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Corrosion inhibition by fruit extracts -Inhibition of corrosion of mild steel in simulated concrete pore solution prepared in sea water by an aqueous extract of apple juice- A Case study

ABSTRACT

The inhibition efficiency of an aqueous extract of apple juice in controlling corrosion of mild steel immersed in ***simulated concrete pore solution (****SCPS) prepared in sea water, has been evaluated by weight loss method. Langmuir adsorption isotherm has been investigated. The mechanistic aspect of corrosion inhibition has been investigated by Electrochemical impedance spectra (AC impedance spectra). The protective film has been analysed by Fluorescence spectroscopy, FTIR spectroscopy and AFM. The SCPS system offers 60% inhibition efficiency to mild steel immersed in sea water. In presence of apple juice extract the inhibition efficiency increases as the concentration of the extract increases. When 10 ml of extract is added, 85% inhibition efficiency is obtained. Electrochemical impedance spectra (AC impedance spectra) reveal that a protective film is formed on the metal surface. In the presence of inhibitor system, charge transfer resistance value increases, impedance value increases, phase angle value increases whereas double layer capacitance value decreases as expected. The FTIR spectral study reveals that the protective film consists of complexes consisting of iron-active principles of the apple juice extract. AFM study reveals that when the inhibition efficiency increases the roughness of the surface decreases or in other words the smoothness of the system increases.*

Keywords: *corrosion inhibition, mild steel l, simulated concrete pore solution ,sea water , an aqueous extract of apple juice, electrochemical studies, FTIR, Fluorescence spectroscopy, AFM.*

1. INTRODUCTION

Corrosion is the process of slowly eating up metals by gas and water vapours present in the atmosphere due to the formation of certain compounds like oxide, sulphide, carbonate, etc. Corrosion is a natural spontaneous and thermodynamically stable process. Corrosion cannot be prevented even though the rate of corrosion can be controlled. There are several methods of controlling corrosion. One such method is use of inhibitors. Corrosion inhibitors are chemical molecules used in small quantities to control corrosion by adsorption on the metal surface or by blanketing effect. Once chromates were used as corrosion inhibitors. But due to environmental toxicity use of chromates were avoided. This being the new trend and need of the hour many researchers are going for extracts of (aqueous, alcoholic etc.,) natural products. This is due to the facts they are less toxic or non toxic, less expensive and readily available . Chemically speaking the extracts contain many active ingredients. These molecules have polar atoms such as oxygen, sulphur , nitrogen and aromatic rings. Some molecules (β-carotene for example) have conjugated dienes also. Hence electron transfer from these molecules to the metal ions (Fe^{2+} for example) generated during the corrosion process is easy. Under these conditions metal-inhibitor complexes are formed on the anodic sites of the metal surface. Thus the corrosion process is controlled. Moreover the plant extract contains many active ingredients. Hence there is

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chance of synergistic effect also. Both anodic reaction and cathodic reactions are controlled, simultaneously. That is the plant extracts act as mixed type of inhibitors and electron pumpers.

Various parts of the natural products, such as leaves, barks, roots and fruits can be used as corrosion inhibitors. In the present study, the use of extracts of some fruits is discussed. A case study is also presented. That is “Inhibition of corrosion of mild steel in simulated concrete pore solution prepared in sea water by an aqueous extract of apple juice” is presented. The use of extracts of fruits as corrosion inhibitors is summarized in Table 1.

Table 1. Use of extracts of fruits as corrosion inhibitors

Tabela 1. Upotreba ekstrakta voća kao inhibitora korozije

S.No	Metal/medium	Name of fruirt	Methods	Findings	Ref
1	mild steel in acidic environment	red dragon fruit (Selenicereus costaricensis) waste peel extracts	Thermodynamic studies. as activation energy (Ea) and changes in enthalpy (ΔHo) and entropy (ΔSo)	97% IE.	1
2	mild steel in 0.5 M HCl pickling environment	Microwave-assisted extraction of Swietenia macrophylla fruit shell	of weight loss (WL), electrochemical (potentiodynamic polarization and AC impedance spectroscopy) and scanning electron microscopy (SEM) techniques	Weight loss results suggest that, the protection efficiency enhances with a rise in the amount of Swietenia macrophylla fruit shell extract and decreases with an increase in the corrosive solution temperature. Mixed type of inhibitor	2
3	low carbon steel in NaCl electrolyte	mulberry fruit (Morus nigra L.) extracts incorporated hybrid (GPTMS-TEOS) composite silanol coatings	electrochemical impedance spectroscopy, electrochemical noise measurement and potentiodynamic polarization. FTIR, contact angle measurement, energy dispersive X-ray spectroscopy (EDX),SEM	The corrosion inhibition efficiencies obtained were 85.57% and 81.37% for hybrid coatings doped with mulberry ethanol extract and water extract, respectively.	3
4	Pitting Potential Improvement of 304 Stainless Steel in Hydrochloric Acid Solution	Terminalia bellirica Fruit Extract	potentiodynamic polarization curves,	95% IE. Langmuir adsorption isotherm	4
5	stainless steel corrosion during acid washing in a multistage flash desalination plant	orange peel extract	Electrochemical methods, quantum chemical calculations,	Langmuir adsorption isotherm	5
6	Mild Steel in Hydrochloric Acid. 0.25 M HCl	Extractfromthe Pericarp of the fruit Tamarindus indica (Tamarind)	scanning electron microscopy and energy-dispersive x-ray spectroscopy. UV-visible spectrum and IR spectrum.	mixed type of inhibitor.	6
7	low carbon steel in H2SO4 solution	grapefruit essential oil extracts	Standard deviation data	above 95 % inhibition	7
8	steel in industrial media	Tomato pomace extract	electrochemical methods, weight loss assay. SEM and AFM	98% IE. Quantum-chemical calculations.	8

9	Carbon Steel in an Acidic Medium	Wild Lycium ferocissimum Miers Fruit Extract. (phenolic extract)	potentiodynamic polarization (PDP), electrochemical impedance spectroscopy (EIS), and weight loss method.	80 % IE.	9
10	Aluminium Alloy in Acidic Medium	Aqueous Extract of Punica Granatum Fruit Peel	potentiodynamic polarization and electrochemical impedance spectroscopy techniques.SEM. FTIR	Langmuir adsorption isotherm.	10

Extracts of various fruits [1-10] have been used as corrosion inhibitors.

Metals: Extracts of various fruits [1-10] have been used as corrosion inhibitors to control various metals and alloys such as mild steel [1-3,6,7,9], stainless steel [4,5,8] and aluminium [10].

Medium: Corrosion of metals have been prevented by flower extracts in various media such as acid [1,2, 4-7,9,10] and sodium chloride [3] medium.

