Role Of Zinc Ions In Increasing Corrosion Inhibition Efficiency

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Abstract: Zinc is a relatively insoluble metal which is caused by the precipitation of zinc hydroxide. Zinc ions have been widely used as corrosion inhibitors along with various additives. The corrosion of various metals such as mild steel, copper, and aluminium have been prevented by zinc ions. Zinc ions exhibit good corrosion inhibition efficiency in acid medium, alkaline medium, and neutral medium. They can be used along with other inhibitors such as calcium gluconate, sodium molybdate, and sodium tungstate. Zinc ions show synergistic effects with these inhibitors. Various surface analysis techniques such as FTIR spectra, SEM, AFM, and EDAX have been used to analyze the nature of protective film formed on metal surface. Usually, the protective film consists of Fe^{2+} inhibitor complex along with $Zn(OH)_2$. When zinc ions are used to prevent corrosion, the adsorption process obeys Langmuir adsorption isotherm.
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Introduction

Zinc have been widely used as corrosion inhibitors[1-70]. After iron, aluminium and copper, zinc is usually the fourth-most used metal, competing with lead. Zinc gives excellent protection against the weather and moisture, so it is preferred. It is cheaper also.

Zinc protects the iron by cathodic protection, since it is higher on the electrochemical scale than iron and will sacrifice itself to protect the iron, reducing it to the metal and eliminating rust. Zinc will not give cathodic protection if it becomes passivated, or covered by a closely adherent layer of hydroxide, since then the necessary currents cannot flow. However, the layer will protect the zinc from corrosion, also protecting the underlying metal. $Zn(OH)_2$ is insoluble for pH between 6 and 13, and in this range the hydroxide will protect the zinc under water.

Occurrence in Nature

Zinc is a natural component of the earth's crust and an inherent part of our environment. Zinc is present not only in rock and soil, but also in air, water and the biosphere. Plants, animals and humans contain zinc.

Minerals and metals are mostly obtained from the earth's crust. The average natural level of zinc in the earth's crust is 70 mg/kg (dry weight), ranging between 10 and 300 mg/kg.

Sphalerite, hemimorphite, smithsonite, and zincite are fairly common minerals; appearing in a variety of colours. Ore deposits containing zinc occur throughout the world in all of the major geological environments of deposition. Carbonate or shale hosted deposits tend to be the largest zinc deposits by volume.

Uses

The largest use of zinc is as a protective coating for iron. The process is called galvanizing with reference to the cathodic protection the zinc offers to the iron. Zinc has occasionally been used in coins and to make die castings.

It supports the immune system and its ability to help the body heal wounds. Zinc is also essential to the senses of taste and smell. DNA cannot be synthesized without zinc, and zinc is also necessary for growth and development from gestation through adolescence. Zinc supplements act to allow the uptake of minerals and vitamins into the blood as well as the absorption of fats and proteins.

Review and Discussion

The use of zinc ions as corrosion inhibitors are discussed in the following section.

Metals

Zinc ions have been used to control the corrosion of various metals such as Mild steel[1,3,4,5,6,8,11,14,22,30,35,54,63,70], Copper[66], Aluminium[2,65], Stainless steel[20], Armco iron[7] and Iron[39].

