

High-temperature inhibitors of stainless steel corrosion in sulfuric acid solutions

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Abstract

The corrosion of chromium-nickel steel 08Kh18N10T in 2 M H₂SO₄ has been studied in a broad temperature range, $t = 0\text{--}200^\circ\text{C}$. Under these conditions, the metal corrosion is enhanced with an increase in t to reach 9.7 kg/(m²·h) at 200°C. It has been shown that a formulation of IFKhAN-92 inhibitor (a substituted triazole) with KI in a molar ratio of 1 : 1 protects this steel in 2 M H₂SO₄ at temperatures up to 140°C, inclusive. The three-component mixture of IFKhAN-92, KI and urotropine (1 : 1 : 4) is more promising in this respect, as it efficiently inhibits corrosion at temperatures up to 180°C and allows the protective effect to be maintained for at least 8 h. This formulation also reliably protects low-carbon steel 20 in 2 M H₂SO₄ at temperatures up to 180°C, inclusive; what is more, corrosion slows down with time in the presence of this mixture.

Key words: *high-temperature acid corrosion, corrosion inhibitors, stainless steel, triazoles.*

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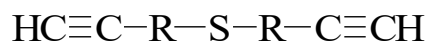
Introduction

Solutions of mineral acids that are used for acidic treatment of oil- and water-bearing beds, removal of scale from metal surfaces, and cleaning of mineral deposits from inside surfaces of pipelines and equipment are of importance among the most corrosive industrial environments. In practice, inhibitory protection of metal structures in mineral acid solutions is mainly performed by organic compounds such as amines, quarternary ammonium salts, as well as pyridine and quinoline derivatives that are generally efficient up to $t = 80^\circ\text{C}$ only. Unfortunately, the vast majority of such inhibitors fail to meet the technological and ecological requirements of modern industries, where acid solutions contacting a metal can be heated to temperatures of 100°C or higher, while compounds used for metal corrosion protection should be, whenever possible, harmless for humans and for the environment. Creation of inhibitors capable of metal protection in acid solutions at

$\geq 80^{\circ}\text{C}$ (high-temperature corrosion inhibitors) is necessary for the oil and gas industry where hydrochloric acid treatment of oil beds with elevated temperatures at the well bottom is needed more and more often. It becomes possible to intensify metal etching and removal of mineral deposits by considerably increasing the temperatures of the acid solutions used in these operations.

Steel protection in mineral acid solutions under high-temperature corrosion conditions presents considerable technological difficulties due to the extreme corrosivity of these media. For example, according to N.I. Podobaev [1], the corrosion rate (k) of St1 steel (composition, mass%: C 0.07; P 0.022; S 0.027; Si 0.02) in 4 M HCl at 250°C was found to be *ca.* 48 kg/(m²·h) (the corrosion test duration was $\tau = 3$ min). Even under “milder” conditions in 2 M HCl at 160°C and with longer exposure ($\tau = 30$ min), the k of steel 20 reaches 12 kg/(m²·h) [2].

The use of corrosion inhibitors is the only acceptable method for steel protection from corrosion under these conditions. The most common formulations recommended for these media contain unsaturated organic compounds [3–9]. In fact, the use of nitrogen-containing inhibitors (BA-6, PKU) in the presence of Sn^{2+} , Cr^{3+} cations and I^{-} anions as additives makes it possible to use hex-1-in-3-ol and propargyl alcohol to protect St1 steel in 4 M HCl at temperatures up to 250°C [1]. A similar formulation was patented by B.R. Keeney and J.W. Johnson [10] who stated that formulations (0.025–25 g/l) comprising acetylenic alcohols, nitrogen-containing compounds and CuI are efficient inhibitors of steel corrosion in HCl, H_2SO_4 , HF, H_3CCOOH and in their mixtures at $t \leq 230^{\circ}\text{C}$. Instead of acetylenic alcohols, the mercapto acetylene derivative of the following general formula can be used:



It is suggested to use primary, secondary and tertiary amines containing $\text{C}_2\text{--C}_6$ hydrocarbon groups or pyridine derivatives as nitrogen-containing compounds. M.L. Walker [11] reported formulations for the protection of N80 steel (composition, mass%: C 0.34–0.38; Si 0.20–0.35; Mn 1.45–1.7; P up to 0.02; S up to 0.015; Cr up to 0.15; V 0.11–0.16) in HCl, HCl+HF, H_2SO_4 , H_3CCOOH , and HCOOH solutions at $t \leq 260^{\circ}\text{C}$. The formulations contain an acetylenic alcohol (5–35%), a quaternary ammonium salt, an aromatic hydrocarbon, and a soluble antimony compound.

