion with its own oscillation frequency under the influence of external exciting forces.

The principles of oscillations occurrence are also fully related to the state of the surface deformed material – all elements of the deformable layer under the influence of external deformation are involved into oscillatory processes with their own oscillation frequencies. It is reflected on the course of processes – formation of "penetration channels", transportation of the inhibitor along them according to the principle of "peristaltic pump".

The role of electrical phenomena in the transport of inhibitor ions in an array of material

"Instantaneous" transportation is carried out by forces of electric nature. In previously considered cases of transportation, the sources of electric fields are electric charges on the moving objects and charges in the solid material. Carriers of electric charges on moving objects are inhibitor molecules decaying into ions. The sources of fields can be potential differences arising on various kinds of inhomogeneities: structural, physical, chemical, etc., forming galvanic pairs with the corresponding galvanic currents. The sources of electric fields are also

phenomena associated with contacts breaking, with formation of charges at the joints of double electric layers. It is this phenomenon that was observed in form of glowing of high intensity degree during hydroabrasive treatment [7]. It was the result of an abrasive particle rebound after its collision with the surface of the material, with formation of charges and subsequent discharges. The prevalence of phenomena is evidenced by the fact that charges are detected on the walls of microcracks [6]. Deformation treatment with grains crushing is accompanied by a large number of breaking contacts acts, formation of new surfaces, which should be accompanied by formation of charges and electric fields. The source of the potential difference can also be external electric fields capable of induction inducing potential differences inside the solid materials.

Presentation and discussion of the results

The given examples of facts of electrically charged particles movement inside solid material provide evidence of electric fields presence inside solid material. If there is a need to create additional electric fields, additional techniques can be applied as part of the treatment devices for pipes outer and inner surfaces. Due to the lack of special equipment for treating pipe surfaces, two types of equipment for treatment of outer and inner surfaces have been developed, depending on the need. For anticorrosion treatment of pipes by using SPD and the inhibitor, it is advisable to fulfill simultaneous treatment of both surfaces in order to create the proper energy background (electric fields). Designed devices for surface treatment of pipes include interchangeable drive or non-drive tool blocks. They allow installation of a wide range of tools from cutting to finishing types of treatment before coating. Structural arrangement of tool blocks allows using one block for treatment of a range of pipe diameters, with the need of 2 – 3 blocks for treatment of the entire range of pipes produced by the enterprise. When developing tool blocks, attention was paid to the thorough removal of scale, which forms an intense galvanic pair with the base metal, leading to corrosion. It is also necessary to remove small fragments of scale held on the surface by electrostatic forces. For this purpose, wire brush tools are used [13].

Specifics of brush tools work lies in a high-speed impact of an elementary tool – wire – followed by a deformation-cutting action and speedy separation from the work surface. The type of wire impact has common features with the type of impact

during waterjet processing, where intense electrical phenomena are observed. As a result, in addition to the electric fields of natural background, the intense electric fields obtained during treatment are added. Double-acting fields can be obtained from inner and outer surfaces.

The deformation-crushing effect on the surface with an adjustable preload force is carried out by the rollers of either the roll-out mill (for the outer surface) or the roll-in mill (for the inner surface). The preload force determines the depth of the crushing effect – it was noted that rolling to get required outer surface with the depth of impact of up to 35 – 40 mm was fulfilled. It is possible to process pipes, depending on their wall thickness, from two sides, or from one outer side.

Thus, the proposed technologies make it possible to eliminate the deficiencies of hot-rolled pipes by proper removal of scale, hardening of the coarse-grained surface layer by grains crushing, and carrying out anticorrosion inhibitory treatment of surfaces and inside the solid material. This is achieved by increasing the pipe products durability.

Particular attention deserves the possibility of preventing inter-crystalline corrosion with its manifestation along the grain boundaries with the formation of loose rust and unresistant corrosion products. As a result of this, the metal quickly loses its strength and ductility, suddenly easily destructing while the appearance of the metal remains unchanged [14, p. 15-16]. In combination with the secretive placement of pipeline routes in soils, inter-crystalline corrosion with its stealth flow poses a great danger.

