

Inhibition of corrosion of mild steel in sea water by an aqueous extract of turmeric powder

P. Mahalakshmi,¹ S. Rajendran,^{2*} G. Nandhini,¹ S.C. Joyce,² N. Vijaya,³
T. Umasankareswari⁴ and N. Renuga Devi⁵

¹PG Department of Chemistry, M.V. Muthiah Government Arts College for Women,
Dindigul-624001, India

²Corrosion Research Centre, Department of Chemistry, St Antony's College of Arts and
Science for Women, Dindigul-62405, India

Affiliated to Mother Teresa Women's University, Kodaikanal, India

³Department of Chemistry, Vellalar College for Women, Thindal, Erode, India

⁴Department of Chemistry, Rajapalayam Raju's College, Rajapalayam, India

⁵Department of Zoology, GTN Arts College, Dindigul, India

*E-mail: susairajendran@gmail.com

Abstract

An aqueous extract of turmeric powder (*Curcuma longa*) has been used as corrosion inhibitor, to control corrosion of mild steel in sea water. Methods such as weight loss method, polarization study and AC impedance spectra have been used. The protective film has been analyzed by UV-visible spectra, Fluorescence spectra and FTIR spectra. The surface morphology has been analyzed by SEM. The Hardness of a metal before and after immersion has been determined. Weight loss study reveals that the maximum corrosion inhibition efficiency of 98% is offered by 10 ml of Turmeric extract. The adsorption study reveals that the active principles (*Curcumin*) are adsorbed on metal surface by Langmuir absorption isotherm. Polarization study reveals that the inhibitor function as cathodic inhibitor, because the corrosion potential is shifted to more negative side. AC impedance spectra confirm the formation of a protective film on the metal surface. Fluorescence spectra confirm that the protective film consists of Fe²⁺–*Curcumin* complex formed on the anodic sites of the metal surface. This is confirmed by FTIR spectra. Vicker hardness (HV) study reveals that in presence of inhibitors, the hardness of the metal increases. In the absence of inhibitors (corrosive medium–sea water), the hardness of the metal decreases. These findings may be used in cooling water systems where sea water can be used as coolant.

Keywords: corrosion inhibition, green inhibitor, mild steel, turmeric powder, electrochemical studies, Vicker hardness.

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Introduction

Corrosion is a natural and spontaneous process just like death. Corrosion is the gradual obliteration of materials by chemical and/or electrochemical reaction with their environment. Corrosion is a natural, spontaneous and thermodynamically favorable process, which converts a refined metal to a more chemically-stable form, such as its oxide, hydroxide, or sulfide. Corrosion is the expression of the desire of the metal to go back to its original state. For a metal to undergo corrosion, air (more precisely oxygen) and water are necessary. In the absence of any one corrosion will not take place. Usually pure metal will not undergo corrosion. However when impurity is introduced, the metal becomes non-homogeneous in nature. Some sites act as anodes and some sites act as cathode. Anode has a tendency to lose electron and cathode has a tendency to accept the electron. For the electron transfer a medium, usually called, an electrolyte is needed. This event we call it corrosion [1]. There are many ways to control the rate of corrosion. One such method is use of inhibitors. To prevent corrosion of metals in solutions or in water (as in cooling water system) corrosion inhibitors are added to the environment. Due to environmental hazards caused by many inhibitors the recent trend is use of green inhibitors. Several research papers have been published in this regard. Jyothi *et al.* [2] have reviewed the use of green inhibitors. Rajendran *et al.* [3] have explained green solution to corrosion problems and also discussed the various methods employed in this field. Usually weight loss methods are adopted to measure the corrosion inhibition efficiencies. The mechanistic aspects have been investigated by electrochemical studies such as polarization study and AC impedance spectra. Sometimes noise measurement has also been used. The protective films formed on the metal surface have been analyzed by surface analysis techniques such as SEM, EDAX, FTIR and AFM. Experiments have been carried out at various temperatures also. Various adsorption isotherms have been proposed. Of all the metals and alloys used, mild steel has been extensively used. The experiments have been carried out in acid medium and neutral medium (sodium chloride). The extracts of the leaves contain many ingredients which have polar groups such as N, O, S and P atoms. The lone pair of electrons present on these atoms are pumped on to the metal surface. This controls the corrosion process. Inhibition effect of orange seed extract on aluminum corrosion in 1 M hydrochloric acid solution has been investigated by Olawale *et al.* [4]. Coffee husk as corrosion inhibitor for mild steel in HCl media by Cordeiro *et al.* [5]. The inhibitor is adsorbed on the metal surface. The adsorption process obeys Langmuir isotherm. Umoren *et al.* have used ethanolic extracts of date palm leaves and seeds to control corrosion of carbon steel in 15% HCl solution [6]. Potentiodynamic polarization study suggests that the extracts function as mixed type of inhibitors. Corrosion inhibition occurs by adsorption of components of the extract on the steel surface and was found to follow Langmuir adsorption isotherm model. Performance of *Centaurea cyanus* aqueous extract towards corrosion mitigation of carbon steel in saline formation water has been evaluated by El-Taib Heakal *et al.* [7]. Weight loss measurements, electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization techniques

have been used. SEM, EDAX and FTIR have been employed. A study of the gorse aqueous extract as a green corrosion inhibitor for mild steel in HCl aqueous solution has been reported by Trindade *et al.* [8]. The high-molecular-weight fraction isolated from the gorse extract showed high inhibition efficiencies. Parthipan *et al.* have used neem extract as a green inhibitor for microbiologically influenced corrosion of carbon steel API 5LX in a hypersaline environments [9]. Salhi *et al.* [10] have used natural product extract as eco-friendly corrosion inhibitor for mild steel in 1 M HCl. The methanolic extract of *Mentha Suaveolens* (EMMS) has been studied as inhibitor mild steel in hydrochloric acid (1 M HCl) solution using by weight loss measurement, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. Al-Khaldi [11] has used natural products as corrosion inhibitor for steel in 0.5 M hydrochloric acid solution. Lemon leaves extracts with saffron, almonds, guava leaves and *Origanum majorana* extracts have been used. Polarization study and AC impedance spectra have been used. Susai Rajendran and Gurmeet Singh have discussed the use of green inhibitors in controlling corrosion of metals and alloys [12]. Recent publications also discuss the use of green inhibitors [13–15].

