**Gravimetric and Sem–Eds Investigation of 09G2S Carbon Steel Corrosion Inhibited by a Diphenylamine Derivative**

Jabbor Jumayeva), Dilsora Jo‘raeva, Zulfiya Berdiyeva

*Bukhara State Technical University, Bukhara, Uzbekistan*

*a)Corresponding author:* [*jabbor.jumayev@mail.ru*](mailto:jabbor.jumayev@mail.ru)

**Abstract:** The corrosion inhibition efficiency of 1-(diphenylamino)butan-2-one for 09G2S carbon steel in 1.0 M HCl solution was investigated using gravimetric and SEM–EDS analyses. The inhibitor significantly reduced the corrosion rate with increasing concentration, achieving a maximum efficiency of 90.50% at 350 mg/L and 298 K. Surface analyses confirmed effective adsorption, formation of a protective film, and suppression of sulfur-containing corrosion products

**Keywords:**Corrosion inhibition; Carbon steel; Diphenylamine derivative; SEM–EDS analysis; Acidic medium; Adsorption mechanism.

**INTRODUCTION**

The protection of steel against corrosion remains a critical issue in the chemical industry. The effective inhibition of steel corrosion in acidic media by nitrogen-containing inhibitors has been demonstrated through chemical, electrochemical, and SEM analyses [1]. Corrosion inhibitors are regarded as one of the most practical and cost-effective approaches for preventing and mitigating corrosion, primarily by forming one or more protective molecular layers on the metal surface that limit the action of the corrosive environment. Previous studies have shown that organic compounds containing heteroatoms such as nitrogen (N), sulfur (S), and oxygen (O) exhibit high inhibition efficiency and therefore represent the most widely used class of corrosion inhibitors [2,3]. Carbon steel, which is extensively applied in industry and of significant economic importance, is particularly susceptible to corrosion in acidic environments, necessitating the development of effective protection strategies. Consequently, the synthesis of nitrogen- and oxygen-containing corrosion inhibitors and the investigation of their inhibition properties are of considerable scientific and practical interest. In this context, a diphenylamine-based corrosion inhibitor was synthesized and evaluated in the present study [4–6].

**METHODS**

An aqueous 0.1 M HCl solution was selected as the aggressive medium. Prior to the experiments, steel specimens were mechanically polished using abrasive paper to obtain a uniform surface. The samples were subsequently rinsed with distilled water, washed with 96% ethanol, and dried. The mass loss of the specimens before and after immersion was measured using an analytical balance (ABS 120-4N, KERN & Sohn GmbH, Germany).

To evaluate the corrosion inhibition efficiency of the synthesized 1-(diphenylamino)butan-2-one, two Drechsel flasks were filled with 0.1 M HCl solution. The inhibitor was added to one flask at a concentration of 350 mg/L, while the other flask served as the blank solution without inhibitor. Steel samples were immersed in the solutions for 24 h. During the experiments, the solution temperature was maintained constant using a thermostat. Each experiment was conducted in triplicate under identical conditions, and the obtained results were averaged. The corrosion rate (CR) of the steel specimens was calculated using the following equation:

(1)

where A is the surface area of the steel specimen (cm²) and T is the immersion time (h).

The inhibition efficiency (IE) was calculated using the following equation:

(2)

where *W₀* and *Wᵢ* represent the weight loss values of the steel specimens in the absence and presence of the inhibitor, respectively [4,6].

Surface investigations and determination of the elemental composition of metal plate samples were carried out using a SEM–EVO MA 10 (Zeiss, Germany) scanning electron microscope. The experiments on the scanning electron microscope were conducted as follows. For sample preparation, circular metal plates were mounted on a circular holder made of a metal alloy, and a carbon film with a double-sided adhesive surface was applied on top. During the measurements, an accelerating voltage of 10.00 kV (EHT – Extra High Tension) was used, and the working distance was 8.5 mm. Images were acquired at various magnifications using the SmartSEM software.

To determine the elemental composition of the samples, energy-dispersive X-ray spectroscopy (EDS) was performed in selected local areas using an energy-dispersive elemental analyzer (Oxford Instruments – Aztec Energy Advanced X-act SDD). For the analysis of the elemental composition, electron micrographs of the selected local regions, compositional tables, and corresponding spectral graphs were obtained.

