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SLOBODYAN, Z. V. (https://orcid.org/0000-0002-3914-9748),
ZIN, I. M. (https://orcid.org/0000-0001-8896-0601),
and KORNIY, S. A. (https://orcid.org/0000-0003-3998-2972)
Karpenko Physico-Mechanical Institute, the NAS of Ukraine,
5, Naukova St., Lviv, 79060, Ukraine,
+380 32 263 8096, pminasu@ipm.lviv.ua

NEW ENVIRONMENT FRIENDLY CORROSION INHIBITOR BASED ON PLANT EXTRACTS AND TECHNOLOGY OF CHEMICAL CLEANING OF THERMAL POWER EQUIPMENT WITH ITS USE

Introduction. *Improvement of environment ecological state is connected with ensuring stable anti-corrosion protection of the metal fund in chemical, gas and oil and energy industries. In particular, conducting high-quality chemical cleaning of thermal power equipment requires the use of effective eco-friendly corrosion inhibitors.*

Problem Statement. *Insufficient attention is paid to the problem of creating eco-inhibitors despite the presence of plant raw materials in Ukraine in the form of wastes of food industry, wood processing, etc.*

Purpose. *New environmentally friendly inhibitor based on plant extracts and the technology of chemical treatment of thermal power equipment with its use.*

Materials and Methods. *Raw materials are oak chips and sawdust, extraction methods are based on the use of aqueous organic and mixed solvents, gravimetric and electrochemical methods for investigating the protective properties of extracts and synergistic compositions based on them, methods of analytical chemistry.*

Results. *The developed eco-inhibitor is a synergistic composition based on oak extract with eco-friendly additives (xanthan gum, urotropin, thiourea, Siegnette salt, urea, technical glycerin and others). It has been found that the effectiveness of the inhibitor in 5% hydrochloric acid is more than 90%, the mechanism of its protective action is mixed and consists in adsorption of synergistic composite components. The presence of eco-inhibitor in the composition of washing solutions don't affect the completeness of dissolution of carbonate deposits as compared with non-inhibiting medium, but twice reduces time of removing salts and corrosion products from heat-exchange surface of power engineering equipments.*

The technological regulations and temporary specifications for its synthesis and the technological instruction for acid-inhibitory cleaning of thermal power equipment have been developed.

Conclusions. *An experimental batch of eco-inhibitor has been obtained. The resulting product has passed laboratory and full-scale industrial tests that confirm its effectiveness in the composition of washing solution.*

Keywords: plant raw material extracts, tannins, eco-inhibitors, corrosion rate, salt deposition, technological scheme of inhibitor synthesis, acid-inhibitory cleaning.

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Industrial water consumption in Ukraine has increased 21 times over the last decade. It uses 46% of the total water intake, with irreversible losses having reached almost half of all consumption [1]. A significant amount of fresh water is spent for aquifer injection to low-debit oil wells [2] and for heat exchange systems with open water cycles. Reduction of water consumption is achieved by transferring cooling thermal systems to closed cycles [3]. However, over time, because of the deposition of corrosion products and salts, the technological parameters of the equipment deteriorate. The same phenomenon is observed in the water injection equipment of oil wells. In both cases, the equipment is maintained through regular cleaning of its internal surfaces.

The simplest, most economical and quite effective way to remove deposits is acid washing of equipment with the use of organic and inorganic acids, in particular hydrochloric, citric or acetic ones [4, 5]. However, because of their corrosive aggressiveness, the acid purification process requires the use of inhibitors. One of the most effective and widely used reagents in acid cleaning of thermal power equipment is HOSP-10 inhibitor (developed by the Karpenko Institute of Physics and Mechanics of the NAS of Ukraine) [6] that protects carbon steels not only from corrosion but also from overflow water and mechanical destruction. However, HOSP-10 that is based on coke production waste (pyridine and quinoline bases) belongs to the 2nd — 3rd toxicity class. Other Ukraine-made inhibitors for acidic environments, for example, C-1, KPI, INCO-c, despite being in high demand, also shall be replaced with safer reagents [7].