The present work is undertaken (i) to evaluate the inhibition efficiency of an aqueous extract of turmeric powder in controlling corrosion of mild steel in sea water, (ii) to study the mechanistic aspects of corrosion inhibition by electrochemical studies such as polarization study and AC impedance spectra, (iii) to study the surface morphology by SEM, (iv) to analyze the protective film by FTIR spectra and (v) to determine the hardness of metal surface before and after corrosion inhibition.

Experimental

Weight loss method

Preparation of specimens

Mild steel specimens of dimensions 1.0×4.0×0.2 cm, were polished to mirror finish, degreased with trichloroethylene, and used for the weight loss method and for surface examination studies. Weights of the polished mild steel specimens were determined before and after immersion in various test solutions. The inhibition efficiencies were calculated from the relation $IE = [(W_1 - W_2)/W_1]100\%$, where W_1 is corrosion rate in the absence of inhibitor and W_2 is the corrosion rate in the presence of inhibitor.

Preparation of yellow inhibitor

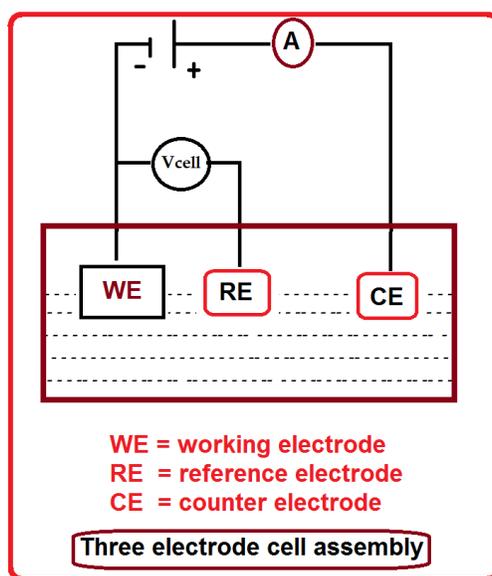
An aqueous extract of a plant material, namely, turmeric powder (*Curcuma longa*) has been prepared by boiling 10 g of shade dried turmeric powder, filtering the suspended impurities and making up to 100 ml in a standard measuring flask. The extract was used to control the corrosion of mild steel in sea water.

Electrochemical studies

In the present work corrosion resistance of mild steel immersed in various test solutions were measured by Polarization study and AC impedance spectra.

Polarization study

In the present study polarization studies were carried out in a CHI Electrochemical work station/analyzer, model 660A. It was provided with automatic IR compensation facility. A three electrode cell assembly was used (Scheme 1).



Scheme 1. Three electrode cell assembly.

The working electrode was mild steel. A SCE was the reference electrode. Platinum was the counter electrode. A time interval of 5 to 10 min was given for the system to attain a steady state open circuit potential. The working electrode and the platinum electrode were immersed in sea water in the absence and presence of inhibitor. Saturated calomel electrode was connected with the test solution through a salt bridge. From polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Tafel slopes anodic b_a and cathodic b_c and LPR (linear polarization resistance) value. The scan rate (V/S) was 0.01. Hold time at (E_{fcs}) was zero and quiet time (s) was two.

AC Impedance spectra

In the present investigation the same instrument and set-up used for polarization study was used to record AC impedance spectra also. A time interval of 5 to 10 min was given for the system to attain a steady state open circuit potential. The real part (Z') and imaginary part (Z'') of the cell impedance were measured in ohms at various frequencies. AC impedance spectra were recorded with initial $E(\text{v})=0$, high frequency (1×10^5 Hz), low frequency (1 Hz), amplitude (V)=0.005 and quiet time (s)=2. From Nyquist plot the values of charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated.

$$R_t = (R_s + R_t) - R_s$$

Where R_s is solution resistance.

C_{dl} values were calculated using the relationship

$$C_{dl} = 1/2 \times 3.14 \times R_t \times f_{max}$$

Where f_{max} is frequency at maximum imaginary impedance.

Surface analysis of protective film

Mild steel specimen was immersed in the inhibitor system for a period of one day. After one day the specimen was taken out, dried and subjected to various surface analysis techniques.

- FTIR spectra were recorded in Perkin-Elmer make, model spectrum two.
- SEM images were recorded in Cartizers make model EVO-18.
- Vicker hardness was recorded in Shimadzu make model HMV-27.
- UV visible spectra were recorded in a Systronics double beam UV-VIS Spectrophotometer 2202
- Fluorescence spectra were recorded in a Shimadzu Spectro fluorophotometer.

Sea water

The composition of sea water used in this study is given in Table 1. Sea water was collected in Bay of Bengal, located at Kanampadi, East Coast Road, Chennai, India.

Table 1. Composition of sea water.