A formulation comprising various acetylenic alcohols, phenyl vinyl ketone, KI and HCOOH was recommended for the protection of N80 and J55 carbon steels (composition, mass%: C 0.34–0.39; Si 0.20–0.35; Mn 1.25–1.5; P up to 0.02; S up to 0.015; Cr up to 0.15; Ni up to 0.20; Cu up to 0.20) and L80 chromium stainless steel (composition, mass%: C 0.15–0.20; Si up to 1.00; Mn 0.25–1.0; P up to 0.02; S up to 0.010; Cr 12.0–14.0; Ni up to 0.20; Cu up to 0.20) in HCl solutions at $t \leq 150^{\circ}\text{C}$ [12]. Formulations based on cinnamic aldehyde and a quaternary ammonium salt are used on the same steels at temperatures up to 120°C [12, 13].

The patent [14] reports data on the protection of N80 steel in 15–28% HCl containing KI (1–2%) and HCOOH additives at 150°C by mixtures of phenylalkenylketones with alkyl- or alkylarylquinolinium salts. R.J. Jasinski and W.W. Frenier [15] recommend to protect steels containing more than 9% Cr in 15% HCl and its mixtures with HF (120–250°C) using formulations of phenylalkenylketones or substituted cinnamic aldehydes with derivatives of nitrogen-containing heterocycles (alkylpyridinium and alkylquinolinium salts). To enhance the protective action of these mixtures, the effects of Bi(III) and Sb(III) compounds soluble in acidic media, as well as CuCl, on this effect were studied. Furthermore, the protective effect of the mixtures was enhanced by addition of KI or HCOOH.

The broad practical application of unsaturated organic compounds is limited by their low thermal stability, liability to resinification in acidic solutions, and high toxicity. These drawbacks are not characteristic of the relatively new group of corrosion inhibitors, *viz.*, triazoles, that have high stability against acids and thermal stability. Furthermore, they are capable of chemisorption on the surface of a corroding metal resulting in formation of protective inhibitor films [16–19]. For example, the formulation that we developed [2] on the basis of IFKhAN-92 inhibitor, a 3-substituted 1,2,4-triazole, makes it possible to protect steel 20 in 2–6 M HCl at $t \leq 160^\circ\text{C}$.

Sulfuric acid solutions have been less thoroughly studied under high-temperature corrosion conditions. Like hydrochloric acid solutions, they are highly corrosive: at 140°C, the k of St3 steel (composition, mass%: C 0.14–0.22; Mn 0.40–0.65; Si 0.15–0.30) reaches 3.8 kg/(m²·h) [20], while at 200°C for steel 20 (composition, mass%: C 0.17–0.24; Si 0.17–0.37; Mn 0.35–0.65; Ni up to 0.3; S up to 0.04; P up to 0.035; Cr up to 0.25; Cu up to 0.3; As up to 0.08), $k = 15$ kg/(m²·h) [21, 22]. Formulations of IFKhAN-92 with KI [20–22] and KBr [21, 22] possess unique properties in the protection of low-carbon steels in H₂SO₄ solutions at $t \geq 100^\circ\text{C}$.

The literature available to us contains no information on the high-temperature corrosion of stainless steels, an important group of structural materials, in H₂SO₄ solutions. Our previous studies [23–25] on the corrosion behavior of chromium-nickel stainless steels in this medium at $t \leq 100^\circ\text{C}$ allow us to assume that their stability is low under these conditions.

In view of the above, it seems worthwhile to study the corrosion of chromium-nickel stainless steel 08Kh18N10T in H₂SO₄ solutions in the range of $t = 0$ –200°C and develop inhibitor formulations for its protection under these conditions. As the basis for the creation of composite inhibitors, we studied IFKhAN-92, whose mixtures with KI considerably hinder the corrosion of chromium-nickel steels in H₂SO₄ solutions at $t \leq 100^\circ\text{C}$ [23–25] and the corrosion of low-carbon steel at $t \leq 200^\circ\text{C}$ [20–22]. It is important to estimate the ability of formulations that we developed for the protection of stainless steels to inhibit the corrosion of low-carbon steels as well.