In view of the above, the so-called "green inhibitors" have recently attracted increased attention of researchers. They are compounds and compositions derived from raw plants that are a renewable material [8]. Such inhibitors have no or little negative impact on the environment, are non-mutagenic, non-carcinogenic products, and rapidly biodegrade in the natural environment [9, 10]. It should be noted that along with the creation of a new class of inhibitors, the problem of food and wood industry waste disposal has been being solved in parallel. The interest in this type of inhibitors is associated not only with the ecological aspect, but also with the lack of chemical materials for the synthesis of the known inhibitors in Ukraine.

Requirements for "green" inhibitors have been formulated by the international regulations REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) [11] and PARCOM (Paris Commission) [12]: no bioaccumulation; biodegradability; zero or very low toxicity. The toxicity of such inhibitors is assessed by LC50 (amount of reagent sufficient to destroy 50% of a certain population of living organisms) and EC50 (effective concentration required to inhibit 50% reproducibility of the studied population). In the PARCOM regulations, the toxicity index of a chemical reagent in a specific environment is considered acceptable if it biodegrades for 60% in 28 days.

In most cases, "green inhibitors" are extracts (aqueous, alcoholic, essential) of various parts of plants: wood, leaves, stems, bark, flowers, and seeds [10]. The composition of plant extracts is diverse as they may contain naphthoquinones, tannins, coumarins, gallic acids, catechin fractions, pinenes, camphenes, terpeneols, flavonoids and so on. Each compound possesses inhibitory properties, but the most effective are those containing nitrogen, oxygen, sulfur, aromatic rings (single or conjugated) and having double ϖ-bonds. The presence of such atoms allows indivisible pairs of electrons of N, O, and S to interact with vacant d-orbitals of transition metals, in particular iron, to be adsorbed by functional groups with ϖ-bonds on the surface of metals. In many cases, such interactions lead not only to the manifestation of van der Waals forces (physical adsorption), but also to chemical interactions (chemisorption) with the formation of clusters and films.

Among plant extracts, the leading role is played by the natural tannins that are multifunctional compounds with antioxidant, preservative, tannic, and anti-corrosion properties [11—13]. The mechanism of protective action of tannins is associated with their tendency to form chelates with iron ions [14—16].

The PMI of the NAS of Ukraine has recently been working on the development of eco-inhibitors based on extracts of wood industry waste, in particular, shavings, bark, sawdust of oak, beech, birch, and pine, the basic components of which are tannins. Based on their practical application, several positions that needed to be solved have been identified: improvement of methods for obtaining the extracts, determination of their real effective concentration, and development of ways to strengthen their protective properties.

The practical implementation of scholarly research and methodological developments includes: 1) developing recipes and manufacturing eco-inhibitor based on extracts of vegetable waste; 2) studying the protective properties of the inhibitor in the environment of hydrochloric and citric acids against carbon steels and copper within the temperature range of 20—60 °C; 3) developing technological regulations, temporary specifications for the release of the inhibitor, and technological instructions for acid cleaning of thermal power equipment with its use; 4) field tests of the technology of acid-inhibitor purification of thermal power equipment.

The raw material for the extracts is shavings and sawdust of common oak (*Quercus robur L.*). The proposed general extraction scheme includes the following stages: preparing raw materials (grinding, drying, sieving), adding solvents (water, acetone, alcohol), mixing, heating, filtration (sieve, centrifuge, vacuum), and conditioning.

Environment friendly reagents such as Siegnette salt, urea, benzoic acid, urotropin, xanthan gum, thiourea, technical glycerin have been selected as potential synergists. The protective properties of extracts, synergists, and developed compositions, their after-effect have been studied by gravimetric and electrochemical methods with the use of 20 carbon steel and M3 copper in 5% hydrochloric and citric acids. The effect of the developed composite inhibitor on bicarbonate — carbonate conversion and the amount of deposited calcium carbonate has been considered.

