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## ANALYSIS OF MODERN ASPECTS OF CORROSION PROBLEMS AND THEIR SOLUTIONS

**Abstract.** The article presents a study of technogenic phosphoride raw materials obtained in Kazakhstan as waste from various industrial processes in order to be used as raw materials for the production of corrosion inhibitors in the oil and gas industry. The chemical composition and physical properties of phosphoride raw materials from various sources were studied, methods of its enrichment were analyzed, and studies were also carried out to change the obtained phosphate compounds in order to increase their effectiveness as corrosion inhibitors. Laboratory tests were carried out on steel samples typical for the oil and gas industry and optimal conditions for the use of synthesized inhibitors were determined. The results of the study show that technogenic phosphoride raw materials can be effectively used for the production of corrosion inhibitors, which will reduce raw material costs and contribute to the sustainable development of the oil and gas industry in Kazakhstan. The article also considers the possibility of modifying the obtained inhibitors in order to improve their properties and expand the scope of application.

Metal corrosion is a serious problem that can lead to significant economic losses and pose a safety risk. Phosphorus inhibitors are an effective corrosion prevention tool used in various industries, including oil and gas, energy, chemical and others. This article is devoted to the study of the effectiveness of phosphate inhibitors of corrosion, describes modern approaches to their study and prospects for further development. Particular attention is paid to the environmental benefits of inhibitors developed based on the processing of man-made raw materials, which contribute to reducing the volume of waste and reducing the environmental burden on nature. The development of inhibitors based on the processing of man-made waste will create a new eco-oriented strategy in the oil and gas industry of Kazakhstan, combining economic efficiency with respect for the environment.

**Key words:** phosphorus inhibitor, metal corrosion, man-made waste, man-made raw materials, gravimetric method, electrochemical method.

**Introduction.** The main focus of research is the creation of new phosphorus inhibitors with improved properties based on molecular design and research, and the development of inhibitors with a targeted mechanism of action aimed at specific types of corrosive processes or metals. Inhibitors with improved properties need to meet the properties of increasing efficiency, reducing toxicity, increasing biodegradability and resistance to temperature and pressure. The modern study of phosphorus corrosion inhibitors is a rapidly developing field of chemistry aimed at developing new and improved inhibitors in order to solve pressing problems in various fields and technologies. The combination of classical approaches with modern methods and technologies makes it possible to create inhibitors with improved properties, more efficiently and safely protect metals from corrosion, and contribute to the sustainable development of various industries.

Corrosion inhibitors are chemicals that are added to aggressive environments to slow down or prevent corrosion processes on metal surfaces. They act by forming a protective layer on the metal surface that prevents the metal from contacting an aggressive environment, or by modifying electrochemical corrosion processes. Green corrosion inhibitors are inhibitors that meet environmental safety requirements. They must be biodegradable, non-toxic to living organisms and not cause environmental pollution. The development of green corrosion inhibitors is an important task in the context of sustainable development and minimizing the impact of the oil and gas industry on the environment. Traditional corrosion inhibitors typically contain toxic and non-biodegradable components. These substances can cause soil, water and air pollution, as well as harm human health. Therefore, the development of green corrosion inhibitors is an urgent task in the modern chemical industry. These compounds often have low toxicity and good biodegradability. Corrosion inhibitors play a crucial role in industry by protecting metal structures and equipment from the destructive effects of corrosion, significantly extending their service life and reducing the cost of operation. They act by various mechanisms, including the formation of protective layers on the metal surface, modification of electrochemical corrosion processes or a change in the chemical composition of an aggressive environment. In the chemical industry, corrosion inhibitors are widely used to protect tanks, pipelines, reactors and other equipment from corrosion caused by aggressive chemicals used in production processes. Corrosion inhibitors are also used in the production of paints, varnishes and other materials, providing protection against corrosion of coatings.

