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# Investigation of Inhibitory Effect of the *Rubus idealis* L. Extract on Corrosion of Copper

**Kasapović, D.[a], Klepo, L.[b], Ostojić, J.[b], Korać, F.[b]***

[a] *University of Zenica, Faculty of Metallurgy and Technology, Travnička cesta 1, 72000 Zenica, B&H*

[b]*University of Sarajevo, Faculty of Science, Zmaja od Bosne 33-35, 71000 Sarajevo, B&H*

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***Corresponding author:**
**Fehim Korać**
E-mail: fkorac9496@gmail.com
Phone: 00-387-33-279-915

**Abstract:** The aim of this work was to examine the impact of raspberry extract (*Rubus idaeus* L.) on copper corrosion characteristics. The raspberry leaf extract was prepared using Soxhlet extraction with ethanol as solvent. The estimation of the total polyphenol content in the obtained sample was determined by UV/Vis spectrophotometric method. The identification and quantification of phenolic acids was performed using HPLC analytical method. In addition, the aim of this work was to examine the impact of individual phenolic compounds (rutin, gallic acid, quercetin, and catechin hydrate) on the corrosion properties of copper. The corrosion rate of copper with the extract of the raspberry leaf of the Polka variety was tested. A copper corrosion test was performed in a 3% NaCl solution without and in the presence of the extract. The copper polarization resistance (Rp) values in 3% NaCl solution without and in the presence of the extract were determined by the linear polarization method. The corrosion behavior of copper in 3% NaCl solution without and in the presence of extract was determined by specific electrochemical parameters: corrosion potential ($E_{corr}$), corrosion current density ($I_{corr}$), and slopes of the anode ($\beta_a$) and cathode ($\beta_k$). The electrochemical impedance spectroscopy method was used to examine the corrosion behavior of copper in 3% NaCl solution without and in the presence of extract. The results obtained by Tafel extrapolation showed that the corrosion rate decreases in the presence of the tested extract. Studies conducted by the electrochemical impedance spectroscopy method show that the tested extract slows down the kinetics of the corrosion process, which is visible through an increase in resistance. The results confirm that the examined extract can be used for protection in an aggressive medium, such as a 3% NaCl solution.

## INTRODUCTION

Copper is a metal that has extensive application due to its good properties. It is used in electrical engineering for the production of wires, sheets, pipes, and in the production of alloys. It is relatively resistant to the effects of the atmosphere and many chemicals. However, it is known to be susceptible to corrosion in an aggressive environment. The use of copper corrosion inhibitors is necessary in these cases because the formation of a passive protective layer cannot be expected (Kasapović, Korać, and Bikić, 2022). Corrosion inhibitors are divided into two groups: those that enhance the formation of a protective oxide film through an oxidizing effect, and those that inhibit corrosion by selective adsorption to the metal surface and forming a barrier that prevents corrosive agents from reaching the metal surface. Several approaches have been used in corrosion prevention science and engineering. Material selection, electrochemical techniques, coating deposition, and corrosion inhibitor application are some of the most common. Corrosion inhibitors are one of the most cost-effective and practical approaches to use. Corrosion inhibitors are compounds that, when introduced in small amounts to a corrosive medium, can slow down the rate of metal corrosion.

Inorganic compounds, for example, are known for their strong inhibitory characteristics, particularly chromates and their derivatives. Despite these environmental laws have restricted their use due to their toxicity and negative impact on human life and ecosystems. One of the key approaches to controlling corrosion in modern society is the use of green corrosion inhibitors, which reduce corrosion rates to a suitable level with minimal environmental impact On the other hand, natural products, such as plant extracts, are readily available and inexpensive. As a result, green chemistry research and its use in corrosion inhibitors has exploded in the twenty-first century. There has been a rush of research on corrosion inhibition utilizing extracts from various plant parts. Plant extracts contain bioactive substances that have been demonstrated to be as effective as commercially available inhibitors (Radošević, 2012; Zakeri, Bahmani and Aghdam, 2022). For example, tobacco extracts are rich in chemical components such as alcohols, polyphenols, nitrogen-containing compounds, terpenes, carboxylic acids, and alkaloids, which may have electrochemical properties such as corrosion inhibition (Patni, Agarwal and Shah, 2019). Many studies have focused on natural organic compounds from plant material. Natural antioxidants are affordable, available, and renewable compounds obtained by extraction from plant material or synthesized. Studies have shown that many of these compounds can be used as effective inhibitors of copper corrosion (Grudić, Bošković, and Gezović, 2018; Al-Nami, 2019; Ahmed and Zhang , 2019; El-Tantawy, *et al.*, 2021).