Physical examination	Acceptable limit	Permissible limit	Sample value
1. Color			Colorless & Clear
2. Odour	Unobjectionable		Unobjectionable
3. Turbidity NT units	1	5	0.2
4. Total dissolved solids mg/l	500	2000	29400
5. Electrical conductivity micro mho/cm			42000
Chemical examination	Acceptable limit	Permissible limit	Sample value
6. pH	6.5–8.5	6.5–8.5	7.46
7. pH Alkalinity as CaCO ₃		0	0
8. Total Alkalinity as CaCO ₃	200	600	140
9. Total Hardness as CaCO ₃	200	600	4000
10. Calcium as Ca	75	200	1200

Chemical examination	Acceptable limit	Permissible limit	Sample value
11. Magnesium as Mg	30	100	240
12. Iron as Fe	0.1	1	0
13. Magnesium as Mg	0.1	0.3	NT
14. Free ammonia as NH ₃	0.5	0.5	0.48
15. Nitrite as NO ₂	0.5	0.5	0.104
16. Nitrate as NO ₃	45	45	25
17. Chloride as Cl	250	1000	15000
18. Fluoride as F	1	1.5	1.8
19. Sulphate as SO ₄	200	400	1170
20. Phosphate as PO ₄	0.5	0.5	1.47
21. Tids Test 4hrs as O ₂			NT

Results and Discussion

An aqueous extract of a plant material, namely, turmeric powder (*Curcuma longa*) has been prepared by boiling 10 g of shade dried turmeric powder, filtering the suspended impurities and making up to 100 ml in a standard measuring flask. The extract was used to control the corrosion of mild steel in sea water. The findings will be useful in cooling water systems. These inhibitors may be added to cooling water carried by pipelines made of mild steel. The inhibition efficiency of the inhibitor system was evaluated by weight loss method. The mechanistic aspects were studied by polarization study and AC impedance spectra.

Analysis of results of weight loss method

Inhibition of corrosion of mild steel in sea water

The weight loss method has been used to evaluate the inhibition efficiency of turmeric extract in controlling corrosion of mild steel in sea water. The inhibition efficiencies (IE) of turmeric extract in controlling corrosion of mild steel are given in Table 2. The corrosion rates are also given in the Table 2.

Table 2. Corrosion rates and inhibition efficiency (IE) of inhibitor system [turmeric extract (TE)] in controlling corrosion of mild steel in sea water.

Volume of turmeric extract, ml	Corrosion rate, mdd	Inhibition efficiency, %
0	35.88	–
2	16.15	55
4	11.48	68

Volume of turmeric extract, ml	Corrosion rate, mdd	Inhibition efficiency, %
6	8.61	76
8	5.02	86
10	0.72	98

The surface coverage of plant extract in controlling corrosion of mild steel immersed in sea water are given in Table 3.

Table 3. Inhibition efficiency and surface coverage.

Volume of turmeric extract, ml	IE, %	Surface coverage, $\theta = \text{IE}/100$
2	55	0.55
4	68	0.68
6	76	0.76
8	86	0.86
10	98	0.98

Adsorption isotherm

Inhibition of corrosion of metals and alloys are mainly due to adsorption of inhibitor molecules on the metal surface. In the case of natural product extracts, the active principles of the extracts get adsorbed on the metal surface.

Table 4. Parameters for the plot of Langmuir adsorption isotherm C vs C/θ .

C	C/θ
2	3.64
4	5.88
6	7.89
8	9.30
10	10.20

The surface coverage θ of the inhibitor on the metal surface was calculated from the relation, $\theta = \text{IE}\% / 100$

A plot of C is C/θ was made. A straight line was obtained. The R^2 value was very high (0.972). All these observations indicate that adsorption of inhibitor molecules on the metal surface obey Langmuir adsorption isotherm.

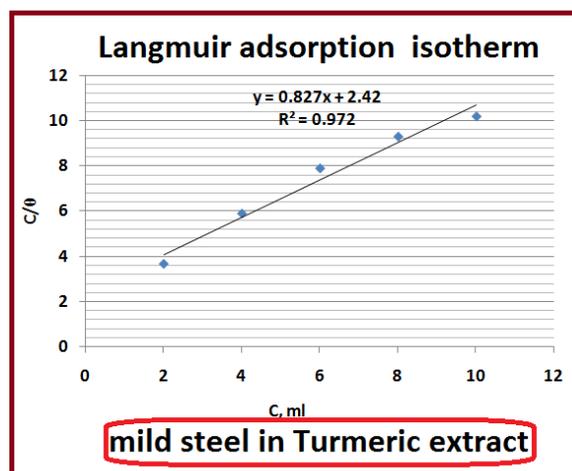


Figure 1. Adsorption isotherm on mild steel immersed in sea water in presence of inhibitor.

Analysis of polarization curves

Corrosion parameters derived from polarization study, namely corrosion potential (E_{corr}), Tafel slope (b_c , b_a), Linear polarization resistance (LPR) values and corrosion current (I_{corr}) values are given in Table 5. The polarization curves of mild steel (MS) immersed in sea water the absence and presence of inhibitor system are shown in Figure 2.

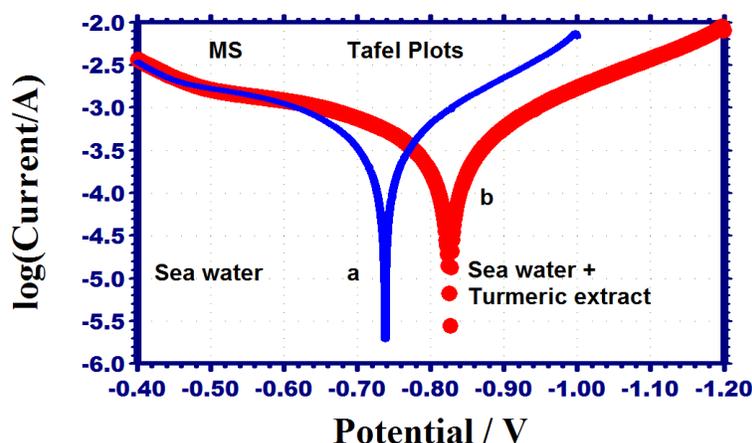


Figure 2. Polarization curves of mild steel immersed in various test solutions. (a) sea water (b) sea water+turmeric extract.

Table 5. Corrosion parameters of mild steel immersed in sea water in the absence and presence of an aqueous extract of turmeric powder obtained by polarization study.