Flowers: Extracts of various flowers such as red dragon fruit[1], Swietenia macrophylla fruit shell [2], mulberry fruit [3], Terminalia bellirica Fruit[4], orange peel extract[5], Tamarind[6], grapefruit[7], Tomato pomace extract[8], Wild Lycium ferocissimum Miers Fruit[9] and Punica Granatum Fruit Peel[10].

Methods: Various methods have been used to control the corrosion process. Weight loss method [2,8] and electrochemical methods[2-5,8-10] have been employed.

Surface analysis of protective films: Methods such as SEM [2,3,6,8,10], FTIR [3,6,10], AFM [8] and EDX [3,6] have been used for this purpose.

Contact angle measurements have not been used to study the hydrophobic nature of the protective film.

Case study

Title: "Inhibition of corrosion of mild steel in simulated concrete pore solution prepared in sea water by an aqueous extract of apple juice"

2. EXPERIMENTAL

Preparation of mild steel specimens

Mild steel specimens of dimensions 1.0 cm x 4.0 cm x 0.2 cm were polished to a mirror finish and degreased with trichloroethylene.

Weight loss method

Mild steel specimens in triplicate were immersed in 100 ml of the simulated concrete pore solution (SCPS) prepared in sea water in the absence and presence of an aqueous extract of apple juice , for a period of one day. The weight of the specimens before and after immersion was determined using a Shimadzu balance, model AY62. The corrosion products were cleaned with Clarke's solution. The corrosion rate was calculated using the following equation.

Corrosion rate =(W/AT) mdd

Where

W = loss in weight (mg)

A = surface area of the specimen (dm^2)

T = period of immersion (days)

The corrosion rate is expressed in mdd units

[mdd = mg/(dm^2) (day)]

The inhibition efficiency was calculated using the relation.

Inhibition efficiency = [(CR_1-CR_2)/CR_1] x 100 %

Where

CR_1 = corrosion rate in the absence of inhibitor

CR_2 = corrosion rate in the presence of inhibitor.

Electrochemical study

AC impedance spectra (Electrochemical Impedance Spectra - EIS)

In the present work, corrosion resistance of mild steel immersed in various test solutions were measured by Electrochemical Impedance Spectra - EIS. The experiments were done at room temperature. Electrochemical Impedance Spectra were recorded in a CHI- electrochemical work station with impedance model 660A. It was provided with iR compensation facility. A three-electrode cell assembly was used. Mild steel was used as working electrode. Platinum was used as counter electrode and saturated calomel electrode (SCE) was used as reference electrode. From Electrochemical Impedance Spectra, corrosion parameters such as charge transfer resistance (Rt), double layer capacitance value (Cdl) and impedance log (Z/Ohm) value were calculated.

Surface characterization study

FTIR

The FTIR spectra were recorded in a Perkin Elmer 1600 series spectrophotometer with resolving power of 4 cm^{-1}.

Atomic force microscopy (AFM)

The mild steel specimens immersed in various test solutions for one day were taken out, rinsed with double distilled water, dried and subjected to the surface examination. The surface morphology measurements of the mild steel surface was carried out by atomic force microscopy (AFM) using SPM Veecodi Innova connected with the software version V7.00 and the scan rate of 0.7 Hz.

3. RESULTS AND DISCUSSION

The inhibition efficiency of an aqueous extract of apple juice in controlling corrosion of mild steel immersed in SCPS prepared in sea water has been evaluated by weight loss method. Langmuir adsorption isotherm has been investigated, The mechanistic aspect of corrosion inhibition has been investigated by Electrochemical impedance spectra (AC impedance spectra). The protective film has been analyzed by Fluorescence spectroscopy, FTIR spectroscopy and AFM.

Weight loss method

The inhibition efficiency of an aqueous extract of apple juice in controlling corrosion of mild steel immersed in SCPS prepared in sea water has been evaluated by weight loss method. Three mild steel specimens were immersed in SCPS prepared in sea water in the absence and presence of an aqueous extract of apple juice extract. The corrosion rates and inhibition efficiencies are given in Table 2.

Table 2 . Corrosion rate and inhibition efficiency of mild steel immersed in SCPS prepared in sea water in the absence and presence of apple juice obtained by weight loss method

Tabela 2. Brzina korozije i efikasnost inhibicije mekog čelika uronjenog u SCPS pripremljen u morskoj vodi u odsustvu i prisustvu soka od jabuke dobijenog metodom gubitka težine

System	Corrosion rate, mdd	IE, %	surface coverage θ	C/θ
Sea water	20.86	-	-	-
SCPS	8.34	60	0.60	0
SCPS + extract 2ml	7.30	65	0.65	3.1
SCPS + extract 4ml	6.47	69	0.69	5.8
SCPS + extract 6ml	5.01	76	0.76	7.9
SCPS + extract 8ml	4.17	80	0.80	10.0
SCPS + extract 10ml	3.13	85	0.85	11.8

It is observed from Table2 that as the concentration of apple juice (C ml) increases, the corrosion rate decreases and inhibition efficiency increases and surface coverage (θ = IE%/100) increases.

Langmuir adsorption isotherm

The Langmuir adsorption isotherm is used to describe the equilibrium between adsorbate and adsorbent system, where the adsorbate adsorption is limited to one molecular layer at or before a relative pressure of unity is reached.

There are the three assumptions of the Langmuir isotherm. They are the adsorption consists entirely of a monolayer at the surface; (2) there is no interaction between molecules on different sites and each site can hold only one adsorbed molecule; (3) the heat of adsorption does not depend on the number of sites and is equal for all sites.

SCPS + Apple juice system

A plot of C vs C/ $\boldsymbol{\theta}$ gives a straight line (Table 3, Figure 1). This indicates that Langmuir adsorption isotherm is obeyed. The R^2 value is very high (0.989). The adsorption consists entirely of a monolayer of the ingredients of apple juice (Figure 1) the metal surface.

Table 3 . Data for Langmuir adsorption isotherm

Tabela 3. Podaci za Langmuir-ovu adsorpcionu izotermu

C, ml of extract	C/ $\boldsymbol{\theta}$
0	0
2	3.1
4	5.8
6	7.9
8	10.0
10	11.8

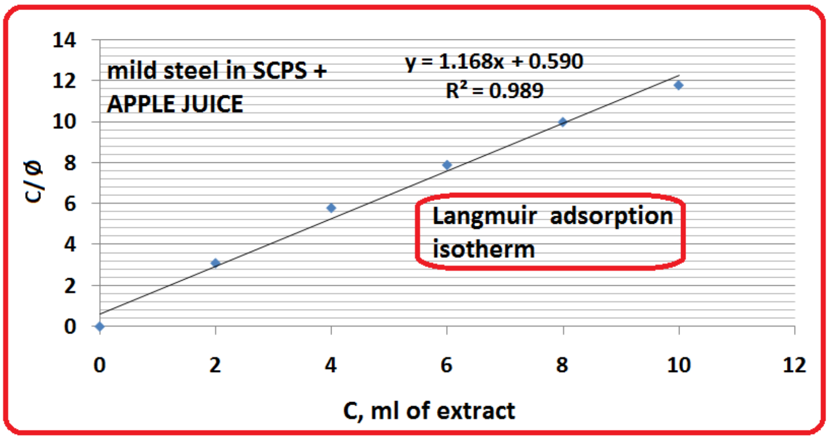


Figure 1. Langmuir adsorption isotherm for apple juice system

Slika 1. Langmuir-ova adsorpciona izoterma za sistem soka od jabuke

Analysis of AC impedance spectra

AC impedance spectra have been used to confirm the formation of protective film on the metal surface. If a protective film is formed on the metal surface, charge transfer resistance (R_t) increases, double layer capacitance value (C_{dl}) decreases and impedance log (Z/Ohm) value increases (Figure 2).