Phosphorus-containing corrosion inhibitors differ from other types of inhibitors by the presence of phosphorus in their structure, which determines their unique mechanisms of action and properties. Unlike traditional inhibitors based on chromium compounds, nitrites, amines or other components, phosphorides are characterized by a more complex chemical composition and the ability to form protective films on the metal surface with higher corrosion resistance. Phosphorus compounds have a higher ability to form insoluble phosphate films on the surface of metals, which act as a barrier between the metal and an aggressive environment. These films are often characterized by higher adhesion, density and fracture resistance compared to films formed by other types of inhibitors.

In addition, phosphorous compounds can act as inhibitors of both cathodic and anodic corrosion reactions. They can slow down both the metal oxidation process (anodic reaction) and the oxidant reduction process (cathodic reaction). This makes them more effective in combating corrosion compared to inhibitors that act on only one of these reactions. However, phosphorus-containing inhibitors have some disadvantages. For example, they may be less effective in the case of high temperatures or pressures, as well as require more thorough preparation of the metal surface before their use. Phosphorus-containing inhibitors are effective corrosion protection agents that are widely used in the oil and gas industry and other industries.

However, their selection and application should be carried out taking into account the specific working conditions and requirements for efficiency and safety.

Kazakhstan has significant reserves of phosphorus raw materials, represented mainly by apatite – natural calcium phosphate with the chemical formula  $\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$ . The main deposits of phosphorites are located in Karaganda, Zhambyl and Kyzylorda regions. Phosphorites of Kazakhstan are characterized by a high content of  $\text{P}_2\text{O}_5$  (up to 30%), and also contain impurities of iron, aluminum, silicon oxides. Phosphorus deposits in Kazakhstan play an important role in the world market for phosphate raw materials. The country is among the leading manufacturers of its products, exporting them to the world market. However, despite significant reserves of phosphate raw materials, Kazakhstan faced a number of problems in this area. However, the country has a significant potential for the development of the phosphate industry and increasing investment in new technologies due to huge reserves of raw materials.

The Karatau field, located in Zhambyl region, is one of the largest in Kazakhstan. High  $\text{P}_2\text{O}_5$  apatite, reaching 30%, is produced here, and is also characterized by a significant amount of impurities such as iron ( $\text{Fe}_2\text{O}_3$ ), aluminum ( $\text{Al}_2\text{O}_3$ ), Silicon ( $\text{SiO}_2$ ) and other elements. The Aktobe field, located in the Aktobe region, contains phosphorites with a low content of  $\text{P}_2\text{O}_5$  (about 20%), but is distinguished by a high concentration of organic substances. The Taraz field, located in the Zhambyl region, is also distinguished by a high content of impurities. Other deposits of Kazakhstan: Zhezkazgan, Ashchysai, Aktau, etc. contain apatite, but the ratio of the main components and impurities is different, which affects their suitability for different purposes. For use as corrosion inhibitors, phosphate minerals of Kazakhstan require special treatment and processing. The process includes: enrichment: removal of impurities by flotation, magnetic separation, gravitational enrichment, etc., which can increase the  $\text{P}_2\text{O}_5$  content and reduce unwanted components.

In resource-rich Kazakhstan, man-made waste is widely used to obtain phosphorus corrosion inhibitors. Shymkent, a large industrial center, has significant reserves of phosphate waste from the production of phosphorus fertilizers and the metallurgical industry. These residues contain phosphorus in various forms, such as calcium, iron and aluminum phosphates, which can be used to synthesize inhibitors. Unlike traditional methods of using mineral resources such as apatite, man-made waste recycling is an environmentally and economically viable approach. If we talk about the main differences and features of obtaining inhibitors from man-made waste in Shymkent, then man-made waste is characterized by a more complex chemical composition than mineral raw materials. They contain not only phosphates, but also various additives, such as metal oxides, sulfates, chlorides, etc. Processing of man-made waste requires more refined and specialized processing in order to remove unnecessary impurities and obtain phosphates with the necessary properties. Inhibitors derived from man-made waste may be of lower quality and stability compared to inhibitors derived from pure mineral raw materials. They will have additives that affect their effectiveness and service life.