According to previous reports, there are two forms of corrosion inhibition:
1. one that coats a metal surface by adsorption to it to protect the active areas from acid attack.
2. An alternative is to use an oxidation mechanism to build a protective coating on the metal surface.

The presence of phenolic components in the plant extract, as well as heteroatoms such as S, P, N, and O groups, may be responsible for both effects. Leaves of plants such as *Olea europaea* L., *Citrus aurantifolia*, and *Hibiscus sabdariffa* have been found to reduce the mild steel corrosion in an acid medium (Patni, *et al.,* 2013 Chitra, *et al.,* 2019). It is assumed that *R. idaeus* leaf extracts could have a similar effect on copper corrosion.
Effective environmental corrosion inhibitors show a high tendency for adsorption. The adsorption mechanism of organic inhibitors at the metal/solution interface can consist of one or more steps. In the first step, the adsorption of an organic inhibitor on the metal surface usually involves the replacement of one or more water molecules that were initially adsorbed on the metal surface (Bikić, 2017):

$$\mathrm{Inh(sol)} + x\mathrm{H_2O(ads)} \rightarrow \mathrm{Inh(ads)} + \mathrm{H_2O(sol)}$$

where:
Inh(sol) - inhibitor in solution,
Inh(ads) – adsorbed inhibitor,
x – number of water molecules displaced by the inhibitor.

The inhibitor combined with the metal ion $M^{2+}$ formed on the metal surface as a result of metal oxidation or dissolution process, creates a metal-inhibitor complex (Bikić, 2017):

$$M \rightarrow M^{2+} + 2e^-$$

$$M^{2+} + \mathrm{Inh(ads)} \rightarrow [\mathrm{M\text{-}Inh}]_{(ads)}^{2+}$$

Depending on the relative solubility of the resulting complex, further dissolution of the metal can be inhibited or catalyzed (Bikić, 2017).
According to previous research on the dissolution of copper in chloride medium, the anodic reaction is reversible, mainly due to the strong, thermodynamically more favorable complexation of copper ions with chloride ions (Lee and Noble, 1986; Deslouis, *et al.*, 1988, Barcia, *et al.,*1993). The cathodic response is dominated by oxygen reduction, which is irreversible. Copper with chloride ions can form several complexes (Lee and Noble, 1986): CuCl, $CuCl_2^-$, $CuCl_3^{2-}$ or $CuCl_4^{3-}$. The formation of the CuCl layer takes place according to the reaction:

$$Cu + Cl^- \rightarrow CuCl$$

CuCl is poorly soluble in NaCl solution, resulting in the formation of an ion $CuCl_2^-$ complex:

$$CuCl + Cl^- \rightarrow CuCl_2^-$$

It is generally accepted that the anodic dissolution of Cu depends on the concentration of $Cl^-$ ions and does not depend on the pH of the solution. At concentrations of $Cl^-$ ions higher than 1 $mol/dm^3$, it is possible to form more complex complexes such as $CuCl_3^{2-}$ and $CuCl_4^{3-}$ (Otmačić and Stupnišek-Lisac, 2003; Kear, Barker, and Walsh, 2004; Otmačić Čurković, Stupnišek-Lisac and Takenouti, 2010).
The cathodic reaction in neutral solutions is:

$$O_2 + H_2O + 4e^- \rightarrow 4OH^-$$

During hydrolysis, $CuCl_2^-$ ions in NaCl solution can cause precipitation of copper (l) oxide:

$$2CuCl_2^- + H_2O \rightarrow Cu_2O + 2H^+ + 4Cl^-$$

or by direct oxidation of copper (Barcia, *et al.*, 1993):

$$2Cu + H_2O \rightarrow Cu_2O + 2H^+ + 2e^-$$

When a passive film is created on a metal (e.g., $Cu_2O$) that does not have good protective properties, pitting corrosion will occur in the presence of aggressive ions, which is very dangerous because it quickly penetrates deep into the metal mass and can lead to cracking of the structure under stress (Winston Revie, 2000). Pitting corrosion most often occurs during the transition from an active to a passive state. The stability of $Cu_2O$ depends on the concentration of chloride ions. The use of inhibitors and alloying reduces the possibility of pitting corrosion.
In this work, electrochemical methods were used to demonstrate the effect of the Polka raspberry leaf extract from the locality of Moševac near Maglaj. Raspberry Polka is one of the best varieties of raspberry. It is a perennial raspberry, a newer variety of raspberry originating in Poland.Raspberry leaf extract is a relatively cheap, readily available, and renewable natural product rich in various organic compounds such as polyphenolic compounds, organic acids, vitamins, etc., which makes it

a potential corrosion inhibitor (Milenković Anđelković, 2016).