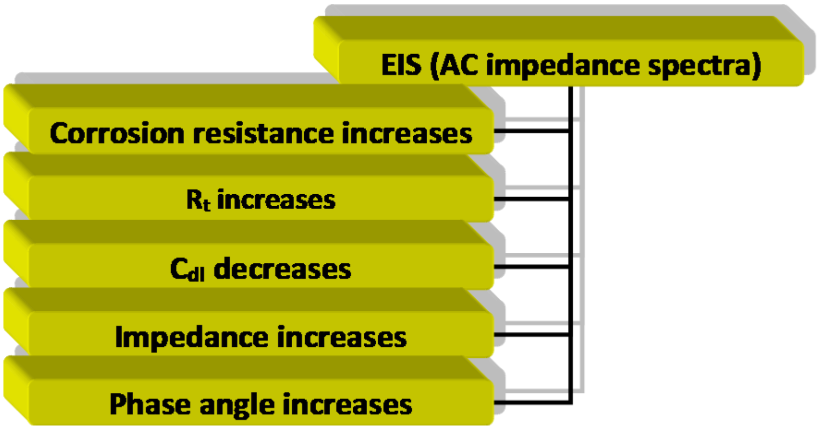


Figure 2. Corrosion parameters obtained from AC impedance spectra (Principles of AC impedance spectra)

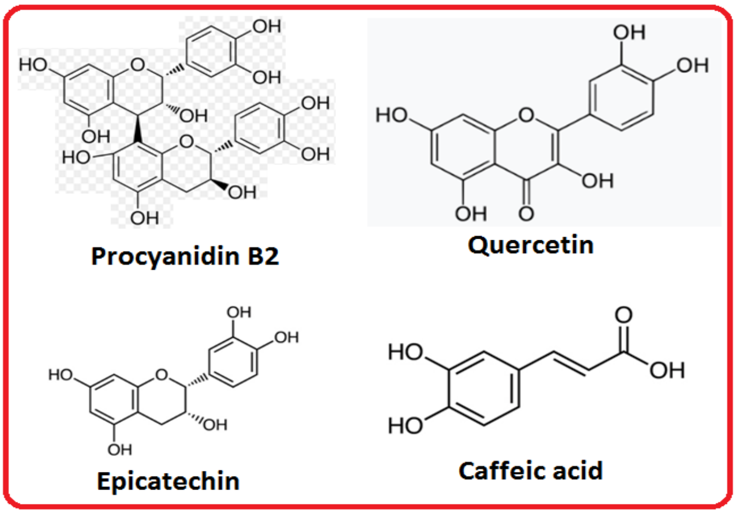
Slika 2. Parametri korozije dobijeni iz spektra impedanse naizmenične struje (Principi spektra impedanse naizmenične struje)

The AC impedance spectra (Nyquist plots and Bode plots) of mild steel immersed in various test solutions are shown in Figures (3-5). The corrosion parameters, namely, charge transfer resistance (R_t), double layer capacitance (C_{dl}), and impedance values are given in Table 3.

It is observed that when mild steel is immersed is sea water, the charge transfer resistance is 42.7 Ohmcm^2. The C_{dl} value is 1.19 x 10^{-7} F/cm^2. The impedance value is 1.671 [log(Z/Ohm)] .

It is further inferred that when mild steel in immersed in SCPS, the charge transfer resistance increases from 42.7 Ohmcm^2 to 50.04 Ohmcm^2. The C_{dl} value decreases from 1.19 x 10^{-7} x 10^{-7} F/cm^2 to 1.02 x 10^{-7} A/cm^2. The impedance value increases from 1.671 to 1.741. It is interesting to observe that when apple juice is added to SCPS system,the charge transfer resistance increases from 42.7 Ohmcm^2 to 55.8 Ohmcm^2. The C_{dl} value decreases from 1.19 x 10^{-7} x 10^{-7} F/cm^2 to 0.91 x 10^{-7} A/cm^2. The impedance value increases from 1.671 to 1.828.

From all these experimental data, the following useful conclusions are scientifically drawn from the principles of AC impedance spectra. When mild steel is immersed in SCPS prepared in sea water the corrosion resistance of mild steel increases. When apple juice is added to SCPS prepared in sea water the corrosion resistance of mild steel further increases. It is interpreted that in the presence of SCPS, the increase in corrosion is due to the formation of $CaCO_3$ and CaO . The increase in corrosion protection in the presence of apple juice is due to the fact that in the presence of apple juice, the ingredients present in apple juice, namely, Quercetin, Epicatechin, Procyanidin B2 and Caffeic acid have been deposited on the metal surface resulting in the formation iron-active ingredient complexes formed on the anodic sites of the metal surface (Schema 1).



Scheme 1: Phenolic compounds present in apples (Quercetin, Epicatechin, Procyanidin B2, Caffeic acid)

Shema 1. Fenolna jedinjenja prisutna u jabukama

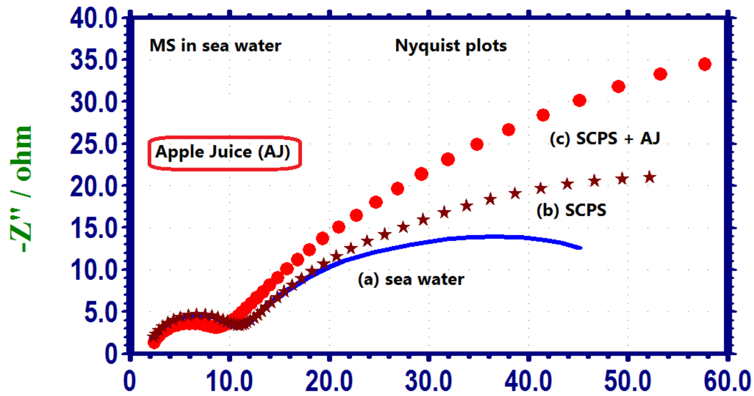


Figure 3. Nyquist plots of mild steel immersed in various test solutions. (a) sea water; (b) SCPS prepared in sea water (c) SCPS + apple juice