**RESULTS AND DISCUSSION**

1-(Diphenylamino)butan-2-one was synthesized and isolated according to the following procedure [4].



The weight loss results obtained for 09G2S steel specimens in 1.0 M HCl solution, both in the absence and presence of the inhibitor, within the temperature range of 298–338 K are presented in Table 1. The results indicate that the corrosion rate decreased significantly with increasing concentration of the synthesized inhibitor. At all investigated temperatures, the inhibitor exhibited very high inhibition efficiency at the optimal concentration of 350 mg/L, while further increases in concentration did not lead to a noticeable improvement in inhibition efficiency.

At an inhibitor concentration of 300 mg/L and a temperature of 298 K, the corrosion rate (CR) of 09G2S steel in the presence of 1-(diphenylamino)butan-2-one was 0.15 mg· cm-2·h-1, whereas the CR value for the uninhibited sample was 1.58 mg·cm-2·h-1. Furthermore, the inhibition efficiency of 1-(diphenylamino)butan-2-one increased gradually with increasing inhibitor concentration, reaching a maximum value of 90.50%. These results indicate that higher inhibitor concentrations promote strong adsorption of 1-(diphenylamino)butan-2-one molecules onto the surface of 09G2S steel, thereby effectively isolating the metal surface from the aggressive corrosive environment.

**TABLE 1.** Corrosion parameters of 09G2S carbon steel determined by the gravimetric method in 1.0 M HCl solution containing different concentrations of 1-(diphenylamino)butan-2-one at various temperatures

|  |  |  |  |
| --- | --- | --- | --- |
| **Temperature (K)** | **Concentration (mg/l)** | **CR (mg sm-2 h-1)** | **IE (%)** |
| 298 | 0 | 1,58 | - |
| 50 | 0,57 | 63,92 |
| 100 | 0,49 | 68,96 |
| 150 | 0,41 | 74,05 |
| 200 | 0,35 | 77,85 |
| 250 | 0,28 | 82,27 |
| 300 | 0,21 | 86,70 |
| 350 | 0,17 | 89,24 |
| 400 | 0,15 | 90,50 |
| 308 | 0 | 2,35 |  |
| 50 | 1,25 | 46,80 |
| 100 | 1,03 | 56,17 |
| 150 | 0,88 | 62,55 |
| 200 | 0,71 | 69,78 |
| 250 | 0,54 | 77,02 |
| 300 | 0,44 | 81,27 |
| 350 | 0,41 | 82,55 |
| 400 | 0,39 | 83,40 |
| 318 | 0 | 3,31 | - |
| 50 | 1,75 | 47,13 |
| 100 | 1,42 | 57,09 |
| 150 | 1,28 | 61,33 |
| 200 | 1,02 | 69,18 |
| 250 | 0,89 | 73,11 |
| 300 | 0,76 | 77,03 |
| 350 | 0,70 | 78,85 |
| 400 | 0,69 | 79,15 |
| 328 | 0 | 3,86 | - |
| 50 | 1,98 | 48,70 |
| 100 | 1,82 | 52,85 |
| 150 | 1,61 | 58,29 |
| 200 | 1,42 | 63,21 |
| 250 | 1,26 | 67,37 |
| 300 | 0,97 | 74,87 |
| 350 | 0,95 | 75,38 |
| 400 | 0,94 | 75,64 |
| 338 | 0 | 4,22 | - |
| 50 | 2,45 | 41,94 |
| 100 | 2,10 | 50,23 |
| 150 | 1,80 | 57,34 |
| 200 | 1,61 | 61,84 |
| 250 | 1,45 | 65,63 |
| 300 | 1,13 | 73,22 |
| 350 | 1,08 | 74,35 |
| 400 | 1,06 | 74,88 |

The SEM micromorphology of 09G2S steel and the corresponding EDS analysis results after immersion in 1 M HCl solution for 24 hours under inhibitor-containing and inhibitor-free conditions are presented in Figure 1. As shown in Figure 1A, the steel surface is severely deteriorated and heavily damaged, with widespread corrosion products and pits. The corresponding EDS spectra and data reveal relatively high contents of oxygen, sulfur, and chlorine, confirming the presence of abundant acid corrosion products on the steel surface under inhibitor-free conditions.