System	E_{corr} , V/SCE	b_c , V/decade	b_a , V/decade	LPR , Ohm cm^2	I_{corr} , A/ cm^2
Sea water	-0.738	5.763	4.479	106	4.006×10^{-4}
Sea water+turmeric extract	-0.827	5.632	4.354	141	3.08×10^{-4}

It is observed from the Table 5 that when mild steel is immersed in sea water, the corrosion potential is -0.738 V/SCE. The LPR value is 106 Ohm cm^2 . The corrosion current value is $4.006 \times 10^{-4} \text{ A/cm}^2$. It is inferred from the Table 5, that in presence of inhibitor, the corrosion potential is shifted from -0.738 to -0.827 V/SCE. This is a cathodic shift. It suggests that the cathodic reaction is controlled predominantly. The LPR value increases from 106 Ohm cm^2 to 141 Ohm cm^2 (Figure 3). Correspondingly the corrosion current value decreases from $4.006 \times 10^{-4} \text{ A/cm}^2$ to $3.08 \times 10^{-4} \text{ A/cm}^2$. These observations confirm that a protective film is formed on the metal surface. This controls the corrosion of metal [16–20].

This is due to the fact in presence of inhibitor system, the active principles of the inhibitor system are adsorbed on the metal surface and a protective film is formed. This prevents the corrosion of metal and hence LPR value increases and corrosion current value decreases.

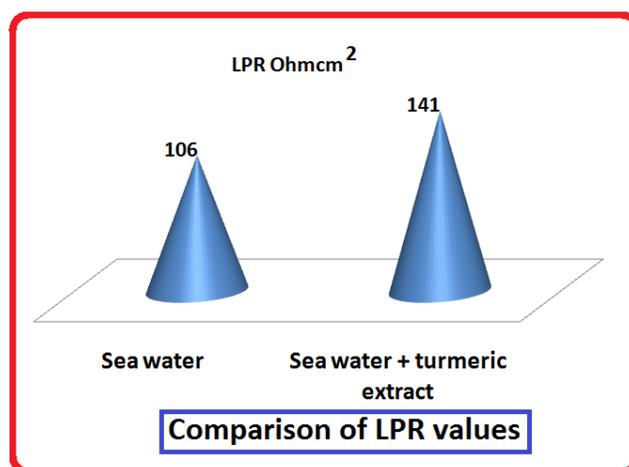


Figure 3. Comparison of LPR values.

Analysis of AC impedance spectra

The protective film formed on the metal surface is confirmed by AC impedance spectra. If a protective film is formed on the metal surface, the charge transfer resistance (R_t) value increases; double layer capacitance value (C_{dl}) decreases and the impedance [$\log(Z/\text{ohm})$] value increases [21–25].

The AC impedance spectra of mild steel immersed in sea water in the absence and presence of inhibitor (turmeric extract) are shown in Figure 4 (Nyquist plots), Figures 5 and 6 (Bode plots). The corrosion parameters, namely R_t , C_{dl} and impedance values, are given in Table 6.

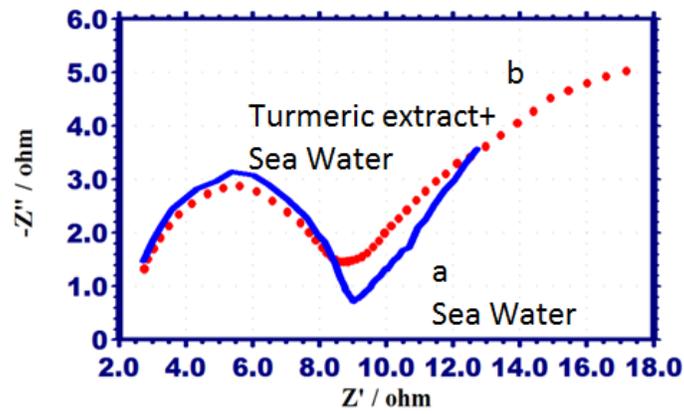


Figure 4. AC impedance spectra of mild steel immersed in various test solution (Nyquist Plot); (a) SW; (b) SW+turmeric extract.

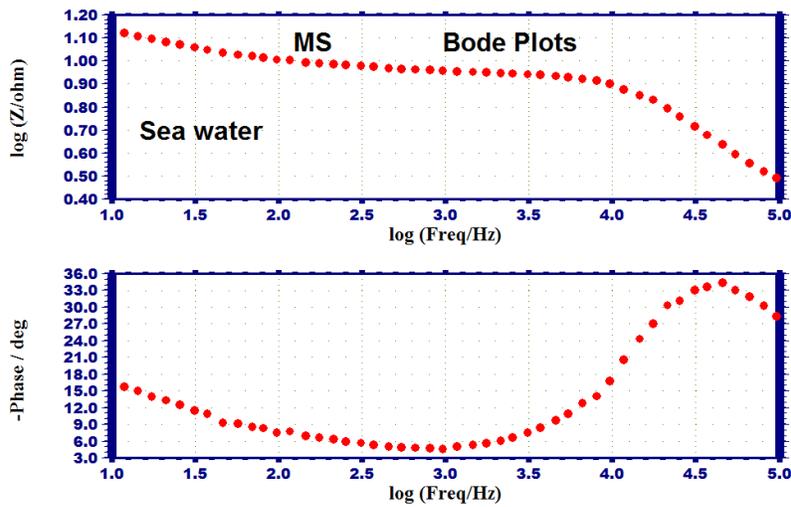


Figure 5. AC impedance spectra of mild steel immersed in SW (Bode plots).