Slika 3. Nyquist-ove krive mekog čelika uronjenog u različita testna rešenja: (a) morska voda; (b) SCPS pripremljen u morskoj vodi, (c) SCPS + sok od jabuke

Table 4. Corrosion parameters of mild steel (MS) immersed in simulated concrete pore solution prepared in sea water, in the absence and presence of inhibitor, an aqueous extract of apple [apple juice (AJ)] obtained by the impedance spectra

Tabela 4. Parametri korozije mekog čelika (MS) uronjenog u simulirani rastvor pora betona pripremljen u morskoj vodi, u odsustvu i prisustvu inhibitora, vodeni ekstrakt jabuke [sok od jabuke (AJ)] dobijen spektrom impedanse

System	Rt, Ohmcm^2	Cdl,F/cm^2	Impedance, [log(Z/Ohm)]
sea water	42.7	1.19×10^{-7}	1.671
SCPS	50.04	1.02×10^{-7}	1.741
SCPS + AJ	55.8	0.91×10^{-7}	1.828

Equivalent circuit diagram for various systems

The equivalent circuit for various systems is shown in Figure 4. This is in accordance with the shape of the corresponding Nyquist plot, wherein two time constants are noticed. The one in the high frequency region is obvious. The one in the low frequency region is less obvious. This type of Nyquist plot is characteristic of film formation and film breaking.

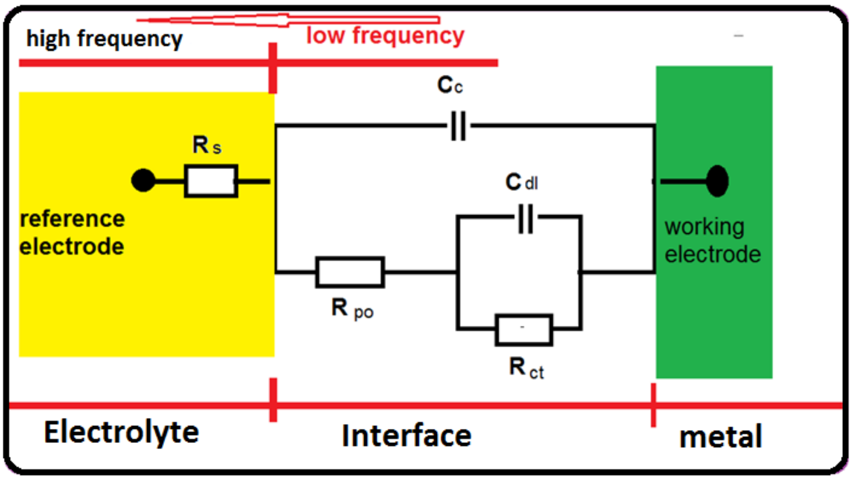


Figure 4. Equivalent circuit diagram for failed coating (Film formation and film breaking)

Slika 4. Ekvivalentna šema za neuspeli premaz (formiranje filma i pucanje filma)

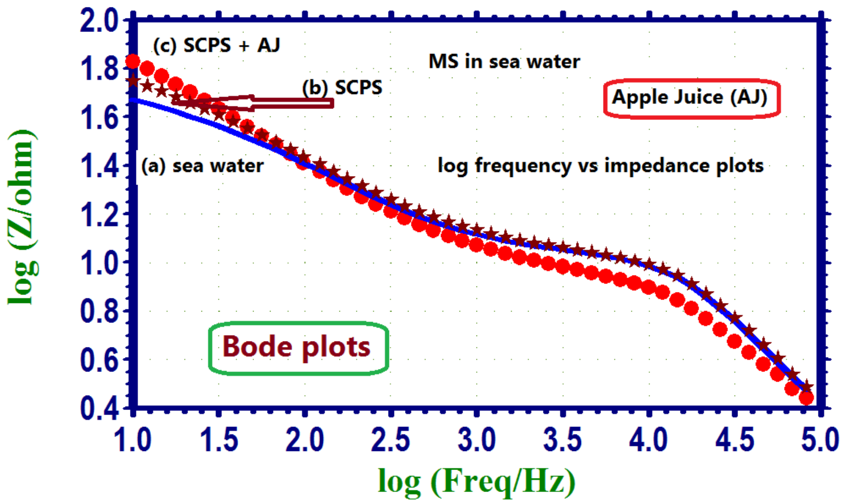


Figure 5. Bode plots of mild steel immersed in various test solutions. (a) sea water; (b) SCPS prepared in sea water (c) SCPS + apple juice

Slika 5. Bode-ove krive mekog čelika uronjene u različita testna rešenja. (a) morska voda; (b) SCPS pripremljen u morskoj vodi (c) SCPS + sok od jabuke

Analysis of FTIR spectra

The active principles of an aqueous extract of apple juice are **Quercetin, Epicatechin, Procyanidin B2, Caffeic acid** (Scheme 1). The main functional groups are phenolic –OH, carbonyl group C=O and ether -O- group. A few drops of an aqueous extract of apple juice were dried on a glass plated. A solid mass was obtained. The FTIR spectrum (KBr) of this solid mass is shown in Figures 6,7. The various stretching frequencies are given in Table 5. The FTIR spectrum (KBr) of the protective film formed on the metal surface after immersion in the solution containing SCPS and apple extract for one day is shown in Figures 8,9,10. The various stretching frequencies are given in Table 5.

Table 5. Stretching frequencies of various functional groups

Tabela 5. Frekvencije istezanja različitih funkcionalnih grupa

Details	solid mass obtained from apple extract	film formed on metal surface
-OH stretching	3403.72 cm^{-1}	3429 cm^{-1}
C-H stretching	2928	2924
C=O stetching	1637.78	1636
O-H bending, carboxylic acid	1408.3	1452
C-H bending, 1,2-disubstituted	779.07	763
C-H bending, aromatic compound	2095.14	Disappeared
phenol O-H bending	1384, 1408	1384, 1452
ether C-O-C stretching	1058.8	1037

