**Study of Physico-Chemical Properties of a Corrosion Inhibitor Synthesized from Urea and Phosphoric Acid**

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**Abstract:** The corrosion inhibition effectiveness of a Linear Alkylbenzene Sulfonic Acid, Urea, and Phosphoric Acid-based inhibitor (referred to as the LKF inhibitor) on 12X18H10T steel in a 15-20% HCl solution was analyzed using the gravimetric method. The results show that at the inhibitor's minimum effective concentration (300 mg/L), the inhibition efficiency reaches 94.5% even at an elevated temperature of 363 K. The protective efficiency against corrosion increases with higher inhibitor concentrations but decreases with rising temperature. This inverse relationship with temperature is explained by the general acceleration of corrosion rates under higher thermal conditions. The adsorption behavior of the LKF inhibitor was found to conform to the Langmuir adsorption isotherm model. Furthermore, Scanning Electron Microscopy (SEM) analysis confirmed the formation of a protective layer on the 12X18H10T steel surface when exposed to the inhibitor, providing direct visual evidence of its protective mechanism.

**Keywords:** linear alkylbenzene sulfonic acid, urea, phosphoric acid, corrosion rate (CR), inhibition efficiency (*η%*), surface coverage degree (*θ*).

**INTRODUCTION**

Today, metal corrosion presents significant economic and safety challenges worldwide, making the resolution of related issues a critical focus of advanced scientific research [1]. In the oil and gas industry, acid stimulation of wells is an effective method for enhancing production output. This process involves injecting a 15-20% hydrochloric acid (HCl) solution under high pressure into oil wells using pipelines made of 12X18H10T grade steel [2,3].

Hydrochloric acid is a highly aggressive medium that induces severe corrosion of steel. To mitigate this corrosion, various inhibitor formulations are employed in the process [1]. Organic compounds containing heteroatoms in their structure are recognized as effective corrosion inhibitors for acidic environments [4–6]. These compounds function by adsorbing onto the metal surface, thereby reducing the corrosion rate [7,8].

Corrosion inhibitors used on an industrial scale to prevent acid corrosion are typically based on unsaturated alcohols, aromatic aldehydes, alkenylphenones, quaternary ammonium salts, and condensation products of certain carbonyl and amine compounds [9; 10]. A significant drawback of most such compounds is their inherent toxicity and low biodegradability, which pose considerable risks to living organisms and the environment [11–13].

Consequently, contemporary research is increasingly focused on developing non-toxic and environmentally benign corrosion inhibitors. A review of the literature indicates that certain pyrimidine derivatives containing donor atoms have previously been studied as corrosion inhibitors in low-concentration acidic media [14]. The pyrimidine-based compounds utilized in this study were synthesized from relatively inexpensive chemical precursors. Building on this foundation, we synthesized and investigated the physico-chemical properties of a novel surfactant containing nitrogen and oxygen donor atoms [15; 16].

For this investigation, an inhibitor synthesized from Linear Alkylbenzene Sulfonic Acid (LABSA), urea, and phosphoric acid—designated as the LKF inhibitor—was selected to study corrosion inhibition on 12X18H10T steel in a 15-20% hydrochloric acid (HCl) solution. This specific choice of compounds was motivated by their non-toxic nature and their possession of various bioactive properties, such as antibacterial activity [17].

The corrosion inhibition performance of the synthesized substance was evaluated using the gravimetric method. Furthermore, the surface morphology of the steel was analyzed via Scanning Electron Microscopy (SEM). This analysis confirmed the adsorption of inhibitor molecules onto the metal surface, allowing the inhibition mechanism to be elucidated.

This study details the synthesis of a novel corrosion inhibitor using the following raw materials: linear alkylbenzene sulfonic acid (LABSA, 97%), urea (99%), phosphoric acid (85%), and distilled water. The synthesis was conducted in a systematic four-stage procedure. In the first stage, 400 g of LABSA was introduced into a 1000 mL three-necked round-bottom flask, followed by the addition of 100 mL of distilled water. The mixture was stirred magnetically for 10–15 minutes until a completely homogeneous solution was obtained, during which the sulfonic acid group of LABSA underwent ionization to form an active anion in the solution.