Experimental procedure

High-temperature corrosion tests ($t = 120\text{--}200^\circ\text{C}$) were carried out in a Huber autoclave (Finland) (the accuracy of temperature control was $\pm 3^\circ\text{C}$). A cylindrical sample (15–50 mm long, depending on the metal corrosion rate, and 18 mm in diameter) of 08X18H10T steel (composition, mass%: C 0.08; Cr 17–19; Ni 9–11; Si 0.8; Mn up to 2; S up to 0.02; P up to 0.035; Cu up to 0.3; Ti up to 0.7) was placed into a quartz vessel containing 100 ml of 2 M H_2SO_4 . The base duration of the tests was 30, 60, or 120 min. The corrosion tests at $t = 0\text{--}100^\circ\text{C}$ were carried out by a similar technique in temperature-controlled corrosion vessels. The tests at $t = 120\text{--}200^\circ\text{C}$ were carried out in an autoclave using the following technique. A specimen was placed into an acid solution at $t = 100^\circ\text{C}$, heated to a required temperature, kept for 40, 70 or 130 min at that temperature, and cooled to 104°C . In order to take the specimen mass loss during autoclave heating and cooling into account, the tests were duplicated with exposure for 10 min at the corresponding temperatures. The corrosion rates for 30, 60, or 120 min periods were calculated from the difference between the specimen mass loss after 40, 70, or 130 minute exposures in the autoclave at the corresponding temperature and the mass loss after a 10-minute exposure.

The same technique was used in the corrosion tests of low-carbon steel 20 (flat specimens, $20\text{ mm} \times 20\text{ mm} \times 3\text{ mm}$) in the H_2SO_4 solution.

The specimens were cleaned on an abrasive disc (ISO 9001, 60 grit) and degreased with acetone prior to each experiment. Due to the low solubility of IFKhAN-92, it was added to H_2SO_4 solutions as a solution in ethanol. The resulting ethanol concentration in the pickling solution was 0.24 mol/l.

The efficiency of inhibitors was estimated from the inhibition coefficient, $\gamma = k_0/k_{\text{in}}$, where k_0 and k_{in} are the corrosion rates in the non-inhibited solution and in the solution with the additive being studied, respectively. In order to estimate quantitatively the effect of additives on IFKhAN-92, the mutual influence coefficients of the mixture components were calculated [26]:

$$K_m = \frac{\gamma_{\text{mix}}}{\prod_{i=1}^m \gamma_i},$$

where γ_{mix} is the corrosion inhibition coefficient for the inhibitor mixture and $\prod_{i=1}^m \gamma_i$ is the product of the corrosion inhibition coefficients for the individual mixture components. At $K_m < 1$, the protective effects of the inhibitor components are mutually reduced; at $K_m = 1$, it has an additive nature; and it is only at $K_m > 1$ that a mutual enhancement of protection by the mixture components is observed.

Experimental results and discussion

08Kh18N10T steel is rather resistant in cold 2 M H₂SO₄ ($t = 0^\circ\text{C}$): the maximum observed k is 0.34 g/(m²·h). However, the corrosion of steel systematically accelerates with an increase in t and, according to the data of 0.5 h tests, it reaches 0.3 kg/(m²·h) at 80°C, 0.7 kg/(m²·h) at 100°C, and 9.7 kg/(m²·h) at 200°C (Figure 1).