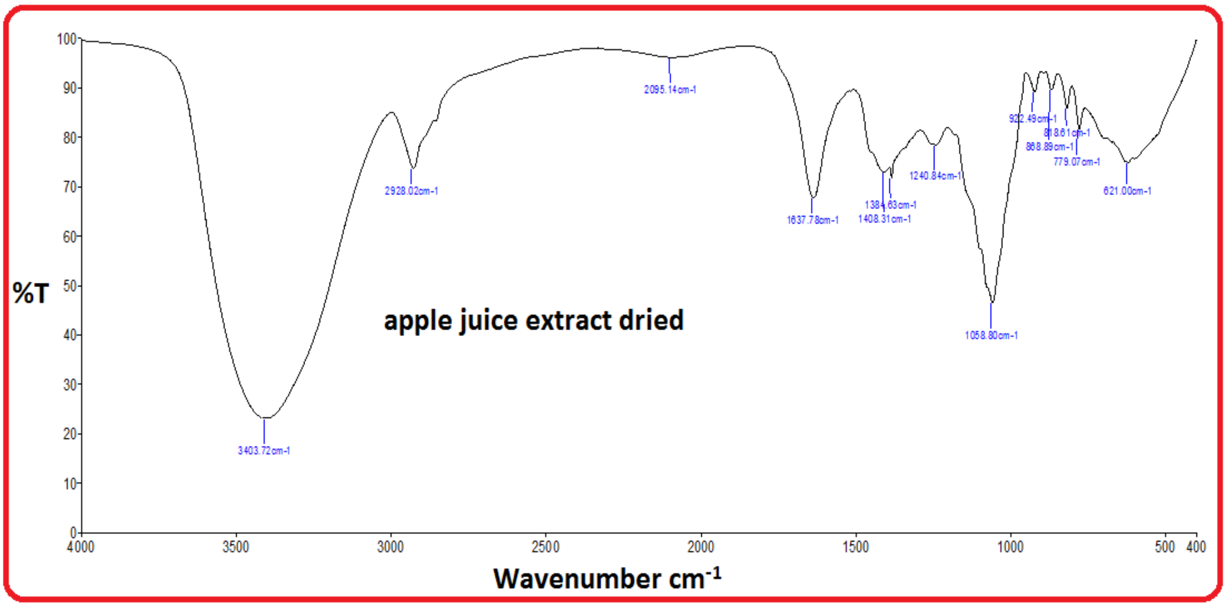


Figure 6. FTIR spectrum of of apple juice extract dried on a glass plate

Slika 6. FTIR spektar ekstrakta soka od jabuke osušenog na staklenoj ploči

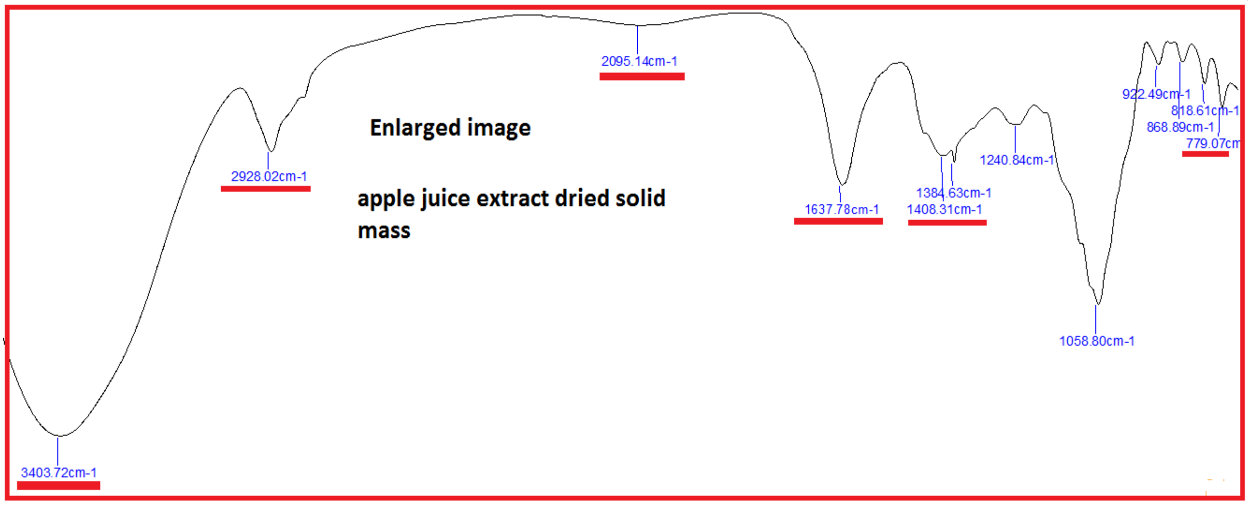


Figure 7. FTIR spectrum of of apple juice extract dried on a glass plate (Enlarged image)

Slika 7. FTIR spektar ekstrakta soka od jabuke sušenog na staklenoj ploči (uvećana slika)

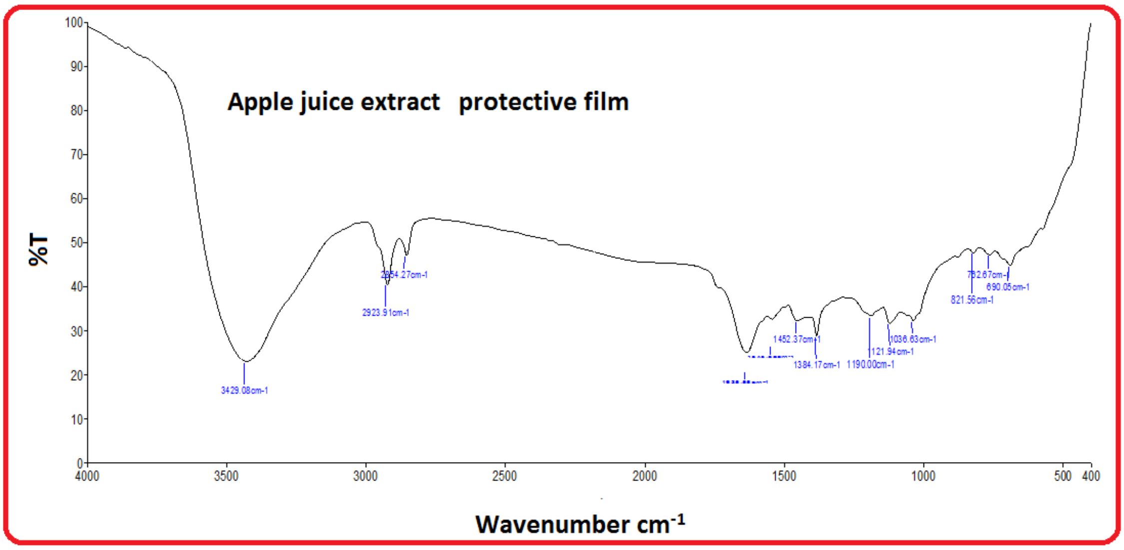


Figure 8. FTIR spectrum (KBr) of protective film.