Perspective directions of improvement

It can be seen from the foregoing that one of the fundamentals of anticorrosive treatment inside the solid metal in order to prevent inter-crystalline corrosion is grain refinement. It is accompanied, in addition to refinement, by the creation of residual compressive stresses, which, in combination with refined grain, provides an increase in anticorrosion properties. Grain refinement in the process of surface plastic deformation (SPD) in order to increase the strength characteristics while enhancing the anticorrosion properties has been widely used in mechanical engineering for a long time [12]. The direction of increasing the anticorrosion properties was developed in connection with the development of nanomaterials characterized by small grain sizes [15], [16], [17], [18], [19].

In addition to that, nanomaterials are characterized by a number of specific features that ensure successful development of anticorrosion treatment

direction inside the solid material. Among them are high mobility of nanostructures atoms, presence of large misalignment angles in the mutual arrangement of crystallographic planes, which generate a high level of dislocation defects, etc. There is an idea that nanostructures can be obtained by complex techniques using intense plastic deformation methods [19]. However, it was found that nanograin can be obtained as a result of processing with wire brushes, which have long been used in mechanical engineering [13].

For the implementation of anticorrosion treatment in the solid material, it is necessary to create "penetration channels". The condition for this is the mobility of structural elements - grains in the process of plastic deformation of the solid material, for example, of a pipe wall. In [9] and [20] the conditions for the occurrence of the long-range action and channeling effects, which can be developed in relation to inhibitory anticorrosion treatment, are considered. Along with the mobility of the grains, there is a refinement process with forming subgrains, which is also accompanied by an increase of anti-corrosion resistance [21].

Conclusions

1. Pipelines made of hot-rolled pipes of the oil and gas industry have significant wear that creates an increased degree of hazard for their operation. A similar situation is in heat supply, where the service life of heating mains is 4 – 6 years, and heat loss due to leaks reaches 50 %. Replacing pipelines in both cases, due to their underground laying, is time-consuming and expensive. Measures are required to extend their service lives.

2. Low corrosion resistance of transportation pipelines made of hot-rolled pipes is associated with the technological features of their production – presence of scale on surfaces and coarse-grained decarburized layers on surfaces. Improvement of indicators can be achieved by thorough removal of scale, hardening surface treatment with grains crushing during surface plastic deformation (SPD), inhibitory treatment of outer surfaces of pipes and structural elements inside the solid materials, combined with strain hardening treatment.

3. Inhibitory treatment inside the solid material ensures elimination of inter-crystalline corrosion proceeding as electrochemical corrosion with water in the entire solid material, causing damage of the entire solid body and disruption of structures.

4. Inhibitory treatment of the crystalline structures elements inside the solid material is feasible

under conditions of the elements mobility in the solid material during surface deformation with grains crushing, creating the conditions for formation of "penetration channels" for the inhibitor in ionic form in the solution to the elements of crystalline formations in the solid material. "Penetration channels" are formed from free volumes existing in the structures of the solid body array and formed as a result of the structural blocks movement and wedging of crushed grains fragments during deformation.

5. Transportation of the inhibitor in ionic form through the "penetration channels" is carried out under the influence of electric fields of the natural background of the material and additional fields created during treatment. Transportation is facilitated by oscillations of structural blocks of a multi-level discrete structure occurring under external deformation, with appearance of a kind of peristaltic pump in the "penetration channel".

6. The use of accessible, widespread inhibitors with various chemical formulas acting as anode passivators of the class of nitrites, phosphates, alkali metal silicates, is recommended; sodium phosphate Na_3PO_4 , sodium nitrite NaNO_2 and others. Sodium nitrite NaNO_2 was used in the abovementioned waterjet treatment.