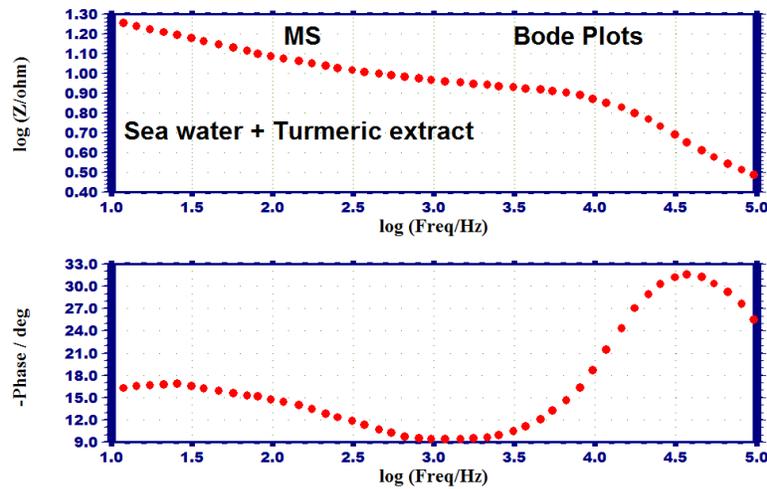


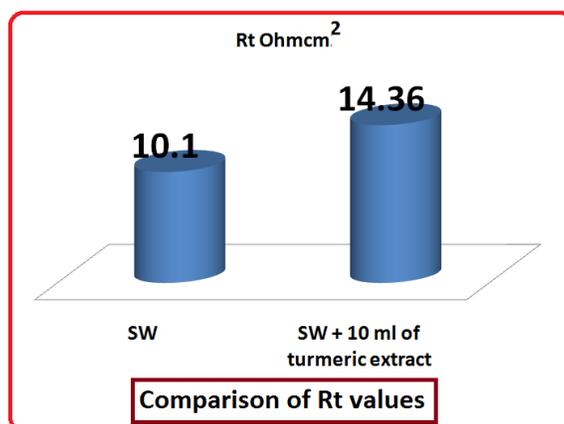
Figure 6. AC impedance spectra of mild steel immersed in SW+turmeric extract (Bode plots).

Table 6. Corrosion parameters of mild steel (MS) immersed in simulated sea water (SW) in the absence and presence of an aqueous extract of a turmeric extract (*Curcuma longa*) obtained by AC impedance spectra.

System	R_t , Ohm cm ²	C_{dl} , F/cm ²	Impedance, log(Z/Ohm)
SW	10.10	5.05×10^{-8}	1.119
SW+10 ml of turmeric extract	14.36	3.55×10^{-8}	1.250

It is observed from the Table 6 that, when MS is immersed in SW, the R_t value is 10.10 Ohm cm². The C_{dl} value is 5.05×10^{-8} F/cm². The impedance value is 1.119.

In the presence of the inhibitor, the R_t value increases from 10.10 Ohm cm² to 14.36 Ohm cm² (Figure 7). The C_{dl} value decreases from 5.05×10^{-8} F/cm² to 3.55×10^{-8} F/cm². The impedance value increases from 1.119 to 1.250. This indicates that a protective film is formed on the metal surface. Hence the corrosion resistance increases in presence of turmeric extract.

**Figure 7.** Comparison of R_t values.

Implication: Mild steel samples were immersed in sea water with turmeric extract (*curcuma longa*) to evaluate corrosion inhibition efficiency of the plant extract. The inhibition efficiency increases with the increase in concentration of plant extract. Inhibition efficiency up to 98% for mild steel was achieved. The results indicate that the corrosion rate decreases, as the concentration of plant extract increases and simultaneously it enhances the inhibition efficiency of the samples. This finding may find application in cooling water industry. To prevent corrosion of mild steel pipelines carrying sea water, the plant extract under investigation may be added, along with sea water.

Analysis of UV-visible absorption spectra

UV-visible absorption spectra have been used in corrosion inhibition study. UV-visible absorption spectrum of an aqueous extract of turmeric powder is shown in Figure 8. Peaks

appear at 351.2 nm, 578 nm and 628.4 nm. A few crystals of ferrous sulphate were added to the solution and shaken well. UV-visible absorption spectrum of this solution is shown Figure 9. Peaks appear at 347.6 nm and 578 nm and 624 nm. Shifts in peak positions are observed. There is change in intensity of the peaks. This spectrum is due to the formation of a complex in solution between Fe^{2+} and active principle of turmeric extract (*Curcumin*).

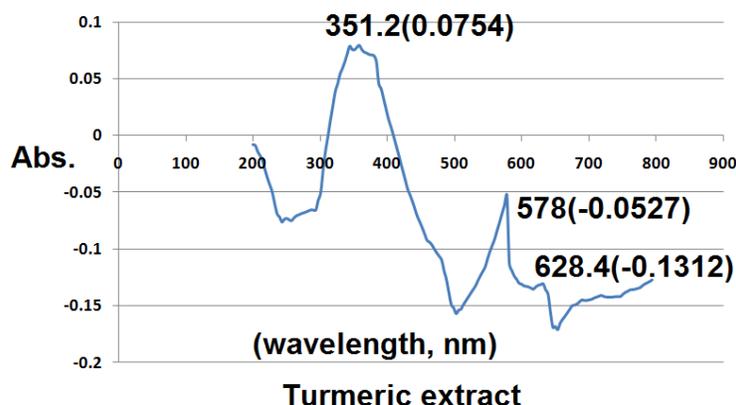


Figure 8. UV-visible absorption spectrum of turmeric extract.