Slika 8. FTIR spektar (KBr) zaštitnog filma

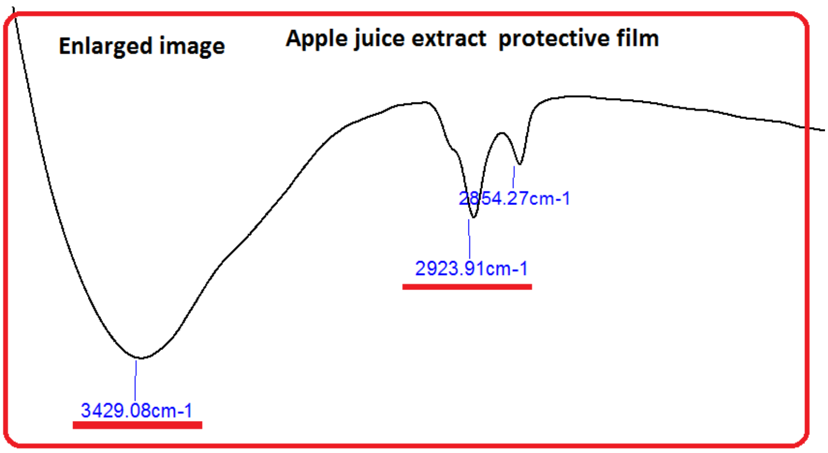


Figure 9. FTIR spectrum (KBr) of protective film(Enlarged image)

Slika 9. FTIR spektar (KBr) zaštitnog filma (uvećana slika)

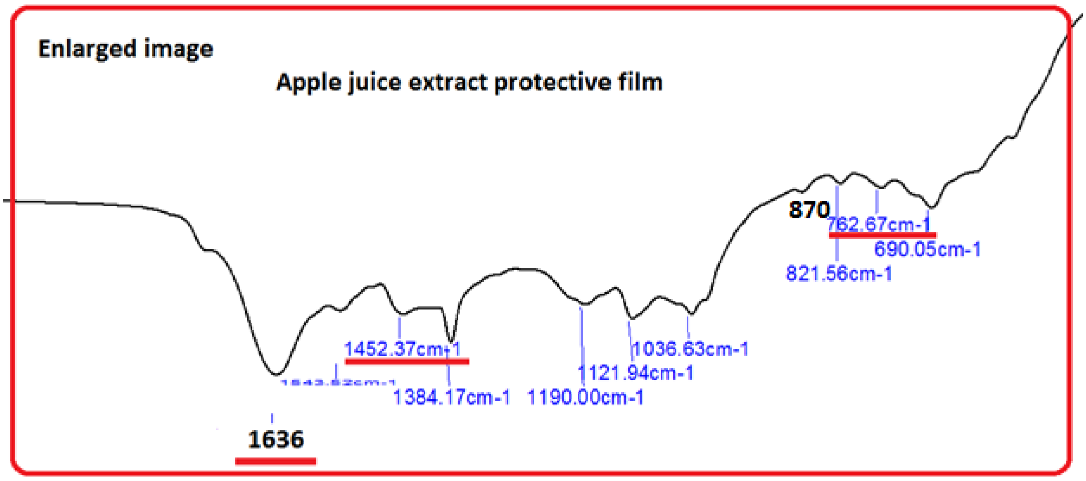


Figure 10. FTIR spectrum(KBr) of protective film (Enlarged image)

Slika 10. FTIR spektar (KBr) zaštitnog filma (uvećana slika)

It is observed from the Table 5 that the Fe^{2+} ions on the metal surface, generated during corrosion process on the metal surface, have coordinated with the polar groups of the active ingredients of the apple juice such as phenolic O-H , C-O-C , and aromatic pi electrons, resulting in the formation of a protective film on the metal surface. This film is responsible for corroion protection.

The peaks at 1452 cm^{-1}, 870 cm^{-1} and 762 cm^{-1} 690 are due to calcium oxide and calcium carbonate formed on the metal surface [11,12].

Luminescence spectra

Luminescence spectra have been used in corrosion inhibition studies. Apple juice extract is mixed with ferrous sulphate solution to prepare a complex consisting of Fe^{2+}-active principles of the ingredients of apple juice. Luminescence spectrum (λ_{ex} = 300nm) of this solution was recorded. A peak appears at 305 nm.

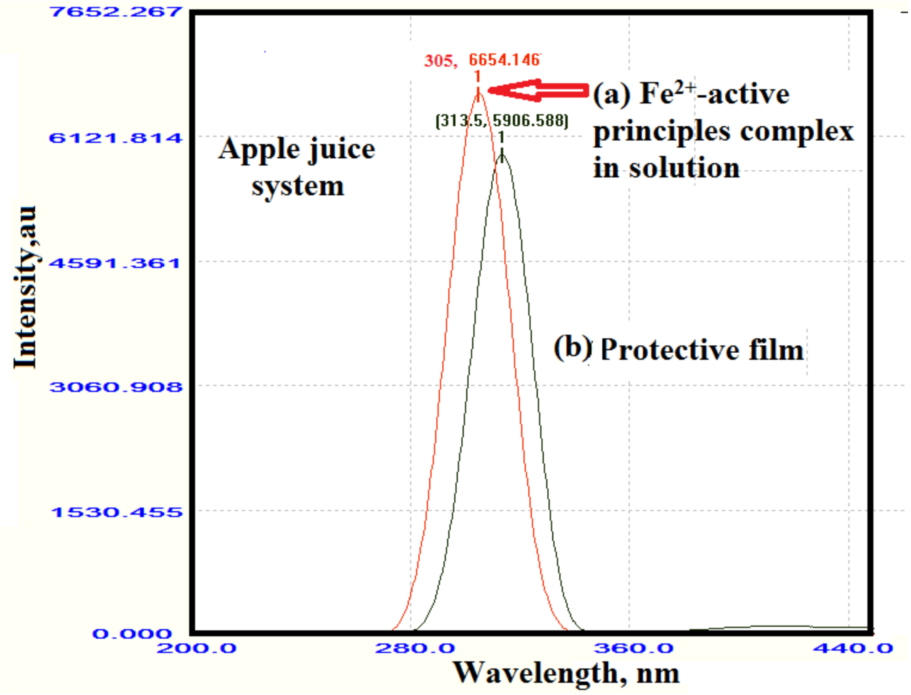


Figure 11. Fluoresence spectra of SCPS + Apple juice

Slika 11. Fluorescentni spektri SCPS + sok od jabuke

Luminescence spectrum (λ_{ex} = 300nm) of the protective film formed on the metal surface after immersion in the solution consisting of SCPS and apple juice for a period of one day is shown in Figure 11. A peak appears at 313.5 nm. This peak very closely matches with the previous peak at 305nm. Thus it is confirmed that the protective film consists of Fe^{2+}-active principles of the ingredients of apple juice. It is noted that there is decrease in the intensity of the peak. This is due to the fact that in the solid state there is restriction in the movement of electrons.