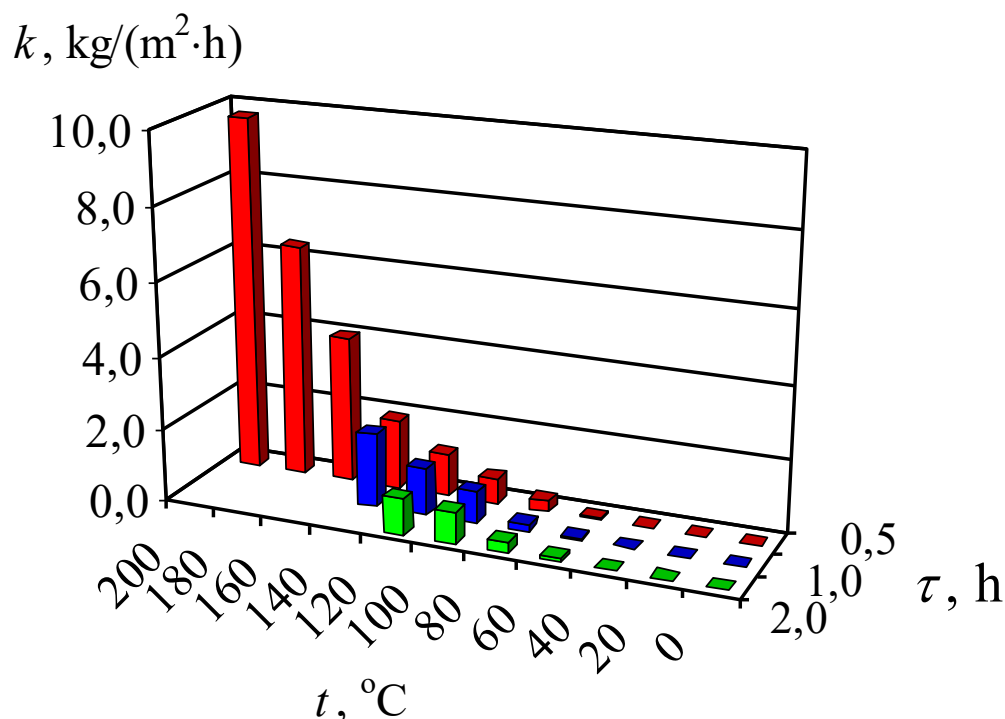


Figure 1. Corrosion rates of 08Kh18N10T steel in 2 M H₂SO₄ at various temperatures.

The equimolar mixture of IFKhAN-92 and KI that we previously developed [23–25] for the protection of stainless steels in sulfuric acid media efficiently protects the metal in 2 M H₂SO₄ at rather low concentrations ($C_{\text{mix}} = 5$ mM) at $t \leq 140^\circ\text{C}$, where $k \leq 10$ g/(m²·h) (Table 1). However, a further t increase by 20°C abruptly decreases γ 3-fold (in 0.5 h tests). Furthermore, corrosion increases with time in the presence of the inhibitor formulation to reach 162 g/(m²·h). To improve steel protection in 2 M H₂SO₄, the content of this inhibitor mixture in the solution was increased to $C = 10$ mM. This allowed us to improve steel protection in 2 M H₂SO₄ at $t > 100^\circ\text{C}$. However, even in this case, according to the data of 2 h tests, $k = 117$ g/(m²·h) at $t = 160^\circ\text{C}$, which does not allow us to expect that this formulation would be efficient at higher temperatures.

Table 1. Corrosion rates (k , g/(m²·h)) and corrosion inhibition coefficients (γ) of 08Kh18N10T steel in 2 M H₂SO₄ at various temperatures.

Inhibitor	Test duration					
	0.5 h		1.0 h		2.0 h	
	k	γ	k	γ	k	γ
0°C						
2.5 mM IFKhAN–92 + 2.5 mM KI	—*	—	—*	—	—*	—
2.5 mM IFKhAN–92 + 2.5 mM KI + 10 mM urotropine	—*	—	—*	—	—*	—
20°C						
2.5 mM IFKhAN–92 + 2.5 mM KI	—*	—	0.04	88	0.02	170
2.5 mM IFKhAN–92 + 2.5 mM KI + 10 mM urotropine	—*	—	—*	—	—*	—
40°C						
2.5 mM IFKhAN–92 + 2.5 mM KI	—*	—	0.07	300	0.10	170
2.5 mM IFKhAN–92 + 2.5 mM KI + 10 mM urotropine	—*	—	—*	—	0.02	850
60°C						
2.5 mM IFKhAN–92 + 2.5 mM KI	0.53	106	0.55	115	0.46	189
2.5 mM IFKhAN–92 + 2.5 mM KI + 10 mM urotropine	0.68	83	0.47	134	0.35	249
80°C						
2.5 mM IFKhAN–92 + 2.5 mM KI	1.0	297	1.1	185	1.0	265
2.5 mM IFKhAN–92 + 2.5 mM KI + 10 mM urotropine	1.1	270	0.80	255	0.81	327
100°C						
5 mM IFKhAN –92	382	1.8	408	2.1	436	2.0
5 mM KI	2.9	243	3.2	274	2.7	315
2.5 mM IFKhAN–92 + 2.5 mM KI	3.8	186	2.7	325	2.5	340
15 mM IFKhAN–92	188	3.8	197	4.5	249	3.4
15 mM urotropine	566	1.2	686	1.3	617	1.4
15 mM KI	2.9	243	2.4	365	2.0	426
2.5 mM IFKHAN–92 + 2.5 mM KI	1.6	441	1.5	585	1.4	608