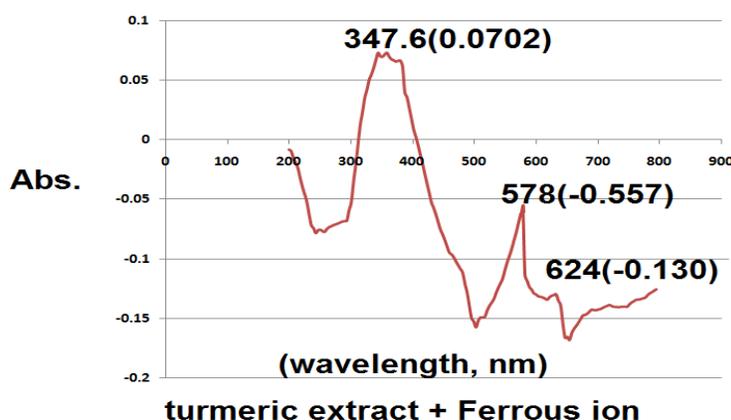


Figure 9. UV-visible absorption spectrum of turmeric extract + Fe^{2+} ion.

Analysis of Fluorescence spectra

The Fe^{2+} –*Curcumin* complex in solution was prepared by mixing ferrous sulphate crystals with an aqueous solution of turmeric extract. The fluorescence spectrum of this complex ($\lambda_{\text{ex}} = 300\text{nm}$) is shown in Figure 10. A peak appears at 580 nm.

The fluorescence spectrum of the protective film formed on metal surface after immersion in the solution containing 10 ml of extract in sea water is shown in Figure 11. A peak appears at 579.5 nm. This peak is very similar to the peak of Fe^{2+} –*Curcumin* complex. This confirms that the protective film consist of Fe^{2+} –*Curcumin* complex formed on the metal surface. It is observed that the intensity of the peak is low. This is due to the fact that

in the solid state, there is restriction in the movement of electrons. Thus it is concluded the protection film consist of Fe^{2+} –*Curcumin* complex.

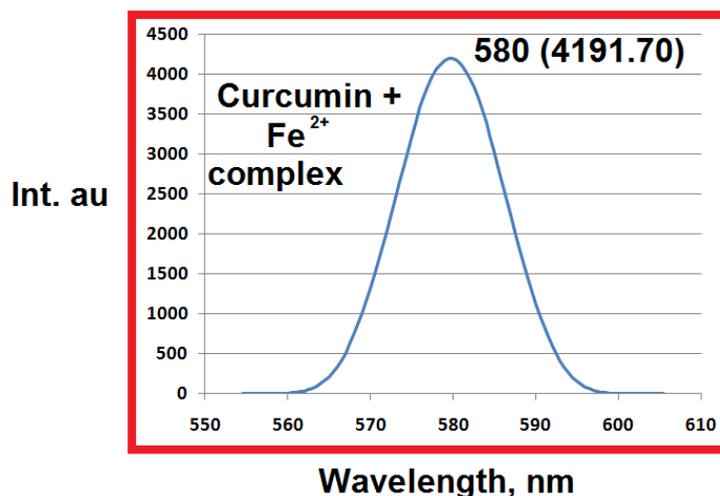


Figure 10. Fluorescence spectrum of turmeric extract+ Fe^{2+} .

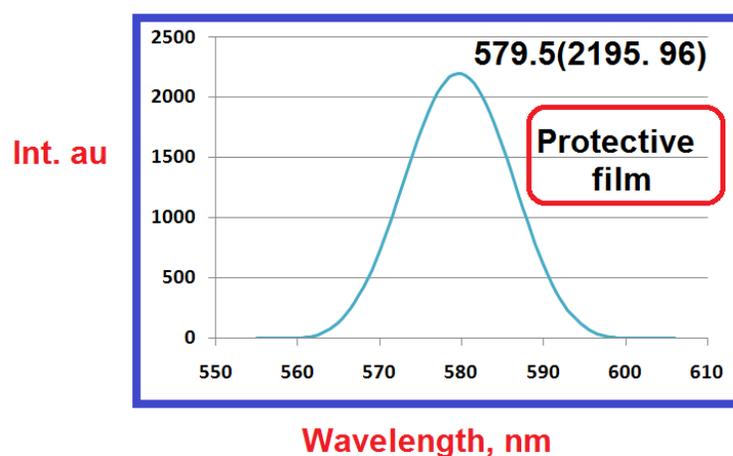


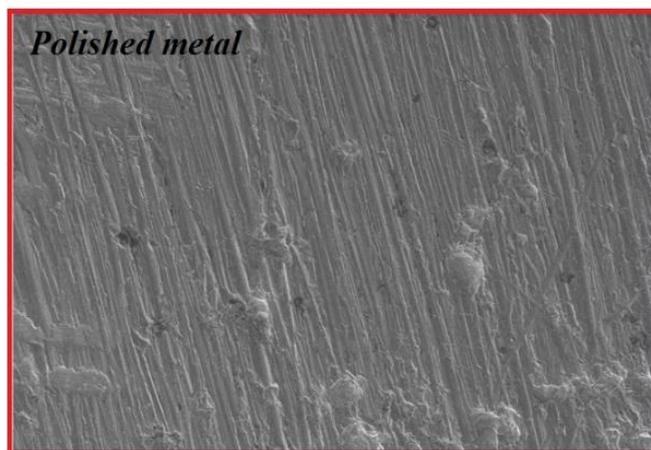
Figure 11. Fluorescence spectrum of protective film.

Analysis of SEM

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electrons emitted by atoms excited by the electron beam are detected using a secondary electron detector (Everhart–Thornley detector). The number of secondary electrons that can be detected, and thus the signal intensity, depends, among other things, on specimen topography. SEM can achieve resolution better than 1 nanometer.