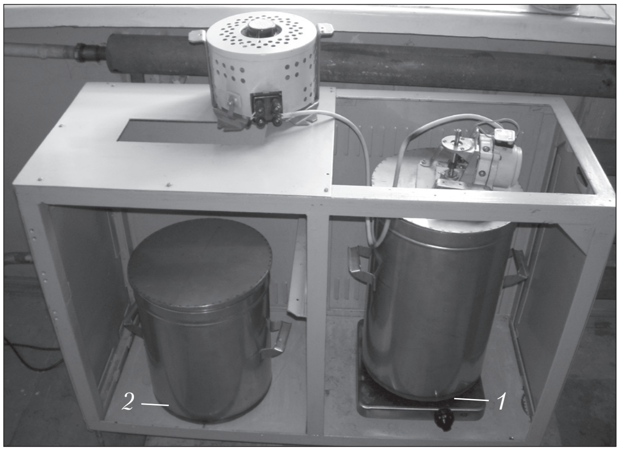


Fig. 1. General view of the installation for the manufacture of experimental batches of extract: *1* — extractor with electric heating; *2* — evaporator

The obtainment of the extracts

The extraction is made in several ways depending on the requirements for completeness of separation and purity of the product: with prior desalination and without it, with the use of different solvents. The obtained aqueous or aqueous-alcoholic extracts are conditioned in two stages: 1) the azeotropic mix and water are distilled off (t = 92—98 °C); 2) the concentrate is dried in an oven (t = 70 °C) until the weight remains constant. The final product is a brown crystalline substance. The yield of active substance depends on the method of extraction and accounts for 48—56%.

The analysis of laboratory extraction results has shown that the most acceptable from an ecological and economic point of view is aqueous extraction. To make experimental batches of the extract, an installation (Fig. 1) consisting of an extractor with electric heating (1) and an evaporator (2) has been made. The test extraction in the experimental installation has become the basis for the development of technology for obtaining a composite inhibitor based on the test extract.

The study of inhibitory properties of extract and potential synergists in 5% hydrochloric and citric acids

It has been found that at a temperature of 25 °C, the corrosion rate (K_m) of 20 steel in 5% hydrochloric and citric acids significantly depends on the concentration of the extract: its increase from 0.2 to 0.8 g/l reduces K_m 1.8—9.6 (in HC1) and 2.8—7.8 (in citric acid) times. At a concentration of 0.8 g/l, the protective efficiency of the extract in both media differs slightly and is 60—65% (Fig. 2).

The inhibitory properties of potential synergists in 5% HC1 have been tested at the two limit concentrations: 2.0 g/l and 0.2 g/l. It has been established that at a concentration of 0.2 g/l, urea and xanthan gum stimulate the corrosion of 20 steel, while thiourea and Siegnette salt have almost no effect on its rate. Only urotropin, technical glycerin, and the obtained extract have shown satisfactory protective properties. Increasing the concentration of test compounds to 2 g/l significantly enhances the inhibitory ability of gum and technical glycerin and has a little effect on the inhibitory effectiveness of the test extract and urotropin (Table 1), as well as slightly reduces the corrosion rate in the presence of urea and Siegnette salt.

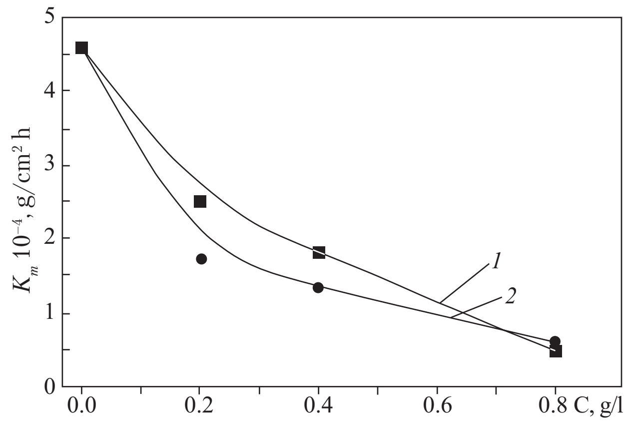


Fig. 2. Dependence of corrosion rate (K_m) of 20 steel on the concentration (C) of the extract in 5% solutions of citric (1) and hydrochloric (2) acids

Despite a sufficiently high individual efficiency, these substances as synergists shall be used at much lower concentrations. The use of gum in the composition has technological limitations: at t = 20—25 °C, it is poorly soluble in water and in 5% HCl solution, foams; at elevated temperature, it swells forming a colloidal solution.