Phosphate slags formed during the production of phosphate fertilizers as raw materials for obtaining phosphate inhibitors from phosphorus production waste in Shymkent. The use of man-made waste to obtain corrosion inhibitors reduces environmental pollution and eliminates valuable resources. The processing of man-made waste can be more profitable from an economic point of view, as it reduces the cost of raw materials and reduces the costs of its transportation. A number of studies are being conducted in Shymkent to develop technologies for processing phosphate waste and obtaining corrosion inhibitors. These studies are aimed at improving the processes of obtaining phosphorus and creating inhibitors with high quality and stability. It should be noted that the extraction of inhibitors from man-made waste requires careful quality control and consideration of the chemical composition of the waste in order to ensure the effectiveness and safety of the obtained inhibitors. In general, Kazakhstan has a

significant potential for the production of phosphoric corrosion inhibitors from both mineral raw materials and man-made waste. The choice of a source of raw materials depends on specific production conditions, economic and environmental factors. The Karachaganak and Chinarev fields are the largest natural gas deposits in Kazakhstan, characterized by high corrosive activity due to the presence of hydrogen sulfide ( $H_2S$ ), carbon dioxide ( $CO_2$ ) and water in oil and gas. Various types of corrosion inhibitors, including phosphorus inhibitors, are used in these fields to prevent corrosion of equipment and pipelines. The presence of hydrogen sulfide ( $H_2S$ ) and carbon dioxide ( $CO_2$ ) increases the corrosive activity of the medium and requires the use of highly effective inhibitors in acidic environments. High temperatures and pressure from oil and gas wells limit the choice of inhibitors and require the use of temperature-resistant inhibitors. Phosphorus inhibitors can be used in combination with other types of inhibitors, such as Amine inhibitors, to improve the overall effectiveness of corrosion protection.

Examples of phosphorus inhibitors used in deposits in Kazakhstan:

Sodium tripolyphosphate ( $Na_5P_3O_{10}$ ): is an effective corrosion inhibitor in acidic environments and has good heat resistance.

Sodium hexametaphosphate ( $Na_6P_6O_{18}$ ): has high efficiency in high temperature and pressure conditions and is well combined with other inhibitors.

Zinc phosphates:  $Zn_3(PO_4)_2$  - effective in corrosion protection in a slightly acidic environment and has good anti-corrosion properties.

**Research materials and methods.** The gravimetric method, based on the determination of the precipitate mass formed by the interaction of phosphates with the corresponding reagent, is one of the methods for analyzing man-made phosphoride raw materials to obtain corrosion inhibitors. This method is used to determine the total phosphorus content in a sample, but does not make it possible to distinguish between different forms of phosphates. In the case of man-made raw materials, characterized by a complex chemical composition and the presence of various impurities, the gravimetric method requires additional stages of sample preparation and selection of special reagents.

Most often, a solution of barium chloride  $BaCl_2$  is used to precipitate phosphates, which forms an insoluble precipitate of barium phosphate  $Ba_3(PO_4)_2$ . After filtration, washing and drying, the precipitate is measured and, knowing the molar mass of barium phosphate by its mass, the mass of phosphorus in the sample can be calculated. However, when analyzing man-made raw materials, it is necessary to take into account the presence of impurities that can affect the accuracy of phosphorus determination. It is also important to note that the gravimetric method is not sensitive enough to detect low phosphorus concentrations, which can be a disadvantage in the analysis of low-phosphorus man-made raw materials. In general, the gravimetric method of analysis of man-made phosphoride raw materials can be used to quickly determine the phosphorus content in samples, but it is necessary to take into account the presence of impurities and the limitations of the method in terms of sensitivity.