|  |  |  |
| --- | --- | --- |
|  |  | |
| **A** | | |
|  | |  |
| **B** | | |

**FIGURE 1.** SEM micrographs of 09G2S steel and the corresponding EDS analysis results after immersion in 1 M HCl solution for 24 h:(A) inhibitor-free condition;(B) in the presence of 350 mg/L 1-(diphenylamino)butan-2-one.

In contrast, in the presence of the inhibitor the steel surfaces were more uniformly covered and exhibited significantly less corrosion damage; in particular, the surface exposed to 1-(diphenylamino)butan-2-one (Figure 1B) appeared smoother and more intact. Moreover, the corresponding EDS spectra and results showed that the amount of acid corrosion products in the inhibitor-treated samples was lower than that in the inhibitor-free sample.

Based on the surface analysis results, 1-(diphenylamino)butan-2-one exhibited a markedly higher inhibition performance. This behavior can be attributed to the presence of heteroatoms and aromatic rings in the 1-(diphenylamino)butan-2-one molecules, which provide a higher density of lone electron pairs. Consequently, 1-(diphenylamino)butan-2-one can effectively adsorb onto the steel surface and form a protective film.

According to the EDS analysis, sulfur was not detected on the surface of 09G2S steel immersed for 24 h in 1 M HCl solution containing the inhibitor. This observation indicates that sulfide corrosion products were not formed on the steel surface and confirms that 1-(diphenylamino)butan-2-one formed an effective adsorbed protective layer, significantly reducing the influence of the aggressive environment.

**CONCLUSION**

The synthesized diphenylamine-based compound, 1-(diphenylamino)butan-2-one, exhibited high corrosion inhibition efficiency for 09G2S carbon steel in 1.0 M HCl solution. Gravimetric measurements showed that increasing the inhibitor concentration led to a significant reduction in corrosion rate, with a maximum inhibition efficiency of 90.50% achieved at 350 mg/L and 298 K. The inhibition efficiency decreased slightly with increasing temperature, indicating that the adsorption of inhibitor molecules on the steel surface plays a dominant role in the corrosion protection mechanism. SEM observations revealed that the steel surface exposed to the uninhibited acidic medium suffered severe corrosion damage, whereas the inhibitor-treated surface remained relatively smooth and intact. EDS analysis confirmed the successful adsorption of inhibitor molecules through the detection of nitrogen signals and the absence of sulfur peaks, indicating that sulfidic corrosion products were effectively suppressed. The high inhibition performance of 1-(diphenylamino)butan-2-one is attributed to the presence of heteroatoms and aromatic rings, which facilitate strong adsorption and the formation of a compact protective film on the steel surface.

**REFERENCES**

1. Praveen B. M., Venkatesha T. V. Metol as corrosion inhibitor for steel //International Journal of Electrochemical Science. – 2009. – Т. 4. – №. 2. – С. 267-275.
2. Desai P. D. et al. Corrosion inhibitors for carbon steel: A review //Vietnam Journal of Chemistry. – 2023. – Т. 61. – №. 1. – С. 15-42.
3. Jumaev J., Sadikova M., Qurbonova S. Analysis of synthesized N-morphophylline-butadiene-2, 3 using modern physical research methods //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – Т. 3304. – №. 1. – С. 040101.
4. Shodmonovna J. D., Khamrokulovich J. J., Khudoyorovich A. E. Study of the corrosion inhibition properties of a compound synthesized from diphenylamine //Universum: технические науки. – 2025. – Т. 11. – №. 11 (140). – С. 41-45.
5. Kurbanov F. P. et al. Investigation of the degree of inhibitor protection relative to conditions at different depths //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – Т. 3304. – №. 1. – С. 040081.
6. Niyozov E. et al. Investigation of physicochemical properties of guanidine-based corrosion inhibitor //E3S Web of Conferences. – EDP Sciences, 2024. – Т. 587. – С. 03004.