7. The unit for simultaneous deformation treatment of both outer and inner surfaces of pipes, combined with inhibitory treatment of the outer surfaces and inside the solid material, has been designed.

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ПІДВИЩЕННЯ СТІЙКОСТІ ГАРЯЧЕКАТАНИХ ТРУБ В НАФТОГАЗОВИХ ТРУБОТРАНСПОРТНИХ СИСТЕМАХ І СИСТЕМАХ ТЕПЛОПОСТАЧАННЯ

Мета – розробка нових технологій антикорозійної обробки, включаючи попередження розвитку міжкристалітної корозії всередині масиву матеріалу з метою підвищення стійкості гарячекатаних труб.

Методика. На основі аналізу умов виготовлення та експлуатації труб виявлена основна причина зниження стійкості нафтогазових трубопроводів що транспортують з гарячекатаних труб через незадовільну корозійну стійкість, яка зумовлює у взаємозалежності і розвиток втомних процесів. В ході теоретичних і практичних досліджень виявлено одна з причин низької корозійної стійкості – повна відсутність антикорозійної обробки всередині масиву металу з метою попередження розвитку небезпечної міжкристалітної корозії.

Результати. На основі проведених експериментальних досліджень розроблені прийоми здійснення антикорозійної обробки всередині масиву матеріалу шляхом забезпечення надходження інгібітору в іонній формі в масив матеріалу. Це здійснюється в процесі пластичного деформування матеріалу з дробленням зерна. У результаті цього, завдяки рухливості зерен і їх фрагментів в умовах деформації, утворюються «канали провідності», за якими під впливом електростатичних полів природного або, при необхідності, і штучного фону, транспортуються іони інгібітору у масив матеріалу. Найбільш важливим результатом цього є інгібіторна обробка поверхні зерен всередині масиву матеріалу з попередженням розвитку електрохімічної міжкристалітної корозії.

Наукова новизна. На основі практичних робіт вперше здійснена антикорозійна обробка всередині масиву матеріалу, чим усувається вкрай небезпечна міжкристалітна корозія, що протікає таємно всередині масиву матеріалу. Передумовою до здійснення транспортування інгібітору в іонній формі всередині масиву матеріалу служать різноманітні приклади переміщень усередині масиву матеріалу різних елементарних утворень. Підтвердженням цього може служити сам факт протікання в масиві міжкристалі-

тної корозії, що протікає по типу електрохімічної, тобто, за участю води. Це свідчить про присутність в масиві молекул води і можливих каналах її проникнення в масив. Приклади можуть бути продовжені; при їх аналізі виявляється спільна риса – наявність у всіх випадках електричної природи, в тому числі, і у молекул води у вигляді дипольного моменту. Іншою умовою можливості транспортування інгібітору є наявність транспортних каналів. Вони утворюються з вільних обсягів, наявністю яких характеризуються кристалічні структури, і обсягів, що виникають у результаті пластичного деформування. Третьою умовою транспортування іонів інгібітору у масиві матеріалу є наявність рушійних сил; як їх виступають сили електричної природи, що забезпечують «миттєві» переміщення мікрооб'єктів. Їх джерелом виступають електростатичні поля матеріалу, що є наслідком великої кількості різниць потенціалів, що виникають на численних і різноманітних неоднорідностях матеріалів. Вони утворюють природний електростатичний фон, який забезпечує переміщення мікрооб'єктів в «моноліті» матеріалу в природних умовах. При необхідності, він може бути доповнений штучним електростатичним фоном, що створений зачисним щітковим інструментом, що здійснює видалення окалини з поверхні труби.

Практична цінність. Ступінь зношеності експлуатованих мереж висока; необхідний обсяг ремонтних робіт, значно перевищує обсяг робіт знову споруджуваних мереж. Такий самий стан і за умовами експлуатації, і за технічним станом мається на трубопроводних мережах теплопостачання, що мають також велику протяжність. Відмови в роботі тих і інших мереж, у зв'язку з їх розміщенням в ґрунтах, пов'язані з високими економічними втратами; те ж саме пов'язано з їх ремонтом. З цих причин подовження терміну служби гарячекатаних труб має велике господарське значення, яке важко переоцінити.

