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Investigation of the microstructure of the oil pipeline pipes destroyed as a result of corrosion

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ABSTRACT
It is shown that the complexity of Kazakhstan's oils requires specific ways to protect oil pipelines from damage caused by metal corrosion. Even the presence of only paraffin in oil can cause sedimentation effects in the volume of liquid (Dorn effect). And the complexity in the molecular composition of oil causes electrophoretic impacts that lead to increased corrosion rate. All this should be considered when developing corrosion protection. The physical and mathematical analysis of possible mechanisms of electrophoretic mobility of components with the participation of liquid systems was carried out. In such a system with ions content, the macroscopic object will move as a charged particle having the same charge sign as the skeleton. The triboelectric effects on the metal/organic liquids (oil, fuel oil, etc.) boundary have been analyzed to determine their influence on the corrosion of pipeline metals. There are many methods used for temperature-strength control of reinforced concrete structures globally. Their majority is associated with the significant challenges of being time-consuming, costly, and prone to errors. Therefore, this study investigated the potential applicability of the surface-strength approach of specimens using non-destructive testing methods to derive temperature-strength relationships as an alternative approach to the currently widely used methods.
Keywords: Corrosion, oil pipeline pipes, electrical, conductivity, diesel, fuel.

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Introduction

In the scientific and technical literature, there are many points of view on determining the number of metals and liquid particles. However, the micromechanism of this reaction is not fully restored. But knowledge of this mechanism is necessary to create adequate internal protection of pipelines from the collision. An analysis of the current state of science shows that it is dominated by electrochemical and chemical approaches to the problems of assimilation of oxygen atoms and the composition of other liquid phases in a stable and often chemically very stable structure of metals and alloys. In the world literature, there is a huge amount of experimental data on redox processes, which leads to the conclusion that it is necessary to somewhat rethink the mechanism of oxygen incorporation into stable structures. In addition, there is a need to take generalizing conclusions from the works of M. Faraday as a theoretical basis for research in this scientific direction, which are now beginning to play a decisive role in the development of ideas about the nature of the chemical bond and the practical application of electrochemical processes.

In the 20th century, a huge amount of experimental material was accumulated, which confirms the correctness of M. Faraday's views on the effect of electric current on chemical reactions. Key points and main theses of the works of M. Faraday:

1. Identity of energy manifestations in the interaction of material objects.

2. Discrete nature of the electric current.

The statement about the identity of energy manifestations in the interaction of material objects provides a basis for revising scientific statements about the mechanism of heat exchange (and, in general, energy exchange) between material objects. There is reason to believe that it is necessary to have an idea about the features of the microstructure of condensed systems and the influence of the liquid microstructure on the transport of electric current in the system. Obviously, there is a need for a more detailed study of the microstructure of alloys and other solid objects to increase the effectiveness of technical solutions for protecting metals from corrosion.

Especially many questions arise when considering the problems of corrosion. According to scientific and technical literature, the following types of corrosion are known:

- continuous corrosion: Corrosion covering the entire surface of the metal;
- uniform corrosion: Continuous corrosion proceeding at the same rate over the entire surface of the metal;
- non-uniform corrosion: Continuous corrosion proceeding at different speeds on different parts of the metal surface;
- local (local) corrosion: Corrosion covering certain parts of the metal surface;
- pitting corrosion (Pitting): Local corrosion of the metal in the form of individual pitting.

The term "corrosion mechanism" means a combination of factors that are both of a chemical nature (corrosion mechanism in the "classical" sense - carbon dioxide, hydrogen sulfide, mixed, etc.) and related to the technological features of pipeline operation (speed and flow structure, various disturbances in the flow characteristics associated with any technological processes at associated objects). "Mechanism of corrosion" defines the causes, corrosion rate of the pipeline, localization and nature of corrosion damage.

The corrosion mechanism is determined by the following factors that need to be evaluated before developing corrosion protection methods.