## EXPERIMENTAL

### Materials preparation

For the application of the Electrochemical Impedance Spectroscopy method, copper samples with dimensions 13x13 mm were used. Before each measurement, the copper working surface was mechanically prepared with sandpaper of different grits, placed on the device, degreased in 97% ethanol, and washed with distilled water. Two types of materials were used to test the electrochemical characteristics of selected metal materials in 3% NaCl solution without and in the presence of the extract. Copper samples with of dimensions d = 15 mm and ranging δ from 1 to 2 mm were used for polarization measurements.

### *Plant extract preparation*

The raspberry leaves were dried in the shade for a few days to remove all moisture content. The dried leaves were then ground in a blender to obtain a fine powder, which was later used for Soxhlet extraction with 96% ethanol as the solvent. The extraction lasted 6 hours, after which the obtained extract was dried in a rotatory evaporator. The extract was stored in a dark bottle in a refrigerator at a temperature of +4 ºC. The extracted sample was of resinous consistency and well soluble in 96% ethanol.

### Total phenolic content

The total phenolic content of *R. idaeus* was analyzed spectrophotometrically by the Folin-Ciocalteu method according to Singleton and Rossi (1965) and Singleton, Orthofer, and Lamuela-Raventós (1999), using a Perkin-Elmer Lambda 650 spectrophotometer. Gallic acid was used as a reference standard. Solutions of gallic acid were prepared in a series of concentrations from 0.00125 to 0.008 mg/ml. A calibration curve was constructed based on the measured absorbance values depending on the different concentrations of gallic acid. The results were expressed as milligrams of gallic acid equivalent (GAE) per gram of extract.

### Analysis of phenolic acids and flavonoids using high-performance liquid chromatography

The HPLC analysis of the raspberry extract was performed on Shimadzu Prominence (modular HPLC) with a UV/Vis detector. The separation of phenolic acid and flavonoids was done using the Nucleosil C18 column (250 mm x 4.6 mm, particle size 5 μm; Macherey-Nagel) with absorbance measurements at 280 nm (for hydroxybenzoic acid derivates, gallic acid) and 360 nm (for flavonoids, quercetin, rutin, and catechin). Standards of phenolic compounds were dissolved in 50% methanol. The mobile phases used for the analysis were Solvent A (1% formic acid) and Solvent B (acetonitrile) at a flow rate of 1 ml/min and using the following linear gradient: 0–10 minute linear rise from 10 to 25% A; 10–20 minute linear rise to 60% A; and 20–30 minute linear rise to 70% A (Vinčić, 2017). The concentrations of standards solutions of phenolic compounds for the formation of calibration curves were in the following range: 4-100 mg/l for rutin, 52.5-420 mg/l for gallic acid, 13.13-52.50 for quercetin and 5.4-540 mg/l for catechin hydrate.

Based on the obtained chromatograms and calibration curves of standard solutions of phenolic compounds, the concentrations of identified phenolic acids and flavonoids (μg/ml or mg/ml) were calculated.

### Electrochemical analysis

Copper with a purity of 99.8% was used to examine the effect of raspberry (*Rubus idaeus* L.) leaf extract on the corrosion characteristics of copper. The chemical composition of copper was tested at the Kemal Kapetanović Institute in Zenica on the atomic absorption spectrometer.

The following polarization measurement methods were used in this research during the electrochemical tests of the corrosion process using DC techniques:

- linear polarization method;
- potentiodynamic polarization method.

The following method was used when testing the corrosion process by AC - techniques:

- Electrochemical Impedance Spectroscopy (EIS).

Copper polarization measurements were performed in a corrosion cell using a Potentiostat/Galvanostat device, PAR, model 263A-2, and PowerCORR® software package. An electrochemical cell contains three electrodes. A carbon electrode is used as an auxiliary electrode, and a saturated calomel electrode (SCE) with a potential of 0.2415 V is used as a reference electrode. All results listed in the paper are in relation to the SCE. The working electrode is a cylindrical body (disk) placed inside a space made of glass and metal. The dimension of the working electrode is d=15 mm and □□from 1 to 2 mm. Sample preparation and care were done according to the ASTM G5 standard (ASTM G5-94). The Electrochemical Impedance Spectroscopy method (EIS) was used to determine the kinetic parameters of the electrochemical reaction of copper corrosion in a 3% NaCl solution without and in the presence of plant extracts. Measurements were performed using the IviumSoft software package on an IVIUM® Vertex One potentiostat/galvanostat. The corrosion kinetic parameters were deduced using IviumSoft software package and PowerCORR® software package.