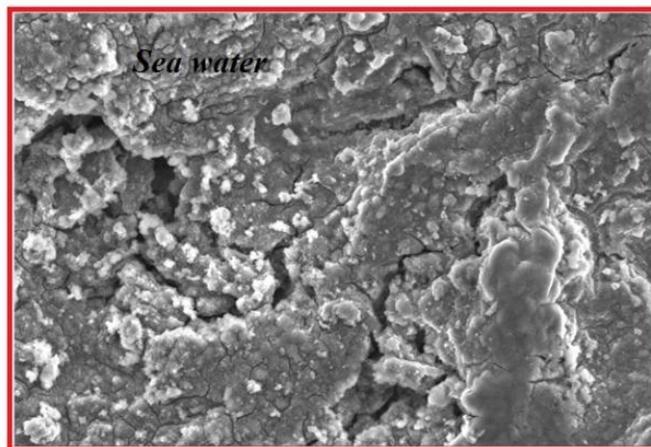
SEM analysis has been widely used in corrosion inhibition study. SEM images are recorded for polished metal surface, metal surface immersed in corrosive medium and metal surface immersed in corrosive medium containing the inhibitor system. In the present study

SEM images were recorded for polished mild steel surface (system A), polished mild steel surface immersed in corrosive medium (SW) (system B) and polished mild steel surface immersed in corrosive medium (SW) containing the inhibitor system (system C). The images are shown in Figures 12–14.



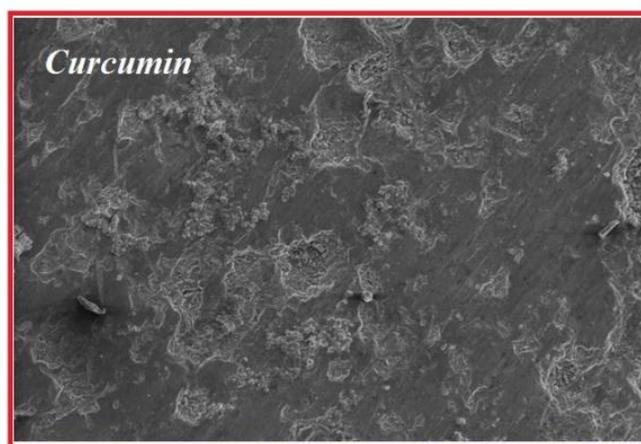
Polished metal

Figure 12. SEM image of polished metal.



Sea water

Figure 13. SEM image of corroded metal (sea water).



Curcumin

Figure 14. SEM image of protective film.

It is observed that for system A (polished mild steel surface) the surface is very smooth. For system B (polished mild steel surface immersed in corrosive medium [SW]) the surface is very rough. Pits are noticed due to corrosion. For system C (polished mild steel surface immersed in corrosive medium [SW] containing the inhibitor system), the surface is smooth, due to the formation of protective film. Thus the SEM is used in corrosion inhibition study.

Analysis of Vicker hardness

The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe a material's ability to resist plastic deformation from a standard source. The Vicker test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) .

The hardness was measured for polished mild steel surface (system A), polished mild steel surface immersed in corrosive medium (sea water) (system B) and polished mild steel surface immersed in corrosive medium (sea water) containing the inhibitor system (system C). The values are given in Tables 7 and 8. It is observed that for system A the hardness is high. For system B the hardness is low because the corroded surface contains iron oxide film which is porous and amorphous. The surface is very rough. Pits are noticed due to corrosion. For system C the surface is smooth, due to the formation of protective film. The hardness is in between that of system A and B. That is, lower than that of polished metal but higher than that of corroded surface. Thus the Vickers hardness is used in corrosion inhibition study.

Table 7. HV (average) for 25 gram load.

System	HV, average
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Polished metal	106.5
Corroded metal sea water	99.5
Inhibited metal turmeric extract	112

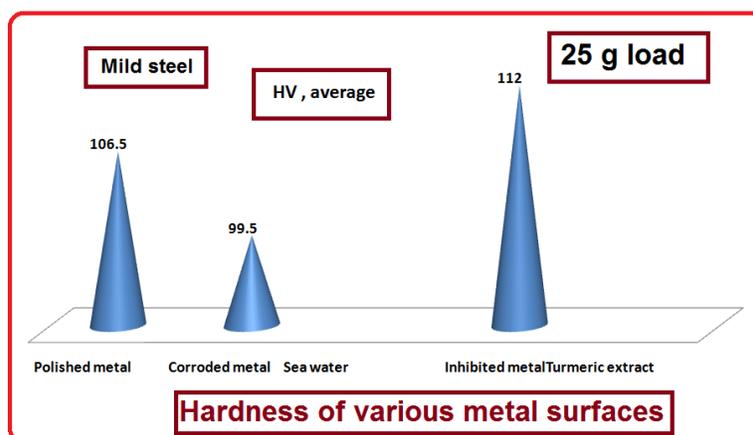


Figure 15. Hardness of various surfaces (25 g load).

Table 8. HV (average) for 50 gram load.

System	HV, average
Polished metal	161.5
Corroded metal sea water	157
Inhibited metal turmeric extract	222.5

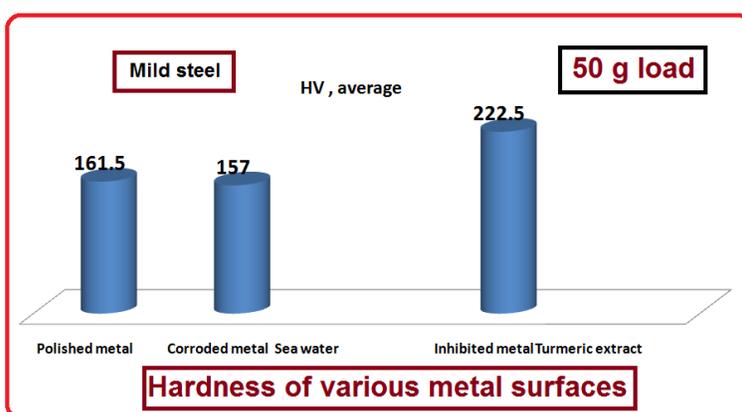


Figure 16. Hardness of various metal surfaces (50 g load).