Electrochemical methods such as polarizing curves and impedance spectroscopy are used to study the effectiveness of corrosion inhibitors derived from man-made phosphoride raw materials. These methods are based on the measurement of electrochemical parameters on the metal surface in a corrosive medium with and without the presence of an inhibitor, which makes it possible to assess its effect on the kinetics of corrosive processes.

The polarizing curve method is based on measuring the dependence of the current on the electrode potential in a corrosive medium. Comparison of polarizing curves with and without an inhibitor allows us to determine the effectiveness of the inhibitor in slowing down corrosion. Polarization curves provide information about corrosion rate, corrosion potential, and polarization resistance. Impedance spectroscopy is a complex method based on measuring the

resistance of an electrochemical system in a wide frequency range. The impedance Spectra contain information about the kinetics of electrochemical processes and the properties of the protective film formed on the metal under the influence of the inhibitor.

Impedance analysis allows you to determine such parameters of the protective film as resistance, capacitance and thickness. For the analysis of technogenic phosphoride raw materials, electrochemical cells with a working electrode made of steel typical for the oil and gas industry are used. A solution that simulates the corrosive environment of oil and gas wells containing hydrogen sulfide (H<sub>2</sub>S), carbon dioxide (CO<sub>2</sub>) and water is used as an electrolyte.

Electrochemical methods make it possible to assess the effectiveness of inhibitors obtained from technogenic phosphoride raw materials in conditions close to the actual conditions of operation of oil and gas wells. Importantly, electrochemical methods are indirect methods for assessing the effectiveness of inhibitors and require correlation with direct test results in the real world. However, electrochemical methods are relatively fast, inexpensive and informative methods and allow us to assess the influence of various factors such as inhibitor concentration, temperature and composition of the corrosive medium on the inhibition efficiency.

Modifications of man-made phosphorus corrosion inhibitors aim to improve their properties such as adhesion to the metal surface, inhibition efficiency, thermal stability, biodegradability and toxicity reduction. Modification can be achieved by introducing new functional groups into the inhibitor molecule, creating a nanostructure or composites with other nanomaterials, and combining with other types of inhibitors. The introduction of new functional groups into the phosphorus inhibitor molecule is one of the main methods of modification aimed at improving its properties related to its adhesion to the metal and inhibition efficiency.

Alkylation: the introduction of alkyl groups (R-, Where r is an alkyl radical) into the inhibitor molecule increases its lipophilicity (proximity to nonpolar media such as a metal surface). This is due to the predominance of hydrocarbon C-H bonds in alkyl groups and a decrease in the polarity of the molecule. The increased lipophilicity of the inhibitor improves its adhesion to the metal surface, which makes it more effective in protecting against corrosion.

Amination: administration of amino groups (-NH<sub>2</sub>) increases the polarity of the inhibitor molecule and may enhance the inhibitory effect. Amines have the ability to form hydrogen bonds, which allows them to firmly adhere to the metal surface and form a protective film. In addition, amines can react with corrosive products, such as metal ions, preventing the further development of corrosion. Introduction of heterocyclic groups: heterocyclic groups are cyclic structures that contain not only carbon atoms, but also other elements such as oxygen, nitrogen, and sulfur. The introduction of heterocyclic groups into the inhibitor molecule can enhance its inhibitory properties by forming strong protective films on the metal surface. This is due to the presence of electron donor atoms (for example, nitrogen) in heterocycles, which increase interaction with the metal surface.

**Results and discussion.** The modification of man-made phosphorus corrosion inhibitors is an integrated approach aimed at increasing their efficiency and expanding the scope of application, which makes them competitive with traditional synthetic inhibitors. Modification is achieved by introducing new functional groups into the inhibitor molecule, creating nanostructural shapes or composites with other nanomaterials, and combining with other types of inhibitors.

Modifications of phosphorus inhibitors have significant advantages:

Improved efficiency: modified inhibitors are more effective in preventing corrosion and extending the service life of equipment.

Extended application range: modified inhibitors can be used in aggressive environments and at high temperatures.

Reduced toxicity: modifications can reduce the toxicity of inhibitors and improve their environmental characteristics.