## RESULTS AND DISCUSSION

The yield of Soxhlet extraction of raspberry leaves (12.0 g) with ethanol was 2.55 g or 21.25%.

### Total phenolic content

The blue color was created by the effect of plant polyphenols on the Folin-Ciocalteu reagent components, which were detected at 725 nm (Chitra, et al., 2019).

To estimate the TPC, an increase in absorbance was measured, indicating an increase in phenol concentration, The TPC of *R. idaeus* leaf extract was 24.39±2.64 mg GA/g DW.

Many factors influence the concentration of phenolic compounds in plants, including cultivar, cultivation method, and location of occurrence, climatic conditions, and harvest time. Also, extraction and analysis procedures influence the final results (Staszowska-Karkut and Materska, 2020).

These findings are consistent with evidence from the literature. According to Pavlović, et al. (2016), the highest TPC concentration was detected in the *R. idaeus* cultivars 'Meeker' (144.20±1.58 mg GAE/g DW) and 'Willamette' (143.38 4.68 mg GAE/g DW), while the lowest TPC content was observed in the 'Tulameen' cultivar (84.64±2.05 mg GAE/g DW). Different phenolic compounds have different responses to the Folin-Ciocalteu reagent. The possible presence of interfering compounds (sugars, aromatic amines, sulfur dioxide, vitamin C, organic acids, Fe (II), and other substances that are not of polyphenolic origin), affects the unrealistic increase in results (Vinčić, 2017). According to Winston Revie, (2000), the total phenols for the domestic raspberry leaf was 811.75 mg GA / kg of a dried sample, which is significantly less than the obtained result.

According to the literature, several other plant products, such as gallic acid, quercetin, and caffeic acid from Syzygium cumini, rutin from Piper longum, myricetin and chlorogenic acid from Cyamopsis tetragonoloba, and flavonoids from Azadirachta indica (flavonoids), have excellent corrosion inhibition efficiency (Singh, Ebenso, and Quraishi , 2012). These findings initiated the search for leaf extracts of *R. idaeus* to determine its corrosion resistance against copper corrosion in 3% NaCl. These findings prompted researchers to look for *R. idaeus* leaf extracts to test their corrosion resistance against copper corrosion in 3% NaCl.

**Analysis of phenolic compounds by HPLC**

The corrosion inhibition properties of plant extracts are to the result of the synergistic activity of phytochemical components such as phenols, flavonoids, alkaloids, tannins, and other compounds found in them. The qualitative and quantitative analysis of *R. idaeus* leaf extract was determined using HPLC with UV/Vis detection. Figure 1 shows the HPLC chromatogram of phenolic acids and flavonoids detected in *R.idaeus* leaf extract.

Gallic acid (12.60±6.19 mg/100g DW, quercetin (33.04±0.15 mg/100g DW) and rutin (71.90±5.65 mg/100g DW) were identified in the analyzed leaf extract. The analysis did not show the presence of catechin in the analyzed sample.

According to Krauze-Baranowska, et al., 2014., among the identified polyphenols in *R. idaeus* ″Willamente″ dry shoot extract are gallic acid (722±6.5 mg/100 g DW), catechin (129.3±11.6 mg/100g DW), epicatechin (791±70.7 mg/100 g DW), isoquercetin and quercetin 3-O-glucuronide (717.57±64.1 mg/100g DW), chlorogenic acid (177.4±15.9 mg/100 g DW), etc. Li, et al. (2015) identified 16 flavonoids, including 4 quercetin derivatives, 2 luteolin derivatives, 8 kaempferol, and 2 isorhamnetin derivatives in leaf extract of *R. idaeus*. Authors Yang et al., (2020) identified 12 polyphenols in extracts of *R. idaeus*. Among them are chlorogenic acid (145.83±120.3 mg/100g DW), catechin (2.320.3±3.25 mg/100g DW), rutin (484.048±129.12 mg/100g DW), quercetin (11.190±12.59 mg/100g DW), kaempferol (0.714±0.89 mg/100g DW), etc. Staszowska-Karkut and Materska, (2020) reported 20 different phenolic compounds in the leaves of *R. idaeus*. Among them are caffeic acid (0.3-77 mg/100g DW), chlorogenic acid (2.9-23 mg/100g DW), gallic acid (2.3-31 mg/100g DM), luteolin (49 mg/100g DW), rutin (5-59 mg/100g DW, catechin (92 mg/100g DW etc. By comparing the obtained results with the literature data, we see that the content of gallic acid agrees with the data of the authors Staszowska-Karkut and Materska. All other results for the identified phenolic components in the analyzed sample were lower compared to the literature, except for rutin which was slightly higher than in the analyzed samples of Staszowska-Karkut and Materska.