Ключові слова: гарячекатані труби, стійкість, надійність, межкуристалітна корозія, антикорозійна обробка, інгібітори, пластична деформація, поверхневе пластичне деформування.

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ПОВЫШЕНИЕ СТОЙКОСТИ ГОРЯЧЕКАТАНЫХ ТРУБ В НЕФТЕГАЗОВЫХ ТРУБОТРАНСПОРТНЫХ СИСТЕМАХ И СИСТЕМАХ ТЕПЛОСНАБЖЕНИЯ

Цель - разработка новых технологий антикоррозионной обработки, включая предупреждение развития межкуристаллитной коррозии внутри массива материала с целью повышения стойкости горячекатаных труб.

Методика. На основе анализа условий изготовления и эксплуатации труб выявлена основная причина снижения стойкости нефтегазовых транспортирующих трубопроводов из горячекатаных труб ввиду неудовлетворительной коррозионной стойкости, обуславливающей во взаимозависимости и развитие усталостных процессов. В ходе теоретических и практических исследований выявлена одна из причин низкой коррозионной стойкости – полное отсутствие антикоррозионной обработки внутри массива металла с целью предупреждения развития опасной межкуристаллитной коррозии.

Результаты. На основе проведенных экспериментальных исследований разработаны приёмы осуществления антикоррозионной обработки внутри массива материала путём обеспечения поступления ингибитора в ионной форме в массив материала. Это осуществляется в процессе пластического деформирования материала с дроблением зерна. В результате этого, благодаря подвижности зёрен и их фрагментов в условиях деформации, образуются «каналы проводимости», по которым под воздействием

вием электростатических полей естественного или, при необходимости, и искусственного фона, транспортируются ионы ингибитора в массив материала. Наиболее важным результатом этого является ингибиторная обработка поверхности зёрен внутри массива материала с предупреждением развития электрохимической межкристаллитной коррозии.

Научная новизна. На основе практических работ впервые осуществлена антикоррозионная обработка внутри массива материала, чем устраняется крайне опасная, скрытно протекающая внутри массива материала, межкристаллитная коррозия. Предпосылкой для осуществления транспортировки ингибитора в ионной форме внутри массива материала служат многообразные примеры перемещений внутри массива материала различных элементарных образований. Подтверждением этого может служить сам факт протекания в массиве межкристаллитной коррозии, протекающей по типу электрохимической, то есть, с участием воды. Это свидетельствует о присутствии в массиве молекул воды и возможных каналов её проникновения в массив. Примеры могут быть продолжены; при их анализе выявляется общая черта – наличие во всех случаях электрической природы, в том числе, и у молекул воды в виде дипольного момента. Другим условием возможности транспортировки ингибитора является наличие транспортных каналов. Они образуются из свободных объёмов, наличием которых характеризуются кристаллические структуры, и объёмов, возникающих в результате пластического деформирования. Третьим условием транспортировки ионов ингибитора в массиве материала является наличие движущих сил; в качестве их выступают силы электрической природы, обеспечивающие «мгновенные» перемещения микрообъектов. Их источником выступают электростатические поля материала, являющиеся следствием большого количества разностей потенциалов, возникающих на многочисленных и разнообразных неоднородностях материалов. Они образуют естественный электростатический фон, который обеспечивает перемещение микрообъектов в «монолите» материала в естественных условиях. При необходимости, он может быть дополнен искусственным электростатическим фоном, создаваемым зачистным щётчным инструментом, осуществляющим удаление окалины с поверхности трубы.