Based on the extract, compositions with synergists (urotropin, technical glycerin, gum in different concentration proportions) have been created and studied. The most effective composition

Table 1. **Influence of Extract and Potential Synergists on Corrosion Rate (K_m), Depth (P), Braking Rate (γ) and Protection Level (Z) of 20 Steel in 5% HCl (τ = 2 h, t = 25 °C)**

E	Concentration, g/l	$K_m \cdot 10^4$, g/cm$^2 \cdot$ h	P, mm/year	γ,	Z, %
5% HC1	—	27.8	30.9	—	—
Extract	2.0	4.5	5.0	6.2	83.7
Xanthan gum	0.2	39.2	43.6	Stimulates corrosion	
	2.0	2.9	3.2	8.4	89.0
Urotropin	0.2	6.5	7.2	4.1	76.0
	2.0	3.5	3.9	7.6	87.0
Thiourea	0.2	21.8	24.3	1.3	21.6
	2.0	12.8	14.3	2.1	52.0
Siegnette salt	0.2	22.6	25.1	1.2	19.0
	2.0	17.6	19.6	1.6	37.0
Urea	0.2	30.5	33.9	Stimulates corrosion	
	2.0	26.7	29.7	1.0	4.0
Technical glycerin	0.2	14.2	15.8	1.9	47.0
	2.0	5.0	5.6	5.6	84.0

is “extract + urotropin + technical glycerin” named TIS-5 (Table 2).

Within the temperature range of 25—60 °C, the protective efficiency of the composition at a concentration of 0.8—1.0 g/l in the case of 20 steel is more than 90% in 5% HC1 and more than 60% in citric acid. As temperature increases, the inhibition of the corrosion process and the protection level get enhanced, with the maximum protective effect observed at 40 °C (Table 3, Figs. 3, 4), which may be explained by a shift in the adsorption-desorption equilibrium of components on the metal surface particularly at this temperature.

Table 2. **Properties of Composite Inhibitor TIS–5**

Physical form	Transparent concentrated brown liquid
Specific density, g/cm³ at 20 °C	1.42
Solubility in water	Good
Solubility in HCI	Good
Solubility in citric acid	Good
Toxicity	No
The steel protection level at an inhibitor concentration of 0.8—3.0 g / l,	0.892
Z within the temperature range 25—60 °C, %	92—95
pH of concentrated aqueous inhibitor solution	0.838

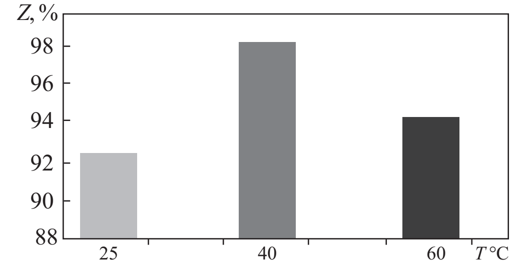


Fig. 3. Influence of temperature on the TIS-5 protection level of 20 steel in 5% HCl

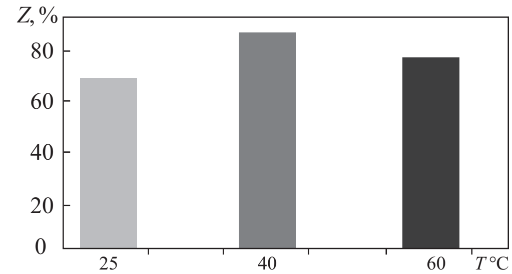


Fig. 4. Influence of temperature on the TIS-5 protection level of 20 steel in 5% citric acid

Based on the temperature dependences of the corrosion rates, the activation energies of the process in hydrochloric and citric acids have been calculated by the formula:

$$E_{act} = [2.303 \cdot R \cdot T_1 \cdot T_2 \cdot \lg (K_2 / K_1] / (T_2 - T_1), \text{J} / \text{mol}$$

where R is the universal gas constant; T_1, T_2 are temperatures of corrosive media during tests, K;