Chemical composition of transported products:
- pH value (pH);
- the concentration of carbon dioxide;
- hydrogen sulfide concentration;
- oxygen concentration;
- ionic composition of the aqueous phase;
- bio injection;
- component composition of the gas phase;

component composition of the liquid hydrocarbon phase [1].

Phase composition of products:
- the proportion of water;
- share of gas;
- the concentration of mechanical impurities [1].

Flow characteristics:
- product consumption;
- flow rate;
- flow structure;
- the presence of an extended water sublayer;
- the existence of local water accumulations;
- the possibility of alternate wetting [1].

Technological characteristics:
- Temperature;
- Pressure;
- Possibility of contact with process fluids.

Corrosion characteristics:
- accident rate due to internal corrosion;
- corrosion rate according to non-destructive testing data;
- corrosion rate from corrosion monitoring results;
- design corrosion rate;
- localization of corrosion defects along the pipe section and the pipeline route [1].

Joint consideration of the classification of types of corrosion and the factors necessary to determine methods of protection against corrosion lead to the following conclusion: the formulation of the concept of "corrosion mechanism", the classification of types of corrosion, and factors affecting the corrosion process, do not apply to the analysis of the mechanism of a chemical reaction leading to the introduction of atoms oxygen and other chemical elements into the metal microstructure. The results of metal corrosion destruction and technological factors influencing the destruction rate are considered.

About 4% of the connecting pieces used in the construction of oil pipelines in the 1950s–1970s were manufactured in the field. Despite the fact that in recent years the number of such parts has significantly reduced, failures associated with their lack of reliability occupy a noticeable share in the total number of failures in the system of oil trunk pipelines. The purpose of this work is to analyze the typical causes of failure of connecting parts using the example of a tee bend with a reinforcing plate. The authors carried out structural and fractographic studies of the defective structure [4]. On the basis of information about the operating conditions and the actual characteristics of the bent metal, as well as data on the centers of destruction and the nature of crack propagation, computer modeling of the stress-strain state of the part was carried out. Based on the results of metallurgical studies and computer modeling, it was established that the cause of the formation through a crack in the weld at the junction of the main oil pipeline and the reserve branch was excess stresses in the area of welding of the reinforcing plate to the branch, exceeding the tensile strength of the material of the tee branch pipe [2].

An analysis of the current state of research on the development of methods for protecting metals from corrosion of oil pipelines shows that much attention in these studies is paid to electrochemical methods of protecting metals from environmental influences [3]. However, in multicomponent systems, combined electrochemical reactions require in-depth study. This is because when exposed to aggressive media on steel structures, many corrosions occur together. This leads to severe accidents on industrial oil pipelines. For example, an underwater fire occurred in the Pemex offshore pipeline in the Gulf of Mexico [5].

An analysis of our studies of chemical processes at the phase boundary of multicomponent systems showed that in some cases, the onset of chemical reactions is influenced by triboelectric effects that occur when individual parts of the system move relative to each other. Therefore, this article discusses some aspects of this phenomenon when pumping oil through main pipelines [6].

Experimental technique

We have shown that substances' physical and chemical properties are determined by the structure of primary elements of the microstructure - "chemical individuals". And thanks to a detailed study of changes occurring in the microstructure, which is reflected in changes in the properties of the macroscopic formation, tribology allows us to calculate the amount of heat generation, durability, and wear and tear of structures, model interacting surfaces, solve the problems of boundary hydrodynamics and in the future to obtain materials with the given properties. In addition, the study of the tribolic effect will allow the causes of various undesirable processes, such as the destruction of materials due to corrosion and others [7].

It is known that tribolytic effects electrify and generate heat, which requires clarification of heat transfer processes at the micro-micro level. To determine the tribolytic impacts of oil and oil products, the oil composition of the Mangystau field in the Ozenmunaigas field was determined [8].