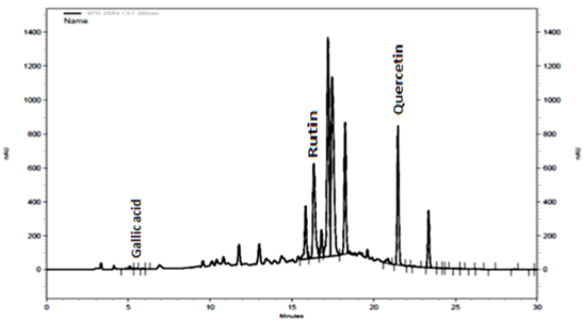


***Figure 1.*** *HPLC chromatogram of R. idaeus leaf extract*

**Effect of extract on copper corrosion characteristics using potentiodynamic polarization method**

Figure 2 shows the polarization curves of copper in 3% NaCl without and with the addition of extract in different concentrations, and the obtained corrosion parameters are shown in Table 1.

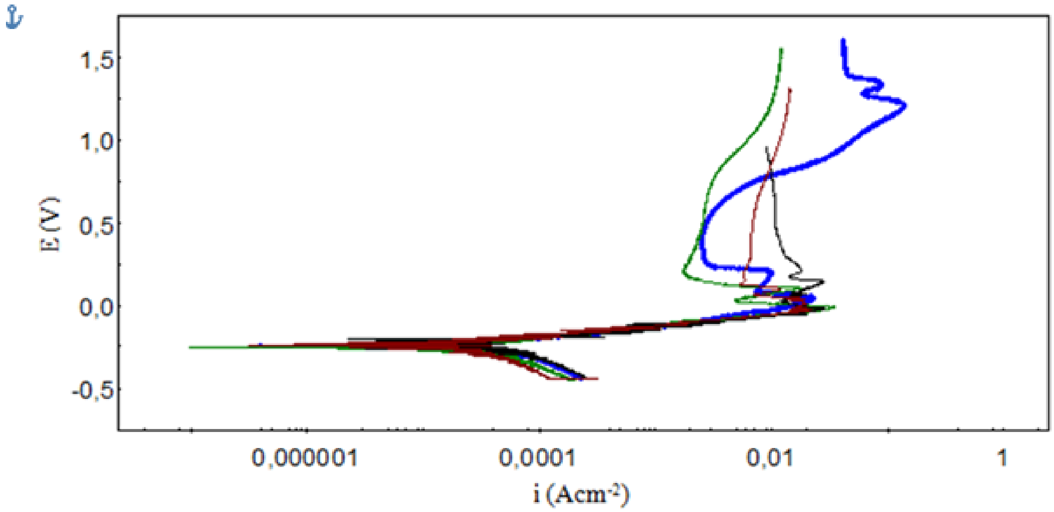


**Figure 2.** Anode and cathode curves of copper polarization in 3% NaCl without and with the addition of extract in different concentrations *----3% NaCl; ----3% NaCl+0,03221g/l; ---- 3% NaCl+0,04828 g/l; ----3% NaCl+0,06432 g/l*

**Table 1.** Corrosion parameters determined by Tafel extrapolation method of copper in 3% NaCl without and with the addition of extract in different concentrations

| **Sample** | ***R.idaeus* leaf extract (g/l)** | **$E_{corr}$ (mV)** | **$i_{corr}$ (μAcm$^{-2}$)** | **$\beta_k$ (mVdec$^{-1}$)** | **$\beta_A$ (mVdec$^{-1}$)** |
|---|---|---|---|---|---|
| Copper sample | Without extract | -226.807 | 9.978 | 309.41 | 67.106 |
| | 0.01612 | -216.815 | 6.756 | 215.847 | 61.897 |
| | 0.03221 | -239.573 | 1.078 | 128.844 | 49.793 |
| | 0.04828 | -216.676 | 1.418 | 135.187 | 42.191 |
| | 0.06432 | -223.303 | 1.347 | 120.318 | 46.423 |
| | 0.08033 | -226.613 | 2.071 | 143.594 | 50.871 |

With increasing extract concentration, the corrosion potential shifts towards more positive values, except for the extract concentration of 0.03221 g/l. The results obtained by the Tafel extrapolation method showed that the corrosion rate decreases in the presence of almost all tested concentrations of extract. In the tested interval, the lowest corrosion rate is at the inhibitor concentration of 0.03221 g/l.