Table 3. **Effect of TIS Composition on 20 Steel Corrosion Rate in 5% HCl and 5% Citric Acid at Different Temperature (τ = 2 h)**

Environment	t, °C	$K_m \cdot 10^4$, g/cm²· h	P, mm/year	γ,	Z, %	E_{act}, kJ/mol
5% HC1	25	27.8	30.9	—	—	20.3
5% HC1 + TIS–5		2.4	2.6	11.8	91.5	57.8
5% HC1	40	189.6	211.2	—	—	
5% HC1 + TIS–5		5.1	5.7	36.9	97.5	
5% HC1	60	303.3	337.0	—	—	
5% HC1 + TIS–5		19.5	21.7	15.5	93.6	
5% citric acid	25	4.91	5.5	—	—	26.0
5% citric acid + TIS–5		1.84	2.1	2.7	63	43.8
5% citric acid	40	12.68	14.1	—	—	
5% citric acid + TIS–5		2.51	2.8	5.1	80	
5% citric acid	60	23.10	25.7	—	—	
5% citric acid + TIS–5		6.90	7.7	3.4	70	

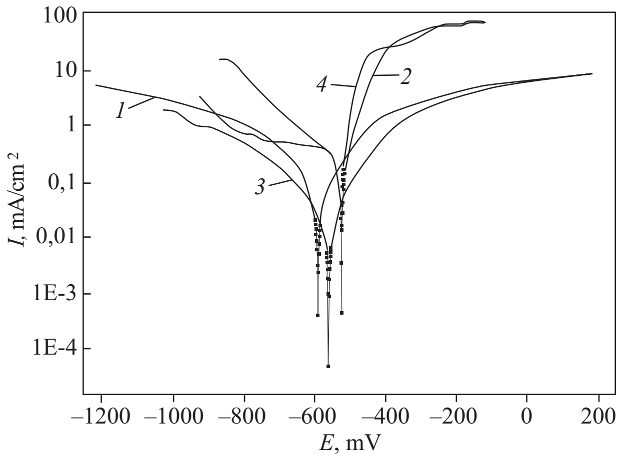


Fig. 5. Polarization curves of 20 steel in solutions: *1* — 5% citric acid; *2* — 5% HCl; *3* — 5% citric acid + TIS—5; *4* — 5% HC1 + TIS—5

K_1, K_2 are corrosion rates at respective temperatures.

Based on the calculations, the activation energy of the corrosion effect of 20 steel is: 20.3 kJ/mol and 26.0 kJ/mol, in 5% HC1 and citric acids, respectively. This fact explains the lower corrosion rate in the latter. Under the influence of TIS-5, E_{act} increases 2.8 times in 5% HC1 and 1.7 times in citric acid. Such values of activation energy indicate possible chemisorption of the inhibitor on the steel surface.

Under the influence of the composition, the corrosion potential of 20 steel in hydrochloric acid shifts towards higher negative values by 20 mV, while in citric acid it moves towards less negative values by 30 mV (Fig. 5). Corrosion currents decrease 3.3 times. Increasing Tafel's constants of cathode and anode reactions in the inhibiting solutions indicate the inhibition of both electrode reactions (Fig. 5, Table 4).

Table 4. **Effect of TIS–5 on Electrochemical Properties* of 20 Steel in 5% HCl and Citric Acid Solutions**

Environment	$-E_{кор}$, mV	$\Delta E_{кор}$, mV	$i_{кор}$, mA/cm²	Tafel's constants	
				$b_к$ mV/дек	b_a mV/дек
5% HC1	524	—	10^{-2}	22	43
5% HC1 + TIS–5	544	20	$3 \cdot 10^{-3}$	60	53
5% citric acid	592	—	$2 \cdot 10^{-3}$	40	50
5% citric acid + TIS–5	562	30	$6 \cdot 10^{-4}$	90	75

*Note. E_{cor} is corrosion potential; $\Delta E_{cor.}$ Is shift in corrosion potential; i_{cor} is corrosion current; $b_к$,b_a are Tafel's constant of cathode and anode reactions.