In this respect, oil and oil products have a special place, which differs in physical and chemical characteristics. The elemental composition of the investigated oils is summarized in Table 1. By sulfur content, the oil belongs to the second class. In terms of elemental composition, oils differ in sulfur content. In oil, the oxygen content increases from 2.6 to 9.4% mass, nitrogen from 0.3 to 2.2% mass. The elemental composition of Ozenmunaigas JSC oil is given in the table. The main components of oil are: carbon 84-85.8%, hydrogen 12.0-13.6%, nitrogen 0.2-0.4, sulfur 1.4-2.0, oxygen 1.1-1.4 % and others. In this case, the light fraction is made up of alkanes

Table 1 - Elemental composition of oil "JSC" Ozenmunaigas

Oil samples	Contents of elements, %					Others,%
	C	H	N	S	O	
Sample A	84.1	13.6	0.4	1.8	1.4	**2.1**
Sample B	85.0	12.8	0.2	2.0	1.1	**0.3**
Sample C	84.8	12.0	0.2	1.4	1.1	**0.5**

Table 2 - Physicochemical characteristics of oil in the Mangystau region

Name	Oil 1	Oil 2	Oil 3
View	Dark Brown	Dark	Dark Brown
Density at 200C, g/cm3	0.816	0.844	0.864
Water Content,%	0.6	0.7	0.8
The concentration of chlorides, mg/l	450	560	600
Kinematic viscosity, mm2/s(20^0C)	56	60	64
Solidification temperature,^{0}C	15- 20	18-21	14-18
Flashing point in the closed crucible,^{0}C	58	56	60
Coking,%	4.6	4.8	5.0
Residual after overclocking 320^0C, including. (%):	54.0	57.0	58.4
Paraffin-Naphtens	46.0	43.5	41.4
Arena	36.0	34.5	34.6
Resins	6.0	7.0	7.0
Asphaltenes	4.0	5.0	6.0
Others	8.0	10.0	11.0

with the number of carbon atoms C1-C11 (normal alkanes 40-50%). Paraffins with carbon atoms C12-C17 make up 20-25% of oil. The content of naphthenic hydrocarbons ranges from 25 to 55%. Resins and asphaltenes contain solids, including porphyrins and other undeciphered substances. [8]

Although oil and products are derived from petroleum fuels, oils are dielectrics under normal conditions. When their fractions move relative, electrostatic charges arise. The experimental values of the specific electrical conductivity of oil and oil products in laboratory conditions allow us to judge their dielectric nature (Table 2) [9].

Electrophysical properties of oils and petroleum products are currently insufficiently studied, especially regarding the movement of individual liquid components relative to each other. In the transportation process in the volume of oil and petroleum products, due to the complex microstructure and certain heterogeneity of the macrostructure, electrostatic charges can be formed. In this case, the potential difference between the individual sections of the fluid volume may be quite significant. The accumulation of electrostatic charges can ultimately be realized as a spark discharge, a chemical process, etc. This leads to ignition of oil products, destruction of pipelines, and premature failure of equipment parts. [[10], [11], [12]].

Functional analysis of these complex systems is necessary to determine the influence of the oil structure on their physical and chemical characteristics. IR spectra of some samples of oils in Kazakhstan have been taken. Below infrared spectra of initial highly paraffinic oil samples and asphalt-resinous paraffinic deposits are presented. Asphalt-paraffin component is manifested in infrared spectra of initial oil. Therefore, this component plays a decisive role in the physical and chemical transformations that occur during oil movement in the pipeline. The following functional groups in the range 2916.70 have been revealed -2848.81 $см^{-1}$ -(CH_2)-; 1461.75 $см^{-1}$ – CH_3-; 719,44 $см^{-1}$ - (CH); 2916.70 -2848.81 $см^{-1}$ -(CH_2)-; 1461.75 $см^{-1}$ – CH_3-. [13].