The linear polarization method shows the results obtained by the potentiostatic polarization of copper in a narrow potential range. Table 2 shows that the addition of different concentrations of the extract reduces the corrosion rate, which means that the polarization resistance increases. Polarization resistance is a measure of a material resistance, and the higher the value, the more corrosion resistant the material is. Corrosion parameters are shown in Table 1.

Polarization measurements performed in a narrow range of potentials confirmed that the extract provides the highest protection at a relatively low concentration of 0.04828 g/l in copper. Therefore, at this concentration, the corrosion rate is the lowes.

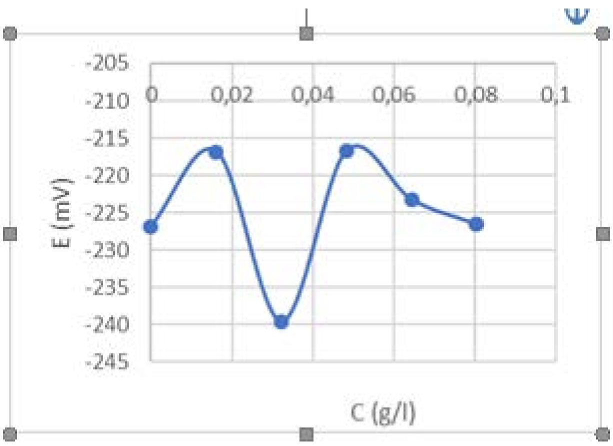


**Figure 3.** Dependence of the Ecor on concentration of extract

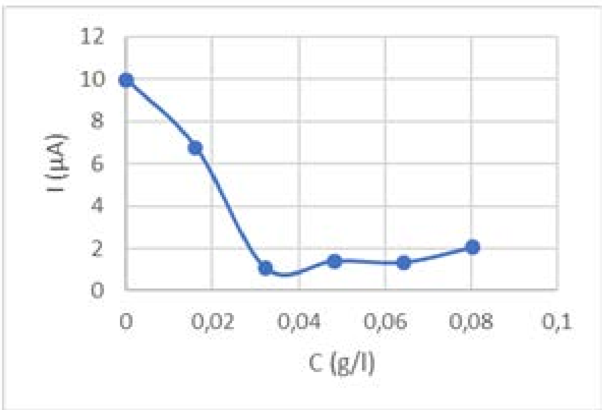


**Figure 4.** Dependence of the icorr on concentration of extract

**Table 2.** Corrosion parameters determined by Linear polarization method of copper in 3% NaCl without and with the addition of extract in different concentrations

| Sample | *R.idaeus* leaf extract (g/l) | R (Ω) | Ecorr (mV) | icorr (μAcm$^{-2}$) |
|---|---|---|---|---|
| | Without extract | 3042.618 | -205.166 | 7.145 |
| | 0.01612 | 3453.884 | -202.546 | 6.294 |
| | 0.03221 | 3341.418 | -211.554 | 6.506 |
| | 0.04828 | 4051.622 | -208.973 | 5.366 |
| | 0.06432 | 4018.02 | -219.27 | 5.410 |
| Copper sample | 0.08033 | 2804.507 | -219.119 | 7.751 |

## Effect of gallic acid (GA), rutin and quercetin on copper corrosion

The effect of individual components of the extract on the corrosion properties of copper was tested. The measurements were performed by adding a solution of individual components at a concentration of 0.032 g/l in 3% NaCl solution.

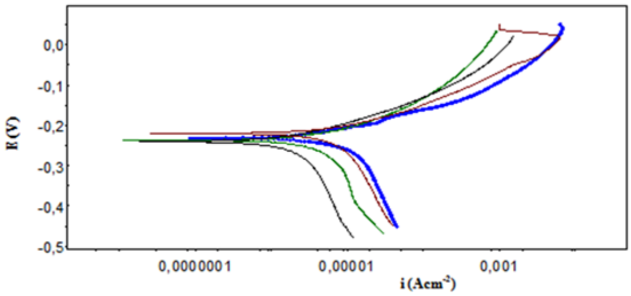


**Figure 5.** Anode and cathode curves of copper polarization in 3% NaCl without and with the addition of standard solution of gallic acid, rutin and quercetin ---- 3% NaCl; ---- 3% NaCl+0.03221g/l gallic acid; ---- 3% NaCl+0.03221g/l rutin; ---- 3% NaCl+0.03221g/l quercetin

Curve profiles in 3% NaCl solution and with the addition of standards they do not differ. There was a decrease in the corrosion current as well as the corrosion potential except for quercetin.