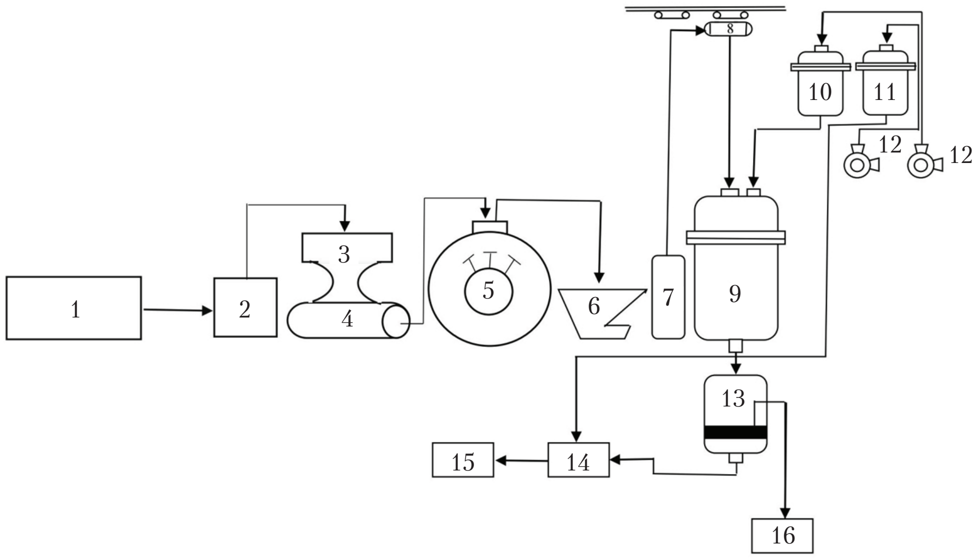
TIS-5 composite inhibitor production process scheme

The scheme for TIS-5 composite inhibitor production on the basis of an extract (Fig. 6) is a three-stage process. At the first stage, initial material (shavings, oak sawdust) is dried and ground in a dryer-crusher; at the second stage, an aqueous extract is obtained in the reactor, separated (decanted) with the use of a filter, and conditioned by evaporation; the third stage is the actual synthesis of TIS-5 inhibitor. The extraction effectiveness depends on the extraction conditions: the amount of raw material, time and temperature of the process. Evaporation is carried out to obtain a solution with a density of 1.20—1.42 g/cm³. Water vapor that releases during the extraction and evaporation of the extract is captured by a filter through the exhaust valve and fed for reuse.

The synthesis of individual batches of inhibitors at the synthesis site of PMI NAS of Ukraine has been possible due to the reconstruction of the reactor room and the modernization of RCHERN 0.63—12 reactor (made of cast iron, enameled, with a bottom discharge and a nominal volume of 0.63 m³) with reducer MP02-10VK-29.6 and electric motor VAO-22-4 having a speed of 47 rpm (Fig. 7).

Studying the influence of TIS-5 composition on salt removal and washing process

The TIS-5 inhibitor in the washing solutions does not change the completeness of dissolution of carbonate deposits as compared with the non-inhibited medium, but halves the time of removal of salts and corrosion products from the heat exchan-



№	Name	Quantity	Characteristics	Material	Notes	№	Name	Quantity	Characteristics	Material	Notes
1	Trench warehouse	1	3 m³	cement		9	Reactor	1	1 m³	cast iron	
2	Scrapper	1	1 m³			10	Metering tank 1	1	0.1 m³		
3	Feeder	1	1 000 kg	3 steel		11	Metering tank 2	1	0.1 m³		
4	Conveyor	1	0.77—1.55 m/s			12—12´	Pumps	1			
5	Drier & crusher	1	183 m³/h			13	Filter	1			
6	Feed tank	1	200 kg	3 steel		14	Mixing tank	1		3 steel	
7	Bucket	1	150 kg	3 steel		15	Storage tank	1		Stainless steel	
8	Electric hoist	1	0.5 t			16	Tailing dump	1			

Fig. 6. TIS—5 inhibitor manufacture process flowchart

ge surfaces of power equipment. The steel surface after cleaning with the inhibiting solution is covered with a protective film that does not undergo visible changes during a week stay of the samples under atmospheric conditions.