Proceeding to the second stage, 200 g of urea was gradually added to the solution in 20 g increments, with the mixture stirred for 5 minutes after each addition. The temperature was carefully maintained at 30 °C using a water bath. Under these conditions, urea formed stable complexes with the LABSA molecules via its ionized ammonium group. In the third stage, 150 g of 85% phosphoric acid was added dropwise to the solution via a pipette or burette. This addition caused the pH of the mixture to decrease from 6 to approximately 2.5. Here, phosphoric acid reacted with urea to generate several ionic complexes, while the phosphate groups simultaneously served as active centers capable of further interaction with metal surfaces. The resulting mixture was then kept at room temperature (20–25 °C) in a sealed container for 2 hours to allow the stabilization of ionic bonds and the formation of macromolecular complexes.

Finally, in the fourth stage, the mixture was filtered through a 0.45‑micron filter, yielding a viscous liquid that functions as a surfactant. The product was stored in an airtight container, protected from light, at 4–8 °C. Based on the mass of the isolated product, the reaction yield was calculated to be 92%. The final inhibitor is a brown, homogeneous liquid with a characteristic odor and exhibits complete solubility in water[17-18].

**METHODS**

The research was conducted using samples of 12X18H10T grade steel with the following elemental composition (wt.%): Carbon (C): up to 0.12% (max), Chromium (Cr): 17.0–19.0%; Nickel (Ni): 9.0–11.0%; Titanium (Ti): up to 0.8%; Manganese (Mn): up to 2.0%; Silicon (Si): up to 0.8%; Sulfur (S): up to 0.025%; Phosphorus (P): up to 0.035%; with the balance being Iron (Fe). For the gravimetric corrosion tests, steel coupons measuring 21 cm² in surface area were prepared from the 12X18H10T steel. Prior to each experiment, the surface of all steel samples was mechanically ground smooth using abrasive papers of varying grit sizes, thoroughly rinsed with distilled water and acetone, and then dried at room temperature. All solvents and chemical reagents used for the synthesis were of analytical grade and employed without further purification.

Gravimetric method experiments were carried out by immersing 12X18H10T steel samples in a 15% HCl solution for a duration of 300 hours. The corrosion rate (CR), inhibition efficiency (η%), and surface coverage degree (θ) were calculated using the following formulae:

(1)

(2)

(3)

where: W - is the weight loss of the sample (mg), A - is the exposed surface area of the sample (cm2), t - is the total immersion time (hours), CR - and CR(i) - are the corrosion rates without and with the inhibitor, respectively.

The experiments on 12X18H10T steel samples were conducted in a 15% HCl solution at 363 K for 300 hours, both in the absence of any inhibitor and in the presence of the LKF inhibitor at a concentration of 300 mg/L. Scanning Electron Microscopy (SEM) analysis was performed using a Zeiss instrument to examine the surface morphology.

**RESULTS AND DISCUSSION**

The influence of inhibitor concentration on the corrosion process of 12X18H10T steel in a 15% HCl solution at 363 K was investigated using the gravimetric method (Table 1). The data presented in Table 1 indicate that the inhibition efficiency of the LKF inhibitor increased as its concentration was raised from 100 to 300 mg/L. Concentrations exceeding 300 mg/L did not result in a significant further improvement in efficiency; therefore, 300 mg/L was identified as the optimal concentration.

At this optimal and higher concentrations, the inhibitor forms a dense and robust protective film on the surface of the 12X18H10T steel. This film acts as an effective barrier, significantly reducing the access of HCl to the metal surface. In other words, the enhanced inhibition performance at elevated concentrations is a direct result of greater surface coverage, whereby a larger proportion of the steel surface is shielded by adsorbed inhibitor molecules.