Corrosion parameters that show tendencies can be obtained from these curves.


**Figure 6.** Ecorr of copper in 3% NaCl solution with the addition of GA, rutin and quercetin in concentration 0.03221 g/l

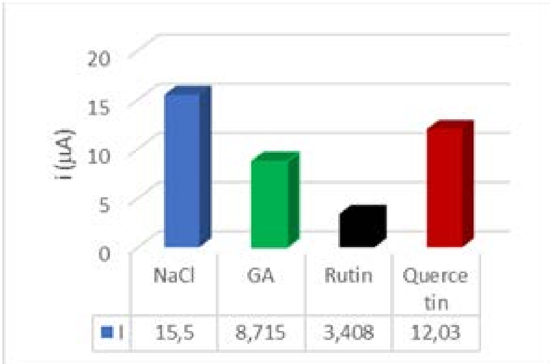


**Figure 7.** icorr of copper in 3% NaCl solution with the addition of GA, rutin and quercetin in concentration 0.03221 g/l

Based on the corrosion parameters obtained from the Tafel curves, it can be seen that gallic acid and rutin show inhibitory effects on the action of NaCl solution on copper. Quercetin increases the corrosion effect when NaCl acts on copper. Effect of extract on copper corrosion characteristics using electrochemical impedance spectroscopy method. The results obtained by electrochemical impedance spectroscopy can be represented by an equivalent electrical circuit, Figure 8.
The results of the electrochemical impedance spectroscopy test are shown in the Nyquist diagram, Figure 9, and were analyzed using an equivalent electrical circuit, and the obtained parameters in Table 3.

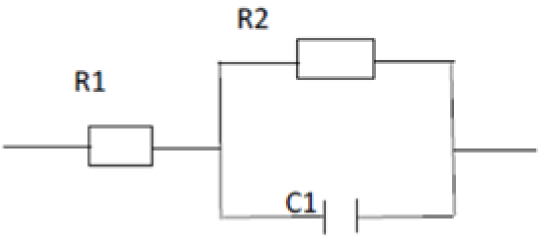


**Figure 8.** Scheme of the equivalent circuit of a simple electrochemical cell C1-capacitor, R1-electrolyte resistance, R2-resistance of charge transmission

From Figure 9 it can be seen that the addition of the tested concentrations of the extract increases the diameter of the impedance curves in copper compared to the one obtained without the addition of extract. It can be concluded that the addition of the extract reduces the corrosion rate. EIS parameters for the extract as well as without it are shown in Table 3 and based on these results it is observed that the highest inhibitor resistance in copper is given by the extract concentration of 0.11227 g/l.

**Table 3.** Parameters obtained by electrochemical impedance spectroscopy of copper in 3% NaCl without and with the addition of extract in different concentrations

| Sample | *R. idaeus* leaf extract (g/l) | R1 (Ω) | R2(Ω) | C(F) |
|---|---|---|---|---|
| Copper sample | Without inhibitor | 110.1 | 2776 | $3.890 \cdot 10^{-4}$ |
| | 0.01612 | 134.7 | 3998 | $5.061 \cdot 10^{-4}$ |
| | 0.03221 | 196.8 | 6168 | $7.314 \cdot 10^{-4}$ |
| | 0.04828 | 219.3 | 6792 | $7.240 \cdot 10^{-4}$ |
| | 0.06432 | 257.6 | 6930 | $8.346 \cdot 10^{-4}$ |
| | 0.08033 | 236.0 | 8044 | $7.889 \cdot 10^{-4}$ |
| | 0,09631 | 309.4 | 9360 | $6.664 \cdot 10^{-4}$ |
| | 0,11227 | 742.3 | 10210 | $5.112 \cdot 10^{-4}$ |