Практическая ценность. Степень изношенности эксплуатируемых сетей высока; требуемый объём ремонтных работ, значительно превышает объём работ вновь сооружаемых сетей. Сходное положение и по условиям эксплуатации, и по техническому состоянию имеется в трубопроводных сетях теплоснабжения, имеющих также большую протяжённость. Отказы в работе тех и других сетей, в связи с их размещением в грунтах, связаны с высокими экономическими потерями; то же самое связано с их ремонтом. По этим причинам продление срока службы горячекатаных труб имеет большое хозяйственное значение, которое трудно переоценить.

Ключевые слова: горячекатаные трубы, стойкость, надёжность, межкристаллитная коррозия, антикоррозионная обработка, ингибиторы, пластическая деформация, поверхностное пластическое деформирование.

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IMPROVING STRENGTH OF HOT-ROLLED PIPES IN OIL AND GAS PIPELINE TRANSPORTATION SYSTEMS AND HEAT SUPPLY SYSTEMS

Purpose. Development of new anticorrosion treatment technologies including prevention of inter-crystalline corrosion propagation inside the solid material in order to increase hot-rolled pipes life.

Methodology. Based on the analysis of pipes manufacture and operation conditions, the main reason

for reduction of the life of oil and gas transport pipelines made of hot-rolled pipes has been defined to be the poor corrosion resistance, which consequently causes propagation of fatigue processes. In course of theoretical and practical studies, one of the reasons for low corrosion resistance was revealed – complete absence of anticorrosion treatment inside the solid metal in order to prevent propagation of dangerous inter-crystalline corrosion.

Results. Based on the conducted experimental studies, practices have been developed to carry out anticorrosion treatment inside the solid material by ensuring feeding of the inhibitor in ionic form into the solid material. This is done through plastic flow deformation of the material with grain refinement. As a result, mobility of grains and their fragments under conditions of deformation cause formation of "conductance channels", along which the inhibitor ions are transported to the solid material under the influence of electrostatic fields of the natural or, if necessary, artificial background. The most important result of this is the inhibitory treatment of the grains surface inside the solid material with prevention of electrochemical inter-crystalline corrosion propagation.

Originality. Based on the practical works, anticorrosion treatment inside the solid material has been carried out for the first time, thereby eliminating the extremely dangerous inter-crystalline corrosion that latently propagates inside the solid material. A prerequisite for transportation of the inhibitor in ionic form inside the solid material are numerous examples of various elementary formations movements inside the solid body of material. This fact can be confirmed by inter-crystalline corrosion propagation in the solid material that generates in the manner of electrochemical corrosion, i.e. with water involved. This suggests the presence of water molecules in the solid material and possible channels of its penetration into the solid body. Many other examples can be given; their analysis reveals a common feature – in all cases there is an electrical nature, including water molecules that have an electrical dipole moment. Another precondition for the possibility of the inhibitor transportation is the presence of transportation channels. They are formed of free volumes, that are characteristic for crystalline structures, and volumes generated as a result of plastic flow deformation. The third precondition for the inhibitor ions transportation inside the solid material is the presence of driving forces; the forces of the electrical nature act in this case, ensuring "instantaneous" movements of micro-objects. Their source is the electrostatic fields of the material being the result of a large number of potential differences arising from the numerous and diverse inhomogeneities of materials. They form the natural electrostatic background, which ensures movement of micro-objects in the "solid body" of the material *in vivo*. If necessary, it can be supplemented with the artificial electrostatic background created by a grinding brush that removes scale from the pipe surface.

Practical implications. The deterioration degree of operated pipeline systems is high; the required amount of repair work significantly exceeds the scope of work for the newly constructed systems. A similar situation both in terms of operating conditions and in technical state is with heating pipeline systems, also being of great length. Failures in operation of both abovementioned systems due to their underground laying bring high economic losses; the same is in case of their repair. For these reasons, extension of hot-rolled pipes service life is of great economic importance, which is hard to overestimate.

Key words: hot-rolled pipes, strength, reliability, inter-crystalline corrosion, anticorrosion treatment, inhibitors, surface plastic deformation.

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