Improved biodegradation: the modification can speed up the biodegradation process of inhibitors after use, reducing the risk of environmental pollution.

Cost reduction: the use of man-made raw materials and modifications can reduce the cost of inhibitor production.

Thus, the modification of technogenic phosphorus inhibitors is a promising direction in the development of inhibitory technology in Kazakhstan. This makes it possible to create more efficient, safe and environmentally friendly corrosion inhibitors for the oil and gas industry. The enrichment and modification of man-made phosphoride raw materials for the production of corrosion inhibitors are the main stages in the process of recycling waste into valuable products and ensure the production of effective and safe inhibitors. Enrichment is the process of removing impurities from phosphoride raw materials, which allows you to increase the concentration of phosphorus and improve the quality of the resulting inhibitor. The main enrichment methods are flotation, magnetic separation, gravity enrichment and acid treatment. These methods allow you to separate unwanted minerals such as iron oxides, silica, and clay from phosphate minerals. Modification of phosphorus inhibitors is the process of changing their structure and properties in order to increase the effectiveness of inhibition and expand the range of applications. The main methods of modification include the introduction of new functional groups, nanostructure and the creation of composites with other nanomaterials. The introduction of new functional groups such as alkyl groups, amino groups or heterocyclic groups improves the adhesion of the inhibitor to the metal surface and increases its effectiveness. The nanostructure allows you to increase the contact surface of the inhibitor with the metal, which increases the inhibition efficiency. Composites with nanomaterials can improve thermal stability, adhesion, and other inhibitor properties. In general, the enrichment and modification of man-made phosphoride raw materials are effective and important steps in the process of obtaining high-quality corrosion inhibitors. They allow you to convert waste into valuable products and reduce environmental pollution. Modification of inhibitors makes it possible to improve their properties and expand the scope of application, which makes them more competitive with traditional synthetic inhibitors.

In conclusion, it should be noted that the extraction of technogenic phosphorus corrosion inhibitors from phosphoride production waste in Kazakhstan represents a promising direction for the sustainable development of the oil and gas industry. This approach provides a comprehensive solution to environmental and economic problems associated with waste disposal. Waste recycling reduces their volume, prevents environmental pollution with harmful substances. The production of inhibitors from secondary raw materials reduces the need for the production and processing of primary resources, which contributes to the reduction of harmful gas emissions and the preservation of Biological Diversity. The economic benefit of recycling is to reduce the cost of producing inhibitors and generate additional income. The development of new technologies for waste processing and the production of inhibitors stimulates the development of Science and technology in Kazakhstan, contributing to the transition to a circular economy. Thus, the extraction of technogenic phosphoric corrosion inhibitors from phosphoride production waste is an important step towards the sustainable development of the oil and gas industry in Kazakhstan, combining environmental safety with economic efficiency.

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## КОРРОЗИЯ ПРОБЛЕМАЛАРЫНЫҢ ЗАМАНАУИ АСПЕКТИЛЕРІН ЖӘНЕ ОЛАРДЫҢ ШЕШІМДЕРІН ТАЛДАУ

**Аңдатпа :** Мақалада мұнай-газ саласында коррозия ингибиторларын өндіру үшін шикізат ретінде пайдалану мақсатында Қазақстанда түрлі өнеркәсіптік процестердің қалдықтары ретінде алынған техногендік фосфорид шикізатын зерттеу ұсынылған. Әр түрлі көздерден алынған фосфорид шикізатының химиялық құрамы мен физикалық қасиеттері зерттелді, оны байыту әдістері талданды, сонымен қатар коррозия ингибиторлары ретіндегі тиімділігін арттыру мақсатында алынған фосфат қосылыстарын өзгерту бойынша зерттеулер жүргізілді. Мұнай-газ саласына тән болат үлгілерінде зертханалық сынақтар жүргізілді және синтезделген ингибиторларды қолданудың оңтайлы шарттары айқындалды. Зерттеу нәтижелері техногендік фосфорид шикізатын коррозия ингибиторларын өндіру үшін тиімді пайдалануға болатынын көрсетеді, бұл шикізат шығындарын азайтады және Қазақстандағы мұнай-газ саласының тұрақты дамуына ықпал етеді. Мақала сонымен қатар олардың қасиеттерін жақсарту және қолдану аясын кеңейту мақсатында алынған ингибиторларды өзгерту мүмкіндігін қарастырады.