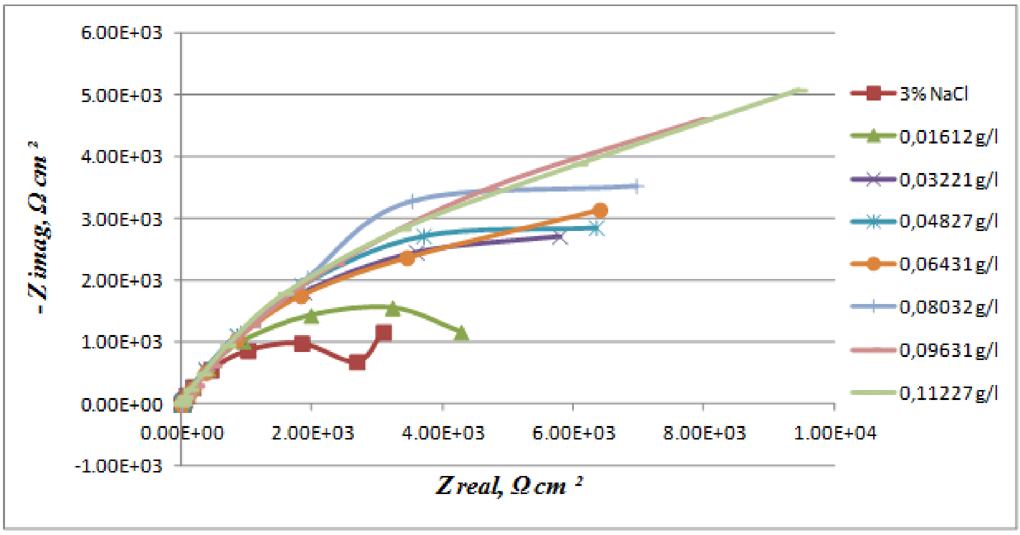


**Figure 9.** Nyquist copper curves in 3% NaCl without and with the addition of extract in different concentrations

## CONCLUSION

The results obtained by DC - techniques (Tafel extrapolation method and linear polarization method) showed that the corrosion rate decreases in the presence of almost all tested extract concentrations Three current peaks appearon the polarization curve recorded for pure copper in 3% NaCl, , which are attributed to the formation of copper chloride and copper oxide Cu2O. In all anode branches of copper polarization curves in the presence of different concentration extracts, it was detected that the areas where copper dissolution occurs and the formation of a soluble $CuCl2^{-}$ complex and its diffusions from the metal surface into the solution and the areas of corrosion product formation occur earlier, which leads to a certain decrease in current density.

Studies conducted by the electrochemical impedance spectroscopy method show that almost all tested extract concentrations slow down the corrosion process kinetics, which is visible through an increase in resistance. Based on the results for the EIS parameters with and without the extract, it was observed that the highest inhibitor resistance in copper was given by the extract concentration of 0.112 g/l.

These results confirm that in an aggressive medium, such as a 3% NaCl solution, the test extract in a concentration of 0.032 g/l can be used for protection, as this concentration met the protection requirements for all test methods. The results of the conducted tests prove that in an aggressive medium, such as a 3% NaCl solution, the extract of raspberry Polka leaf can be used as an inhibitor of copper's corrosion at room temperature.

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## Summary/Sažetak

Ova studija ispituje utjecaj ekstrakta maline (*Rubus idaeus* L.) na karakteristike korozije bakra. Ekstrakt lista maline pripremljen je Soxhlet ekstrakcijom s etanolom kao otapalom. Procjena ukupnog sadržaja polifenola u dobivenom uzorku određena je UV/Vis spektrofotometrijskom metodom. HPLC analitičkom metodom izvršena je identifikacija i kvantifikacija fenolnih kiselina i flavonoida (rutin, galna kiselina, kvercetin i katehin hidrat). Nakon dobivanja i ispitivanja ekstrakta lista maline Polka, ispitana je brzina korozije bakra. Ispitivanje korozije bakra u 3% otopini NaCl bez i u prisutnosti ekstrakta.Vrijednosti otpora polarizacije bakra (Rp) u 3% otopini NaCl bez i u prisutnosti ekstrakta, određene su metodom linearne polarizacije. Korozijsko ponašanje bakra u 3% otopini NaCl bez i u prisutnosti ekstrakta i specifični elektrokemijski parametri: potencijal korozije (Ecorr), gustoća struje korozije (Icorr) i nagib anode (βa) i katode (βk). Metodom spektroskopije elektrokemijske impedancije ispitano je korozijsko ponašanje bakra u 3% otopini NaCl bez i u prisutnosti ekstrakta. Rezultati dobiveni Tafelovom metodom ekstrapolacije, pokazali su da se brzina korozije smanjuje u prisutnosti ispitivanog ekstrakta. Istraživanja provedena metodom elektrokemijske impedančne spektroskopije pokazuju da ispitivani ekstrakt usporava kinetiku procesa korozije, što je vidljivo kroz povećanje otpora. Rezultati potvrđuju da se testni ekstrakt može koristiti za zaštitu u agresivnom mediju, kao što je 3% otopina NaCl.