Analysis of FTIR spectra

FTIR spectra have been used to confirm the formation of protective film on the metal surface, during corrosion inhibition process. In the present study, an aqueous extract of turmeric powder has been used as corrosion inhibitor. The main active principle of this extract is

Curcumin (Figure 17). A few drops of the extract was placed on glass plate and dried. A solid mass was obtained. It was mixed with KBr and made in the pellet form and FTIR spectrum was recorded (Figure 18). The FTIR spectrum of the protective film formed on the metal surface after immersion for a period of one day, in the solution containing sea water and extract solution is shown in Figure 19.

It is observed from the Figures 17 and 18, that the stretching frequencies of various functional groups have shifted. The results are summarized in Table 9. The shifts in frequencies of various functional groups indicate that the inhibitor has coordinated with Fe^{2+} on the metal surface, through oxygen atoms of hydroxyl group, carbonyl group and alkyl aryl ether, and also through π -electrons of the alkene group and benzene ring. Thus the study leads to the conclusion that the protective film consists of iron curcumin complex formed metal surface.

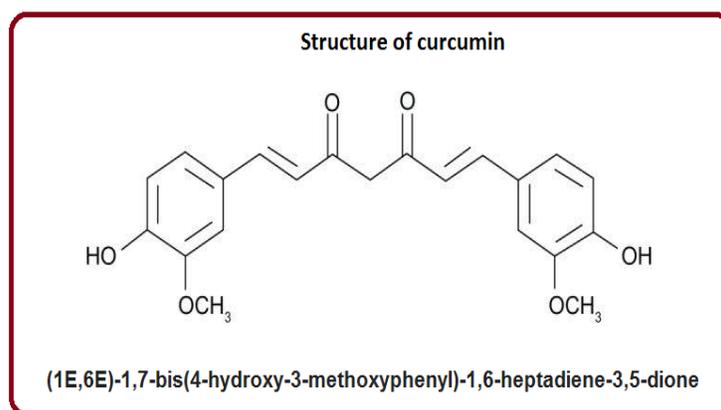


Figure 17. Structure of *Curcumin*.

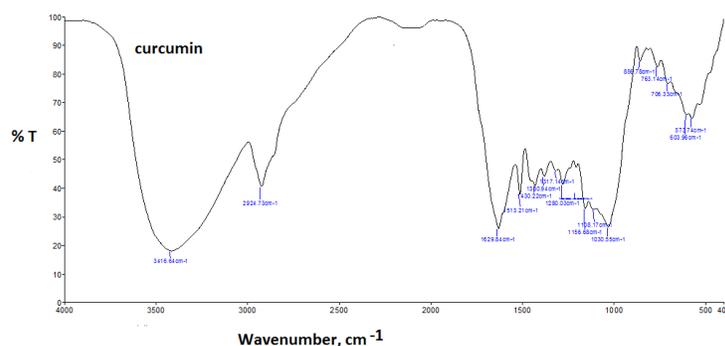


Figure 18. FTIR spectrum of *Curcumin*.

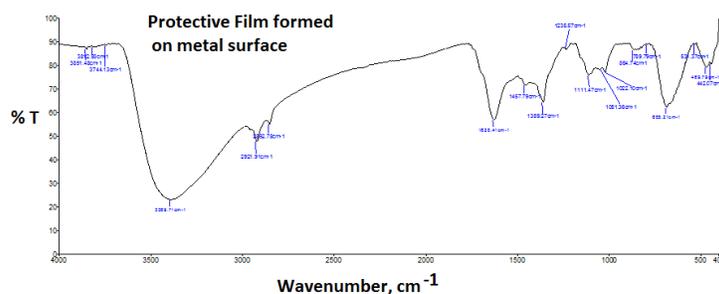


Figure 19. FTIR spectrum of protective film.

Table 9. Stretching frequencies of various functional groups.

Various functional groups	Stretching frequency, cm^{-1}	
	Active ingredient of inhibitor (<i>Curcumin</i>)	Protective film formed on the MS surface
OH	3417	3390
C=O	1629	1628
C=C (alkene)	1513	1520
C=C (aromatic ring)	1430	1458
C–O–C	1157	1111

Conclusions

In the present study an aqueous extract of turmeric powder has been used as corrosion inhibitor, to control corrosion of mild steel in sea water. Methods such as weight loss method, polarization study and AC impedance spectra have been used. The protective film has been analyzed by UV-visible spectra, Fluorescence spectra and FTIR spectra. The surface morphology has been analyzed by SEM. The Hardness of a metal before and after immersion have been determined. This study leads to the following conclusion:

- Weight loss study reveals that the maximum corrosion inhibition efficiency of 98% is offered by 10 ml of turmeric extract.
- The adsorption study reveals that the active principles (*Curcumin*) are adsorbed on metal surface by Langmuir absorption isotherm.
- Polarization study reveals that the inhibitor function as cathodic inhibitor, because the corrosion potential is shifted to more negative side.
- AC impedance spectra confirm the formation of a protective film on the metal surface.
- Fluorescence spectra confirm that the protective film consists of Fe^{2+} –*Curcumin* complex formed on the anodic sites of the metal surface.
- This is confirmed by FTIR spectra.

- Vickers hardness (HV) study reveals that in presence of inhibitors, the hardness of the metal increases. In the absence of inhibitors (corrosive medium–sea water), the hardness of the metal decreases.
- These findings may be used in cooling water systems where sea water can be used as coolant.

Scope for further study

In the present study an aqueous extract of turmeric powder has been used as corrosion inhibitor, to control corrosion of mild steel in sea water. Methods such as weight loss method, polarization study and AC impedance spectra have been used. The protective film has been analyzed by UV-visible spectra, Fluorescence spectra and FTIR spectra. The surface morphology has been analyzed by SEM. The Hardness of a metal before and after immersion have been determined. The study can be extended further:

- Other metals such as copper and other alloys such as SS316 L can be used.
- Instead of sea water, ground water and well water can be used.
- AFM study can be used.
- Contact angle measurement can be carried out.

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