The washing process is carried out by circulating a closed circuit: buffer tank — pump — buffer tank. The pump capacity ensures the flow rate of the washing solution at the level of ~ 0. 1 m/s (Q_{pump} = 1800—2000 m³/h). Depending on the amount of deposits and their chemical composition, the dissolution process may last from several hours to one day and be carried out at different temperature (if possible, while heating). The release time of the cleaning object from the washing solution is 25—45 min.

The completeness of the removal (Fig. 8) of salt deposits is controlled by analytical determination of changes in the acidity of the washing solution and the amount of washed out salts of calcium and magnesium (change in the total hardness).

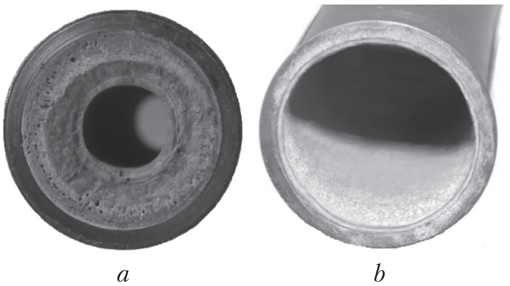
Fig. 7. Renovated reactor section for synthesis in the Institute's Department

Practical implementation of research results

The end product of the research works is the development of technology for acid purification of thermal power equipment from salt deposits and corrosion products with the use the developed TIS-5 inhibitor. The advantage of this technology is its environment friendliness, because unlike the existing techniques involving inhibitors of the 2nd and 3rd toxicity classes, it uses backwash water that does not have a negative impact on the environment; the raw material is locally made and available; the solid residue after the extraction may be used as pressed fuel.

Thus, in the course of the research, the experimental plant for obtaining TIS-5 composite inhibitor based on oak extract has been made and tested; an experimental batch of inhibitor has been manufactured; a program for acid purification of thermal power equipment from salt deposits and corrosion products with the use of TIS-5 inhibitor and technical instructions for conducting the process of acid-inhibitory washing of condensers, compressors, evaporators, closed water circulation systems, etc. have been developed.

The innovative technology may also be used to clean heat exchange equipment, including two-drum water-tube reconstructed boilers, *Evaco* condensers, boilers, and other industrial and domestic heating appliances. Among potential consumers of the proposed technology are enterprises of the heat industry (e.g., Burshtyn TPP, Kalush TPP and others), communal enterprises (local boilers, heating systems, individual heat boilers), as well as boilers, water circulation systems, heat exchangers, condensers of food enterprises (*Terra Food*, *Rozhysche*, *Vapnyarsky* cheese factories, *Lvivkholod*). The technology has been tested in food industry and offered to heat and utility companies as a profitable alternative to the technology that uses the toxic inhibitor HOSP-10.



a *b*

Fig. 8. Sample of condenser tube cutting before washing *(a)* and after washing with eco-inhibitor solution *(b)*

Therefore, in the course of the research, methods for synthesis of laboratory and experimental samples of plant raw material extracts have been developed; an installation for synthesis of experimental batches of inhibitor has been made; an aqueous extract from oak raw materials and its crystalline form have been obtained. The yield of the final product makes up 48—56%.

It has been determined that extracts from oak raw materials in the range of concentrations of 0.2—0.8 g/l protect steel 20 in 5% hydrochloric and citric acids for 60—65%. At an extract concentration of 0.8 g/l, the corrosion rate of steel 20 decreases 9 times in hydrochloric acid and 6—7 times in citric acid.

A synergistic eco-composition TIS-5 has been created based on oak extract. It has been found that in the temperature range of 25—60 °C, the protective effectiveness of this composition exceeds 90% in hydrochloric acid solution and 60% in citric acid solution. As temperature increases, the inhibition of the corrosion process and the protection level get enhanced.