Inhibitor	Test duration					
	0.5 h		1.0 h		2.0 h	
	<i>k</i>	γ	<i>k</i>	γ	<i>k</i>	γ
+ 10 mM urotropine						
5 mM IFKhaN-92 + 5 mM KI + 20 mM urotropine	2.1	336	2.6	337	1.5	567
120°C						
2.5 mM IFKhaN-92 + 2.5 mM KI	5.0	234	4.9	263	6.5	140
5 mM IFKhaN-92 + 5 mM KI	0.96	1219	1.8	717	3.5	260
2.5 mM IFKhaN-92 + 2.5 mM KI + 10 mM urotropine	2.7	433	2.5	516	2.1	433
5 mM IFKhaN-92 + 5 mM KI + 20 mM urotropine	2.7	433	3.8	339	5.3	172
140°C						
2.5 mM IFKhaN-92 + 2.5 mM KI	8.8	216	9.5	213	10	–
5 mM IFKhaN-92 + 5 mM KI	3.2	594	7.7	262	10	–
2.5 mM IFKhaN-92 + 2.5 mM KI + 10 mM urotropine	9.2	207	8.7	232	6.8	–
5 mM IFKhaN-92 + 5 mM KI + 20 mM urotropine	3.5	543	5.4	374	6.5	–
160°C						
2.5 mM IFKhaN-92 + 2.5 mM KI	56	72	138	–	162	–
5 mM IFKhaN-92 + 5 mM KI	33	122	41	–	117	–
2.5 mM IFKhaN-92 + 2.5 mM KI + 10 mM urotropine	21	191	30	–	40	–
5 mM IFKhaN-92 + 5 mM KI + 20 mM urotropine	20	201	15	–	11	–
180°C						
2.5 mM IFKhaN-92 + 2.5 mM KI + 10 mM urotropine	56	114	67	–	123	–
2.5 mM IFKhaN-92 + 2.5 mM KI + 25 mM urotropine	87	73	89	–	122	–
5 mM IFKhaN-92 + 5 mM KI + 20 mM urotropine	20	319	55	–	100	–
10 mM IFKHAN-92 + 5 mM KI + 15 mM urotropine	80	80	80	–	166	–

Inhibitor	Test duration					
	0.5 h		1.0 h		2.0 h	
	<i>k</i>	γ	<i>k</i>	γ	<i>k</i>	γ
15 mM IFKhAN-92 + 10 mM KI + 15 mM urotropine	31	205	60	–	121	–
200°C						
2.5 mM IFKhAN-92 + 2.5 mM KI + 10 mM urotropine	823	12	735	–	513	–
5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine	844	12	654	–	455	–
10 mM IFKhAN-92 + 10 mM KI + 40 mM urotropine	882	11	770	–	744	–
20 mM IFKhAN-92 + 10 mM KI + 100 mM urotropine	1190	8.1	805	–	712	–

* The change in the specimen mass during the corrosion test is below the balance sensitivity (0.1 mg).

Steel protection in H_2SO_4 solution can be improved by using a three-component mixture based on IFKhAN-92 and KI. As an additive to this mixture, we used urotropine, which we recommended previously [2, 22] to increase the inhibiting effect of IFKhAN-92 in HCl solutions at $t > 100^\circ\text{C}$. Preliminary tests were performed using a three-component formulation with $C = 30$ mM. The tests performed at 180°C have shown that the formulation of 5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine has higher efficiency than 2.5 mM IFKhAN-92 + 2.5 mM KI + 25 mM urotropine or 10 mM IFKhAN-92 + 5 mM KI + 15 mM urotropine. Even a mixture with a higher content of the components (15 mM IFKhAN-92 + 10 mM KI + 15 mM urotropine) is inferior to it in efficiency. Though the corrosion rate increases with time in the presence of the mixture of 5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine, $k = 100$ g/(m²·h) at $t = 180^\circ\text{C}$, even according to 2 h tests, which is an interesting result. Further studies have shown that this mixture can be used for efficient steel protection at $t = 100\text{--}180^\circ\text{C}$ for at least 2 h. An important property of the formulation of 5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine is that the protective effect is maintained in time. For example, at 160°C , $k = 18$ g/(m²·h) in 4 hour tests and 30 g/(m²·h) in 8 hour tests. Unfortunately, this formulation abruptly loses protective efficiency at 200°C , where the minimum k is 455 g/(m²·h) according to 2 hour tests. Attempts to increase the concentration of the components in the inhibitor mixture only decreased its protective effect.