**TABLE 1.** Concentration-dependence of the anti-corrosion characteristics of the LKF inhibitor

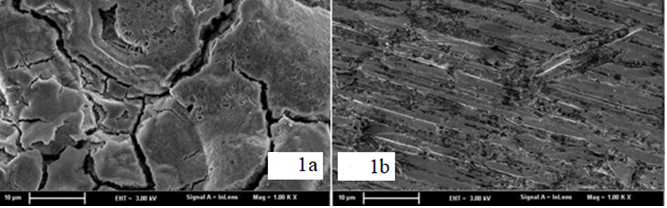
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **S, 10-4 m2** | **τ, hour** | **Mass, m0, g** | **Mass, m, g** | **Δm** | **Consentration of inhibitor, mg/ml** | **Corrosion rate** | **Z, %** | **γ** |
| 1 | 21 | 300 | 23,42 | 22,595 | 0,825 | - | 1,31 | - | - |
| 2 | 21 | 300 | 23,58 | 23,383 | 0,197 | 100 | 0,313 | 76,11 | 4,18 |
| 3 | 21 | 300 | 23,56 | 23,4 | 0,160 | 150 | 0,255 | 80,55 | 5,14 |
| 4 | 21 | 300 | 23,61 | 23.512 | 0,098 | 200 | 0,156 | 88,08 | 8,39 |
| 5 | 21 | 300 | 23,45 | 23,365 | 0,085 | 250 | 0,135 | 89,7 | 9,7 |
| 6 | 21 | 300 | 23,57 | 23,514 | 0,056 | 300 | 0,089 | 93,21 | 14,72 |

Experimental results investigating the effect of the LKF inhibitor on 12X18H10T grade steel provide clear evidence of its anti-corrosion efficacy. While the control sample (without inhibitor) experienced a mass loss of 0.825 g over 300 hours, all samples containing the inhibitor showed a sharp reduction in mass loss. This reduction reached its minimum at the highest tested concentration (300 mg/L), with a mass loss of only 0.056 g. These findings directly demonstrate that the degree of protection offered by the inhibitor is strongly dependent on its concentration. As the inhibitor concentration was increased from 100 mg/L to 300 mg/L, the corrosion rate exhibited a significant decline from 0.313 to 0.089 g. Correspondingly, the inhibitor's protection efficiency (Z%) rose from 76.11% to 93.21%, achieving near-complete surface coverage of approximately 93%. The concurrent increase in the protection coefficient (γ) from 4.18 to 14.72 indicates that, at the highest concentration, the corrosion process was slowed by nearly a factor of 15 compared to the uninhibited control. Analysis of the results confirms that the maximum efficiency (Z=93.21%, γ=14.72) was observed at the concentration of 300 mg/L. However, considering that the incremental gain in efficiency between 250 mg/L (Z=89.7%) and 300 mg/L is relatively modest, the optimal concentration from both economic and practical standpoints can be selected within the range of 250–300 mg/L.

To qualitatively and quantitatively assess the morphological changes occurring on the surface of 12X18H10T steel samples during corrosion testing, Scanning Electron Microscopy (SEM) analysis was performed. In this study, samples were exposed for 300 hours to a 15% HCl solution, both in the absence of inhibitor (control environment) and in the presence of the LKF inhibitor. The obtained SEM micrographs (Figures 1a and 1b) enabled a comparative analysis of the metal surface's corrosion state.

SEM images of the sample immersed in the LKF-containing solution revealed that the initial smooth texture of the metal surface was largely preserved, with no significant signs of corrosive damage, such as pitting or erosion, being observed. This finding confirms the ability of the LKF inhibitor to form a coherent and stable protective layer on the steel surface. This layer acts as an effective barrier, isolating the substrate from direct contact and interaction with the aggressive medium (H+ ions).