ANALYSIS OF AFM

Atomic force microscopy is used widely in corrosion inhibition study. The roughness of the metal surface can be investigated and measured for three systems, namely polished metal (system A), polished metal immersed in the blank solution(SCPS) (system-B) and polished metal immersed in the inhibitor system (SCPS + Apple juice) (system C) (Fig. 12-14).The average roughness (Ra), RMS roughness (Rq) and maximum peak -to -valley height can be derived from AFM images. In general, for the three systems, A, B and C the average roughness is in following order A>B>C. This indicates that a protective film is formed on the metal surface and hence corrosion inhibition efficiency increases for system B and system C. The average roughness decreases as the corrosion inhibition efficiency increases. The high value of the average roughness for polished metal (system A) may be due to the formation of iron oxide formed on the metal surface. As the smoothness increases the inhibition efficiency increases. 2D images and 3D images are produced in AFM study (Fig. 12-14). Section analysis is another aspect of AFM.

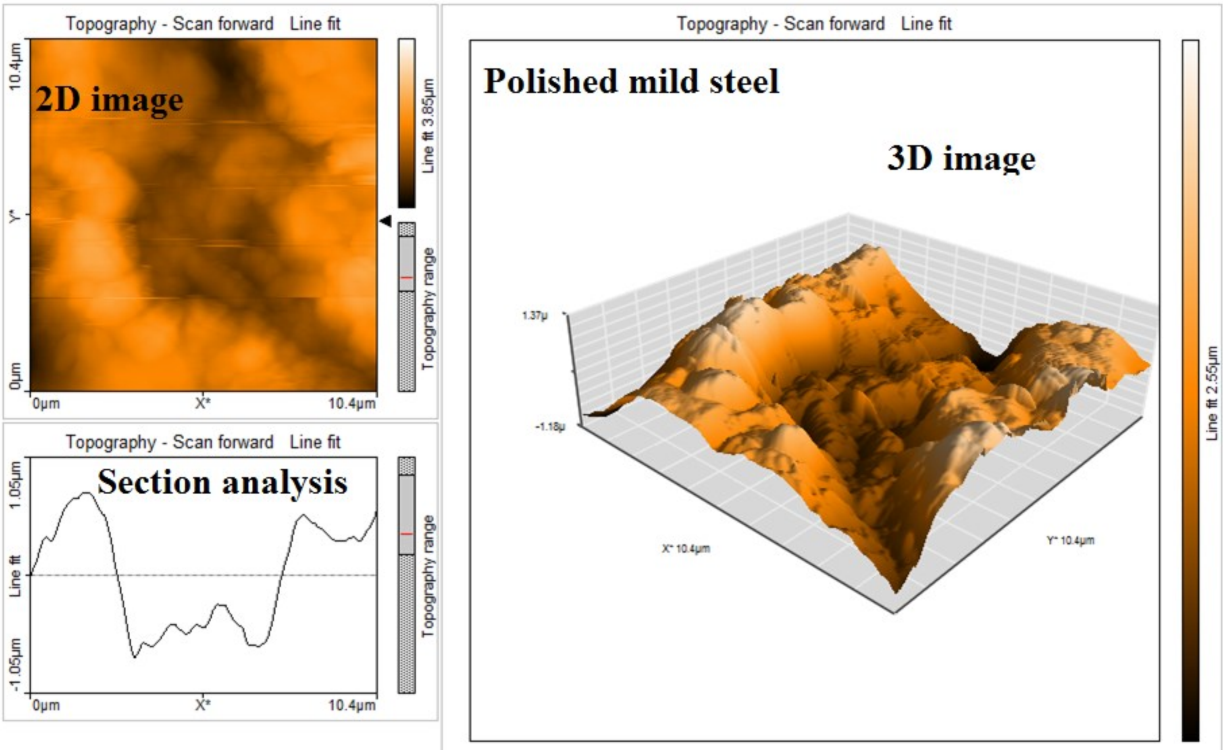


Figure 12. Polished mild steel

Slika 12. Polirani meki čelik

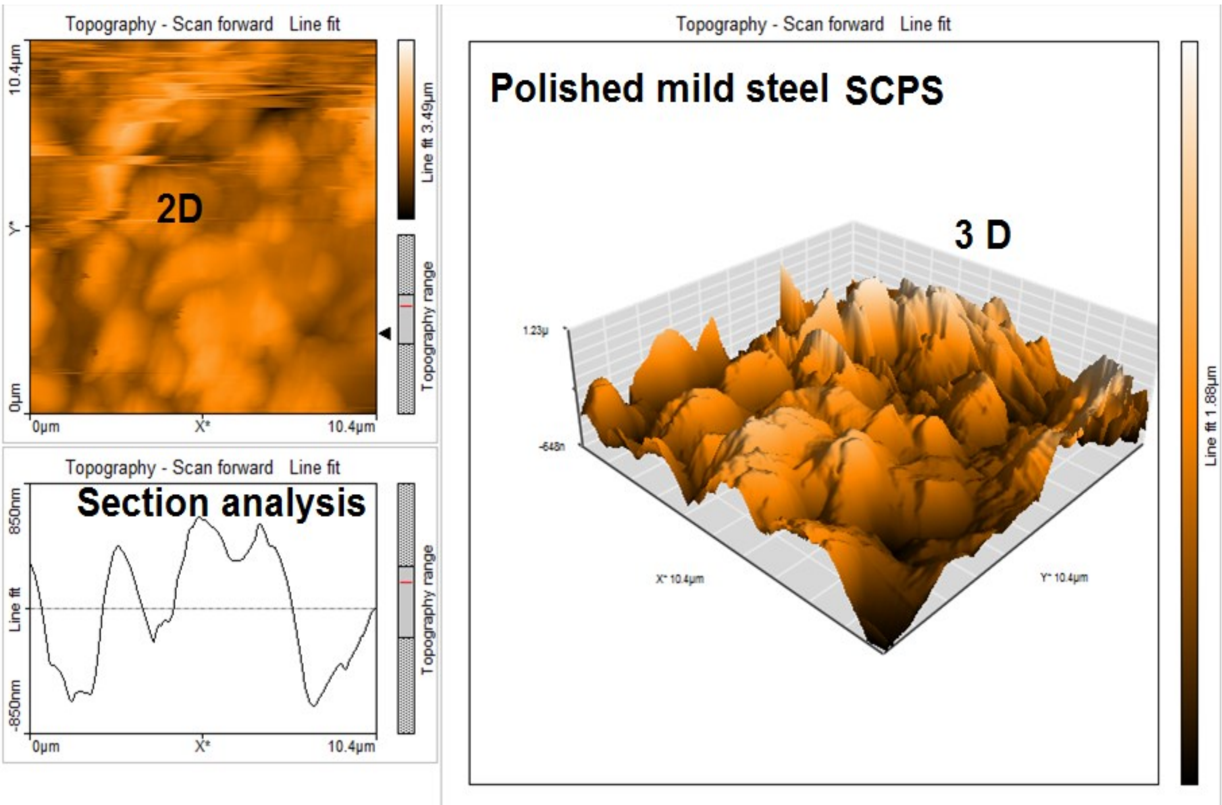


Figure 13. Polished mild steel immersed in SCPS

Slika 13. Polirani meki čelik uronjen u SCPS

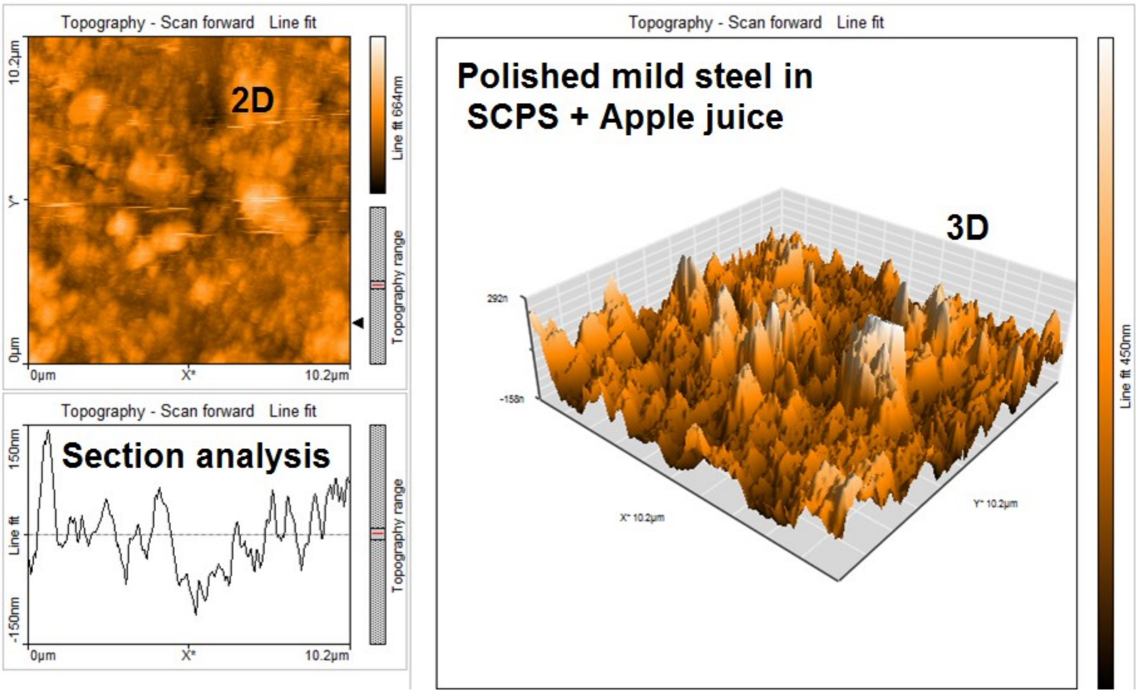


Figure 14. Polished mild steel immersed in SCPS +Apple juice

Slika 14. Polirani meki čelik uronjen u SCPS + sok od jabuke

Table 6: AFM parameters of various surfaces

Tabela 6. AFM parametri različitih površina

Samples	RMS (R_q) Roughness (nm)	Average (R_a) Roughness (nm)	Maximum peak – to valley–height (nm)
Polished mild steel (Control)	422.76 nm	396.01nm	1290.5nm
Mild Steel immersed in SCPS	239.13nm	205.74nm	973.88nm
Mild steel immersed in SCPS + Apple juice	91.984nm	69.477nm	415.76nm

4. CONCLUSIONS

The inhibition efficiency SCPS prepared in sea water in controlling corrosion of mild steel immersed in SCPS prepared in sea water has been evaluated by weight loss method. Langmuir adsorption isotherm has been investigated, The mechanistic aspect of corrosion inhibition has been investigated by Electrochemical impedance spectra (AC impedance spectra). The protective film has been analysed by Fluorescence spectroscopy, FTIR spectroscopy and AFM.

The SCPS system offers 60% inhibition efficiency to mild steel immersed in sea water.

In presence of apple juice extract the inhibition efficiency increases as the concentration of the extract increases