Corrosion activation energies of steel have been determined. They amount to 20.3 kJ/mol in 5% hydrochloric acid solution and 26.0 kJ/mol in 5% citric acid solution, which explains the lower corrosion rates in the latter. In the presence of the TIS-5 composition, the activation energy increases 2.8 times (in 5% HC1 solution) and 1.7 times (in 5% citric acid). Such values of activation energy indicate the possibility of chemisorption of the inhibitor on the steel surface. Electrochemical studies have shown that the synergistic composition TIS-5 in acidic media adsorbed on the steel surface inhibits both electrode reactions.

On the basis of the research and the obtained results the respective regulatory documents and specifications (technological regulations, temporary specifications for manufacture of the inhibitor and the instruction on acid clearing of the heat power equipment with use of the developed eco-inhibitor) have been developed. An experimental batch of inhibitor has been manufactured and tested in the bench trials and in field conditions. The results have confirmed the protective effectiveness of the inhibitor in washing solution.

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З.В. Слободян (https://orcid.org/0000-0002-3914-9748),
І.М. Зінь (https://orcid.org/0000-0001-8896-0601),
С.А. Корній (https://orcid.org/0000-0003-3998-2972)
Фізико-механічний інститут ім. Г.В. Карпенка НАН України,
вул. Наукова, 5, Львів, 79060, Україна,
+380 32 263 8096, pminasu@ipm.lviv.ua

НОВИЙ ЕКОЛОГІЧНО БЕЗПЕЧНИЙ ІНГІБІТОР НА ОСНОВІ ЕКСТРАКТІВ РОСЛИННОЇ СИРОВИНИ ТА ТЕХНОЛОГІЯ ХІМІЧНОГО ОЧИЩЕННЯ ТЕПЛОЕНЕРГЕТИЧНОГО ОБЛАДНАННЯ З ЙОГО ВИКОРИСТАННЯМ

Вступ. Покращення екологічного стану довкілля пов'язано із забезпеченням стабільного протикорозійного захисту металофонду в хімічній, газо-, нафтодобувній та енергетичній промисловостях. Зокрема, проведення якісного хімічного очищення теплоенергетичного обладнання вимагає застосування ефективних екобезпечних інгібіторів корозії.

Проблематика. Проблемі створення екоінгібіторів в Україні приділено недостатньо уваги, хоча наявність рослинної сировини у вигляді відходів харчового, деревообробного та низки інших виробництв дозволяє успішно вирішувати цю проблему.

Мета. Розробка нового екологічно безпечного інгібітора на основі екстрактів з рослинної сировини та технології хімічного очищення теплоенергетичного обладнання з його використанням.

Матеріали й методи. Вихідною сировиною слугували стружка та тирса дуба; застосовано методи екстракції з використанням водних, органічних та змішаних розчинників, гравіметричний та електрохімічні методи дослідження захисних властивостей екстрактів та синергічних композицій на їх основі, методи аналітичної хімії.

Результати. Розроблений екоінгібітор є синергічною композицією на основі екстракту дуба з додаванням екобезпечних допоміжних речовин (ксантанову камедь, уротропін, тіосечовину, сегнетову сіль, карбамід, технічний гліцерин та інших). Встановлено, що ефективність інгібітору у 5% хлоридній кислоті становить понад 90%, механізм його захисної дії має змішаний характер і полягає в адсорбції складників синергічної композиції. Інгібітор у складі промивних розчинів не змінює повноту розчинення карбонатних відкладів порівняно з неінгібованим розчином, проте вдвічі зменшує час усунення солей твердості та продуктів корозії з поверхонь теплообміну енергетичного обладнання. Розроблено технологічний регламент і тимчасові технічні умови на його одержання та технологічну інструкцію на проведення кислотно-інгібіторного очищення теплоенергетичного обладнання.

Висновки. Отримано дослідну партію екоінгібітору, який пройшов стендову та натурну апробацію, що підтвердили його ефективність у складі промивного розчину.

Ключові слова: екстракти рослинної сировини, таніни, еко-інгібітори, швидкість корозії, солевідкладення, технологічна схема синтезу інгібітора, кислотно-інгібіторне очищення.