Table 3 - Values of specific electrical conductivity of oil and oil products

Oil and petroleum products	Specific Electroconductivity, См·м. $^{-1}$
Oil Uzenmunaigas	$1·10^{-5}$ - $4·10^{-5}$
Mazut	$1·10^{-7}$ - $2·10^{-9}$
Gasoline (N.K. - 140^{0}C)	$4·10^{-11}$ - $6·10^{-12}$
Kerosene (fr. 140- 180^{0}C)	$1·10^{-10}$ - $4,6·10^{-12}$
Aerial gasoline (fr. 40- 180^{0}C)	$1,1·10^{-11}$ - $4,6·10^{-11}$
Jet fuel (fr.180- 260^{0}C)	$1·10^{-10}$ - $1·10^{-12}$
Diesel (fr.220- 280^{0}C)	$3·10^{-11}$ - $5·10^{-11}$
Gasoil (fr.240- 350^{0}C)	$2·10^{-8}$ - $4·10^{-9}$

Results and Discussion

Oil and petroleum products are a source of fire hazards, including those caused by electric charges caused by triboelectric effects. These circumstances require a more detailed study of these systems. The mechanism of occurrence of electrostatic charges between surfaces of two moving liquids, liquid-solid surfaces of bodies, is still insufficiently studied and requires a fundamental solution to the problem [14]. Experimental values of specific electrical conductivity of oil and petroleum products under laboratory conditions have been obtained, allowing us to judge their dielectric character. The values of electrical conductivity of oils and petroleum products have been established [15].

Oil and petroleum products are bad conductors. According to literature data, specific electrical conductivity is 10-5-10-8 Om-1m-1 for crude oil. However, even an insignificant content of impurities in the movement of these liquids causes the formation of electrostatic charges. A material object is able to produce positive or negative charges, which are characterized by a triboelectric scale. At the mechanical movement of oil components relative to each other, the polarization of hydrocarbon molecules occurs, which results in interphase potential difference [[16], [17]].

Electrophysical properties of oil products (gasoline, kerosene, etc.) were determined to determine triboelectric effects at the boundary between metal/organic liquids (oil, fuel oil, etc.) to determine their influence on the corrosion of pipeline metals. As a parameter of electrical characteristics of oil products, current forces were measured and the results are summarized in the table [18].

Table 4 - Influence of gasoline pumping speed on electrification current values

No.	Pumping speed, m/s	Measured current strength, μA	Relative error, %
1	1.0	0.901	5.0
2	2.0	1.044	7.0
3	3.0	1.216	6.0
4	4.0	1.645	5.0
5	5.0	1.735	5.0
6	6.0	1.971	7.0
7	7.0	2.105	6.0
8	8.0	2.403	5.0

Table 5 - Influence of kerosene pumping speed on electricization current values

No	Pumpings peed, m/s	Measuredcurre ntstrength, μA	Relativeerror, %
1	1.0	0.706	6.0
2	2.0	0.978	5.0
3	3.0	1.045	6.0
4	4.0	1.119	6.0
5	5.0	1.265	5.0
6	6.0	1.339	7.0
7	7.0	1.827	6.0
8	8.0	1.951	5.0

Table 6 - Influence of diesel fuel pumping speed on current electrification values

No.	Pumping speed, m/s	Measured current strength, µA	Relative error, %
1	1.0	0.617	5.0
2	2.0	0.781	7.0
3	3.0	0.899	6.0
4	4.0	1.103	5.0
5	5.0	1.266	5.0
6	6.0	1.322	7.0
7	7.0	1.474	6.0
8	8.0	1.537	5.0

As the pumping rate of petroleum products increases, the value of current strength increases due to the appearance of triboelectrification in the systems studied. The appearance of the triboelectrization effect is caused by electrification, i.e. occurrence of electric potential in oil products, which causes corrosion [19].

Any disturbance of this equilibrium state leads to polarizations of "electromagnetic matter" on the surface of substances and creates a triboelectric effect. During friction and deformation of materials, "electromagnetic matter" is polarized, the electromagnetic interaction changes, and "electromagnetic matter" is released in the form of heat, and at the places of rupture of the bond simultaneously appears electric charges with the corresponding potentials [20].

Conclusions

In the case of system stationarity disorders, depending on the nature of the process, "electromagnetic matter" manifests itself in heat, light, electromagnetic field, bias current, etc. Friction and deformation of materials lead to polarizations of "electromagnetic matter", which changes the electromagnetic interaction of the system and releases "electromagnetic matter" in the form of heat. In the places of rupture of communication simultaneously, there are electric charges with corresponding potentials causing triboelectric effects.