In stark contrast, SEM analysis of the control sample exposed to the uninhibited 15% HCl solution recorded distinct evidence of corrosive attack. The surface exhibited widespread pitting corrosion, indicative of a localized corrosion mechanism that actively propagates under conditions of high chloride ion (Cl-) concentration and low pH. Due to the strongly acidic nature of HCl, the surface oxide layer was rapidly dissolved, leading to an accelerated rate of iron dissolution (Fe + 2H+ → Fe2+ + H2). The pronounced surface roughness and high degree of damage visible in the SEM images illustrate the markedly increased corrosion rate resulting from the highly aggressive environment and the absence of any protective film.



**FIGURE 1.** SEM images of the steel coupon. (1a.) Left: Sample after 300 hours of immersion in 15% HCl solution without inhibitor. (1b.) Right: Sample exposed to the acidic solution containing the inhibitor

A comparison of the micrographs clearly demonstrates that the absence of pits or major cavities on the inhibitor-treated sample is attributable to the effective adsorption of LKF molecules and the integrity of the protective layer they form. Functional groups within the molecule (–NH3+, -C=O, PO43-, etc.) facilitate strong bonding to the metal oxide/hydroxide surface via donor-acceptor interactions, resulting in the formation of a mono- or polymolecular adsorption layer. The SEM data indicate that this layer provides protection not merely through physical passivation but also by thermodynamically and kinetically inhibiting the corrosion process, thereby reducing the electrochemical activity of the surface. These findings underscore the significant role of organic inhibitors in shielding metals from aggressive environments. They confirm that inhibitors such as LKF can serve as highly effective agents in the chemical industry, particularly for enhancing the corrosion resistance of metallic structures.

**CONCLUSION**

In conclusion, gravimetric analyses demonstrate that the LKF inhibitor is highly effective for 12X18H10T steel in a 15% HCl environment. As the inhibitor concentration increased from 100 mg/L to 300 mg/L, the corrosion rate decreased sharply, while the protection efficiency (Z) rose from 76.11% to 93.21%. At the concentration of 300 mg/L, the corrosion process was slowed by nearly a factor of 15 (γ=14.72) compared to the uninhibited control, confirming the inhibitor's high activity. Taking economic efficiency into account, an optimal working concentration within the range of 250–300 mg/L is recommended. Scanning Electron Microscopy (SEM) provided visual confirmation of the inhibitor's protective mechanism. While the surface of the control sample (without inhibitor) exhibited widespread and deep pitting corrosion, the surface of the inhibitor-treated sample remained nearly identical to its initial, uncorroded state. This observation confirms that LKF molecules form a dense, coherent, and stable adsorbed layer on the steel surface, effectively blocking direct contact with the aggressive medium (H+ and Cl- ions).

The study's results not only provide experimental validation of the newly synthesized inhibitor's efficacy but also establish a foundation for its practical application. The LKF inhibitor can be recommended as a promising anti-corrosion agent for use in the chemical, oil and gas, and energy industries. It holds potential for extending the service life, enhancing operational safety, and improving the technical-economic performance of highly alloyed steels (e.g., 12X18H10T) and construction structures operating in acidic environments.

Thus, the present study successfully developed an optimal synthesis protocol for the novel LKF corrosion inhibitor and experimentally confirmed its high efficacy along with its protective mechanism, which operates through the formation of a coherent adsorption layer. These findings define clear pathways for its practical application. For future work, it would be highly relevant to conduct more in-depth investigations into the inhibitor's performance across different metals and corrosive environments, as well as to study the thermodynamic and electrochemical parameters governing its adsorption process.

**ACKNOWLEDGEMENT**

The authors express their sincere gratitude to the scientific supervisors, laboratory personnel, and specialists who contributed to the execution of this research. The authors also acknowledge the research laboratories that provided reagents, technological equipment, and analytical instruments necessary for this work. Special thanks are extended to colleagues who assisted in data evaluation and to all experts involved in organizing and supporting the experimental procedures.

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