Металл коррозиясы - бұл айтарлықтай экономикалық шығындарға әкелетін және қауіпсіздікке қауіп төндіретін күрделі мәселе. Фосфор ингибиторлары - мұнай-газ, энергетика, химия және басқаларын қоса алғанда, әртүрлі салаларда қолданылатын

коррозияны болдырмаудың тиімді құралы. Бұл мақала коррозияның фосфат ингибиторларының тиімділігін зерттеуге арналған, оларды зерттеудің заманауи тәсілдерін және одан әрі даму перспективаларын сипаттайды. Қалдықтар көлемін азайтуға және табиғатқа экологиялық жүктемені азайтуға ықпал ететін техногендік шикізатты өңдеуге негізделген әзірленген ингибиторлардың экологиялық пайдасына ерекше назар аударылады. Техногендік қалдықтарды қайта өңдеу негізінде ингибиторларды әзірлеу экономикалық тиімділікті қоршаған ортаға құрметпен ұштастыра отырып, Қазақстанның мұнай-газ саласында жаңа эко-бағдарланған стратегияны жасайды.

**Кілт сөздер:** фосфор ингибиторы, металл коррозиясы, техногенді қалдықтар, техногенді шикізат, гравиметриялық әдіс, электрохимиялық әдіс.

## АНАЛИЗ СОВРЕМЕННЫХ АСПЕКТОВ ПРОБЛЕМ КОРРОЗИИ И ПУТЕЙ ИХ РЕШЕНИЯ

**Анотация:** В статье представлено исследование техногенного фосфоридного сырья, получаемого в Казахстане в качестве отходов различных промышленных процессов с целью его использования в качестве сырья для производства ингибиторов коррозии в нефтегазовой промышленности. Были изучены химический состав и физические свойства фосфоридного сырья из различных источников, проанализированы методы его обогащения, а также проведены исследования по изменению полученных фосфатных соединений с целью повышения их эффективности в качестве ингибиторов коррозии. Рассмотрены образцы стали, характерные для нефтегазовой отрасли, и определены оптимальные условия применения синтезированных ингибиторов. Результаты исследования показывают, что техногенное фосфоридное сырье может быть эффективно использовано для производства ингибиторов коррозии, что снизит затраты на сырье и будет способствовать устойчивому развитию нефтегазовой отрасли Казахстана. В статье также рассматривается возможность модификации полученных ингибиторов с целью улучшения их свойств и расширения сферы применения.

Коррозия металлов-серьезная проблема, которая может привести к значительным экономическим потерям и поставить под угрозу безопасность. Ингибиторы фосфора являются эффективным средством предотвращения коррозии, используемым в различных отраслях промышленности, включая нефтегазовую, энергетическую, химическую и другие. Данная статья посвящена изучению эффективности фосфатных ингибиторов коррозии, описывает современные подходы к их изучению и перспективы дальнейшего развития. Особое внимание уделяется экологическим преимуществам разработанных ингибиторов, основанных на переработке техногенного сырья, которые способствуют уменьшению объемов отходов и снижению экологической нагрузки на природу. Разработка ингибиторов на основе переработки техногенных отходов создает новую эко-ориентированную стратегию в нефтегазовой отрасли Казахстана, сочетая экономическую эффективность с уважением к окружающей среде.

**Ключевые слова:** ингибитор фосфора, коррозия металлов, техногенные отходы, техногенное сырье, гравиметрический метод, электрохимический метод.