Conflict of interest. The correspondent author declares that there is no conflict of interest on behalf of all authors.

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Коррозия нәтижесінде қираған мұнай құбырының құбырларының микроқұрылымын зерттеу

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Материалтану және коррозия мәселелері жөніндегі ғылыми-білім беру орталығы
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ТҮЙІНДЕМЕ:
Бұл жұмыста Қазақстан мұнайының күрделі болу себебінен мұнай құбырларын металл коррозиясынан болатын зақымданудан қорғаудың ерекше тәсілдері қажет болатыны көрсетілген. Мұнайда тек парафиндердің болуының өзі сұйықтықтың негізгі бөлігінде шөгу әсерін тудыруы мүмкін (Дорн эффектісі). Ал мұнайдың молекулалық құрамының күрделілігі электрофоретикалық әсерлер туғызып, коррозия жылдамдығының артуына әкеледі. Мұның бәрін коррозиядан қорғауды әзірлеу кезінде ескеру қажет. Сұйық жүйелердің қатысуымен компоненттердің электрофоретикалық қозғалғыштығының мүмкін механизмдерінің физикалық-математикалық талдауы жүргізілді. Құрамында иондар бар мұндай жүйеде макроскопиялық нысан қаңқа сияқты заряд белгісімен зарядталған бөлшек ретінде қозғалады. Металл/органикалық сұйықтық шекарасындағы (мұнай, мазут және т.б.) трибоэлектрлік әсерлерді талдау, олардың құбыр металдарының коррозиясына әсерін анықтау үшін жүргізілді. Бүкіл әлемде темірбетон конструкцияларын температуралық және беріктік жағынан сынау үшін қолданылатын көптеген әдістер бар және олардың көпшілігі айтарлықтай қиындықтармен, уақытты қажет ететін, шығындармен және қателіктермен байланысты. Осылайша, бұл зерттеуде қазіргі уақытта кеңінен қолданылатын әдістерге балама тәсіл ретінде температура-беріктік қатынасын алу үшін бұзбайтын сынау әдістерін пайдалана отырып, үлгілердің бетінің беріктігін анықтау әдісінің әлеуетті қолдану мүмкіндігі зерттелді.

Түйін сөздер: коррозия, мұнай құбырлары, электрөткізгіштік, дизель отынын айдау жылдамдығы, электрлену тоғының мәндері.

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Исследование микроструктуры труб нефтепровода, разрушенных в результате коррозии

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АННОТАЦИЯ
Показано, что сложность казахстанских нефти требует особых способов защиты нефтепроводов от повреждений, вызванных коррозией металлов. Даже присутствие в нефти только парафинов может вызвать эффекты седиментации в объеме жидкости (эффект Дорна). А сложность молекулярного состава масла вызывает электрофоретические эффекты, приводящие к увеличению скорости коррозии. Все это следует учитывать при разработке защиты от коррозии. Проведен физико-математический анализ возможных механизмов электрофоретической подвижности компонентов с участием жидких систем. В такой системе с содержанием ионов макроскопический объект будет двигаться как заряженная частица, имеющая тот же знак заряда, что и скелет. Проведен анализ трибоэлектрических эффектов на границе металл/органические жидкости (нефть, мазут и др.) для определения их влияния на коррозию металлов трубопроводов. Существует множество методов, используемых для температурно-прочностного контроля железобетонных конструкций во всем мире, и большинство из них связаны со значительными трудностями, требующими много времени, затратами и подверженными ошибкам. Таким образом, в этом исследовании изучалась потенциальная применимость метода определения поверхностной прочности образцов с использованием методов неразрушающего контроля для получения соотношений температуры и прочности в качестве альтернативного подхода к широко используемым в настоящее время методам.

Ключевые слова: коррозия, нефтепроводы, электропроводность, скорость впрыска дизельного топлива, значения тока электризации

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