When 10 ml of extract is added, 85% inhibition efficiency is obtained.

Electrochemical impedance spectra (AC impedance spectra) reveal that a protective film is formed on the metal surface.

In the presence of inhibitor system , charge transfer resistance value increases, impedance value increases, phase angle value increases whereas double layer capacitance value decreases as expected.

The FTIR spectral study reveals that the protective film consists of complexes consisting of iron-active principles of the apple juice extract.

AFM study reveals that when the inhibition efficiency increases the roughness of the surface decreases or in other words the smoothness of the system increases.

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IZVOD

INHIBICIJA KOROZIJE VOĆNIM EKSTRAKTIMA - INHIBICIJA KOROZIJE MEKOG ČELIKA U SIMULIRANOM RASTVORU PORA BETONA PRIPREMLJENOM U MORSKOJ VODI VODENIM EKSTRAKTOM SOKA OD JABUKE - STUDIJA SLUČAJA

Efikasnost inhibicije vodenog ekstrakta soka od jabuke u kontroli korozije mekog čelika uronjenog u rastvor simuliranih betonskih pora (SCPS) pripremljen u morskoj vodi, procenjena je metodom gubitka težine. Istražena je Lengmirova izoterma adsorpcije. Mehanički aspekt inhibicije korozije je istražen spektrima elektrohemijske impedanse (AC impedance spectra). Zaštitni film je analiziran fluorescentnom spektroskopijom, FTIR spektroskopijom i AFM. SCPS sistem nudi efikasnost inhibicije od 60% za meki čelik uronjen u morsku vodu. U prisustvu ekstrakta soka od jabuke efikasnost inhibicije se povećava kako se koncentracija ekstrakta povećava. Kada se doda 10 ml ekstrakta, postiže se 85% efikasnost inhibicije. Spektri elektrohemijske impedanse (AC impedance spectra) otkrivaju da se na površini metala formira zaštitni film. U prisustvu inhibitornog sistema, vrednost otpora prenosa naelektrisanja se povećava, vrednost impedanse raste, vrednost faznog ugla se povećava dok vrednost kapacitivnosti dvojnog sloja opada prema očekivanjima. FTIR spektralna studija otkriva da se zaštitni film sastoji od kompleksa koji se sastoje od gvožđe aktivnih supstanic ekstrakta soka od jabuke. AFM studija otkriva da kada se efikasnost inhibicije poveća, hrapavost površine se smanjuje ili drugim rečima, glatkoća sistema se povećava.

***Ključne reči**: inhibicija korozije, meki čelik, simulirani rastvor pora betona, morska voda, vodeni ekstrakt soka od jabuke, elektrohemijske studije, FTIR, fluorescentna spektroskopija, AFM.*

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