An increase in the acid concentration in the background solution considerably increased its corrosivity. The k values at $t = 160^\circ\text{C}$ are 4.0 kg/(m²·h) in 2 M H_2SO_4 , 9.9 kg/(m²·h) in 4 M H_2SO_4 , and 12.5 kg/(m²·h) in 6 M H_2SO_4 . The three-component inhibitor mixture that we developed ($C_{\text{mix}} = 30$ mM) inhibits the metal corrosion in 4 M

H₂SO₄ to 203, 173 and 154 g/(m²·h) according to 0.5, 1, 2 h corrosion tests, respectively. The protective effects in 6 M H₂SO₄ under the same conditions are lower, namely, $k = 542$, 513, and 440 g/(m²·h).

The formulation of IFKhAN-92, KI and urotropine ($C_{\text{mix}} = 30$ mM) with a component molar ratio of 1 : 1 : 4 is efficient for 08Kh18N10T steel protection under high-temperature corrosion conditions at $t = 100$ – 180°C . To minimize the inhibitor consumption, it is important to study the effect of this mixture on the corrosion process at lower C_{in} values. The mixture of 2.5 mM IFKhAN-92 + 2.5 mM KI + 10 mM urotropine is generally less efficient in the inhibition of steel corrosion than a similar mixture with $C = 30$ mM, but it is sufficiently adequate even at $t = 160^{\circ}\text{C}$ where $k \leq 40$ g/(m²·h). Comparison of the mixtures of 2.5 mM IFKhAN-92 + 2.5 mM KI and 2.5 mM IFKhAN-92 + 2.5 mM KI + 10 mM urotropine shows that the first mixture can be more efficient in the initial stages of the corrosion process, but the second mixture ensures higher protection after 2 h of the corrosion process. Both formulations manifest an antagonism in the action of their components. At $t = 100^{\circ}\text{C}$, $K_m = 0.43$ – 0.56 for the first mixture and 0.27 – 0.40 for the second one. To a large extent, the observed effect is due to the high efficiency of KI in the hindrance of chromium-nickel steel corrosion in H₂SO₄ solution. IFKhAN-92 or especially urotropine alone weakly affect the corrosion process.

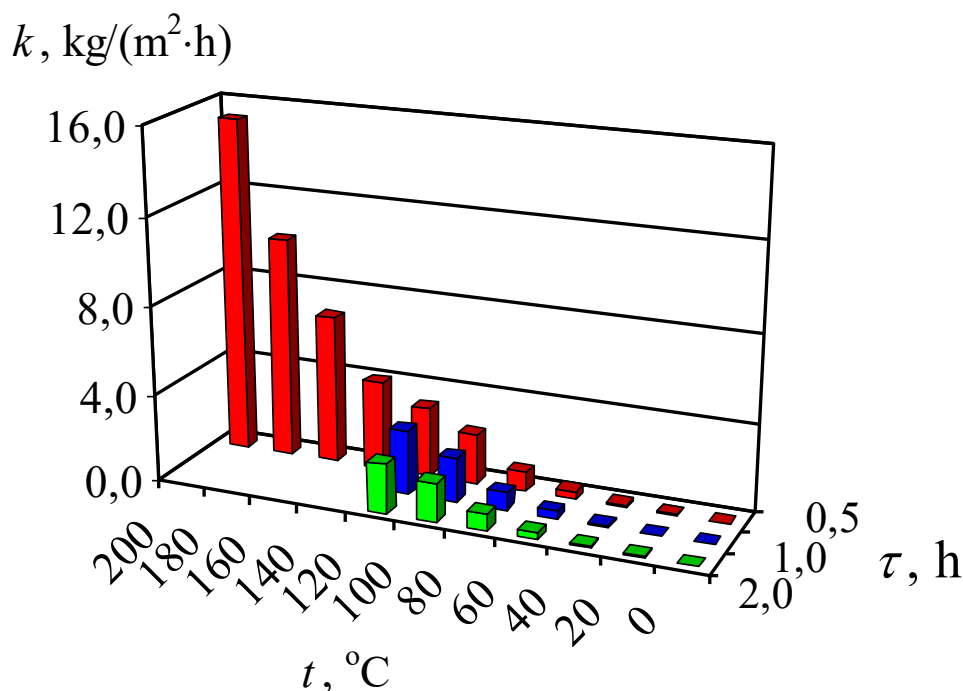


Figure 2. Corrosion rates of steel 20 in 2 M H₂SO₄ at various temperatures.

The three-component mixture (5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine) is efficient in hindering not only the corrosion of chromium-nickel steel but also that of low-carbon steel that is even less resistant in H₂SO₄ solutions (Figure 2) at $t \leq 180^{\circ}\text{C}$, where it

provides $k \leq 200 \text{ g}/(\text{m}^2 \cdot \text{h})$ (Table 2). It is only at 200°C , like in the case of stainless steel, that this inhibitor mixture loses protection efficiency. At $t \leq 160^\circ\text{C}$, this mixture slows down corrosion with time for at least 2 h. Even at 160°C , the k value decreases with time for at least 8 h: $k = 6.6 \text{ g}/(\text{m}^2 \cdot \text{h})$ in 4 h tests and $3.5 \text{ g}/(\text{m}^2 \cdot \text{h})$ in 8 h tests, which we believe to be a unique result. In fact, the mass loss of specimens during the last 6 h out of the 8 h of the corrosion process amounts to 8% of the total mass loss.

Table 2. Corrosion rates (k , $\text{g}/(\text{m}^2 \cdot \text{h})$) and corrosion inhibition coefficients (γ) of steel 20 in 2 M H_2SO_4 + 5 mM IFKhAN-92 + 5 mM KI + 20 mM urotropine at various temperatures.

Temperature, $^\circ\text{C}$	Test duration					
	0.5 h		1.0 h		2.0 h	
	k	γ	k	γ	k	γ
0	0.23	41	0.21	57	0.20	43
20	0.37	120	0.27	130	0.22	150
40	0.84	130	0.69	140	0.49	190
60	1.6	220	1.1	310	0.78	400
80	2.6	340	2.0	420	1.6	460
100	4.2	540	3.2	640	2.6	670
120	9.9	320	9.1	320	8.0	280
140	16	250	12	–	11	–
160	18	380	17	–	13	–
180	100	100	130	–	200	–
200	360	43	430	–	480	–

Thus, our hypothesis about the applicability of formulations based on IFKhAN-92 for the protection of chromium-nickel steel in H_2SO_4 solutions under high-temperature corrosion conditions was confirmed. The three-component formulation of IFKhAN-92, KI and urotropine (1 : 1 : 4) that we created reliably protects such steel at $t \leq 180^\circ\text{C}$ in 2–4 M H_2SO_4 ; in some cases, efficiency is maintained for at least 8 h. To a large extent, the reasons for the high protective action of the inhibitor formulation developed by us lie in the uniqueness of the action mechanism of IFKhAN-92 [27], which is critically important in metal protection under high-temperature corrosion conditions. IFKhAN-92 can:

- be strongly adsorbed on a corroding metal surface;
- form a polymolecular protective layer on the metal that favors the strongest protection;
- be thermally stable in solutions of acids (without resinification);
- enhance the protective effect at high-temperature conditions when combined with other thermally stable additives.

Conclusions

1. Chromium-nickel steel has low corrosion resistance in H_2SO_4 solutions, especially under high-temperature corrosion conditions ($t \geq 80^\circ\text{C}$). The formulation of IFKhAN-92 with KI (1:1) allows this steel to be protected in 2 M H_2SO_4 at temperatures up to 140°C , inclusive.
2. The three-component mixture of IFKhAN-92, KI and urotropine (1:1:4) is even more efficient and hinders the corrosion of chromium-nickel steel at temperatures up to 180°C , inclusive. This mixture can maintain its protective effect in the acid solution for at least 8 h.
3. The formulation of IFKhAN-92, KI and urotropine (1:1:4) also reliably protects low-carbon steel in 2 M H_2SO_4 at temperatures up to 180°C , inclusive. The corrosion of steel in acid solution slows down with time in the presence of this mixture.

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