Table 1. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
1	Carbon Steel	Sothuparai dam water	Zn^{2+}	Sodium molybdate (SM)	Weight-loss, electrochemical methods, polarization study, UV fluorescent, AC impedance and FTIR spectroscopy.	Protective film consists of Fe^{2+}-MoO_4^{2-} complex and $Zn(OH)_2$. The protective film is found to be UV fluorescent.	1
2	Aluminium	Aqueous solution containing 60 ppm Cl^- ions.	Zn^{2+}	Calcium gluconate (CG)	Electrochemical techniques such as polarization study, AC impedance spectral study. weight loss study, Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM).	The protective film consists of Al^{3+}CG complex and $Zn(OH)_2$.	2
3	Carbon steel	Sea water	Zn^{2+}	Sodium molybdate (SM)	Weight-loss method, polarization study and AC impedance spectra, FTIR, and luminescence spectra, atomic force microscopy(AFM) and UV – fluorescent.	Protective film consists of Fe^{2+}_ molybdate complex and $Zn(OH)_2$.	3
4	Carbon steel	120 ppm of Cl^- and 73.58 ppm of sulphate ion.	50 ppm of Zn^{2+}	250 pm of ethylphosphonic acid (EPA)	Weight loss method, polarization study, AC impedance, FTIR, and UV-visible reflectance.	Anodic inhibitor, protective film consists of Fe^{2+} - EPA complex.	4
5	Mild Steel	Aqueous chloride media containing cupric ions.	Zinc ions	-	Thiocyanate method at 480 nm using a WPA S104 spectrophotometer.	Zinc ion inhibits mild steel corrosion in low acidic and near neutral media containing chloride and cupric ions.	5
6	Carbon steel	Low chloride aqueous medium	Zn^{2+}	Ascorbic acid, 2-phos-phonobutane-1,2,4-tri-carboxylic acid (PBTC), 1-hydroxy-ethane-1,1-diphosphoic acid(HEDP) and nitrilotris-(methylenephosphonic acid) (NTMP)	Gravinmetry, electrochemical impedance and potentiodynamic polarization studies, X-ray photoelectron and reflection absorption FTIR spectroscopy.	Ternary inhibitor, Surface film have been analysed.	6
7	Armco iron	3% Chloride solution	Zn^{2+}	Piperidin-1-yl-phosphonic acid(PPA)	Weight loss method, Surface analysis, Potentiodynamic polarization study, and Fourier transform infrared (FTIR) spectrum.	Synergistic effect exists between Zn^{2+} and PPA. Surface film analysis showed that in the absence of Zn^{2+}, the protective film consists of Fe^{2+}- PPA complex formed on the anodic sites of the metal surface, whereas in the presence Zn^{2+} of ,the protective film consists of Fe^{2+}–PPA complex and $Zn(OH)_2$.	7
8	Carbon Steel	60 ppm of Cl^-	Zn^{2+}	2-chloroethylphospho-nic acid(2-CIEPA)	Polarization study, AC impedance spectra and FTIR spectra.	Mixed inhibitor. Protective film consists of Fe^{2+}- 2-CIEPA complex and $Zn(OH)_2$.	8
9	Carbon Steel	Netural aqueous environment	Zn^{2+}	N-(2-hydroxyethyl) imino-bis(methylphos-phonic acid [HEIBMPA]	Potentiostatic polarization study, reflection-absorption FTIR spectrum, and X-ray photoelectron spectra.	Ternary inhibitor system. The film consisted of [Fe(III)-HEIBMPA-molybdate] complex, [Fe(III), Zn(II)-HEIBMPA-molybdate] complex, oxides and hydroxides of iron an $Zn(OH)_2$.	9

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
10	Carbon Steel	Neutral oxygen-containing chloride solutions	Zn^{2+}	1-hydroxyethylidene 1,1 diphosphonic acid (HEDP).	-	The predominant corrosion control mechanism of of the zinc-HEDP mixture was on the anodic(metal dissolution) reaction. The effectiveness the zinc-HEDP mixtures can enhance inhibition by increasing the zinc content of the mixture.	10
11	Carbon Steel	Rain water	Zn^{2+}	Sodium dodecyl sulphate(SDS) and 1-hydroxyethane-1,1-diphosphonic acid(HEDP)	Weight loss method and FTIR spectroscopy.	The protective film consists of Fe^{2+}-SDS complex, Fe^{2+}-HEDP complex and $Zn(OH)_2$. The HEDP- Zn^{2+} system shows good IE. The protective film consists of Fe^{2+}-HEDP complex and $Zn(OH)_2$.	11
12	Carbon Steel	Chloride Solution	Zn^{2+}	N-Phosphonomethyl-glycine (NPMG)	Polarization, Electrochemical impedance measurements, XPS and AES spectra.	Films consisted of hydrous ferric oxides ($Fe(OH)_3$ and FeOOH) with small amounts of Fe-NPMG complex, ZnO, and corrosion products.	12
13	Carbon Steel	Trisodium orthophosphate (TOP)	Zn^{2+}	Sodium salt of diethyldithiocarbamate (NaDEDTC), 1-hydroxy ethyledene-1, 1-diphosphonic acid (HEDP)	Weight loss, Potentiodynamic polarization methods, SEM and EDS study.	It shows the formation of an adsorbed protective film on the Carbon steelsurface. Potentiodynamic polarization curves indicate the mixed nature of the inhibitors of the blend. Adsorption of the new blend of inhibitors on the Carbon steelsurface was found to obey Langmuir adsorption isotherm.	13
14	Carbon Steel	Low Chloride aqueous medium	Zinc ions	N-N-bis(phospho-nomethyl) glycine (BPMG), Tungstate	Potentiodynamic polarization, Impedance Studies, X-ray photoelectron spectroscopy(XPS), FTIR, and Scanning electron microscopy (SEM).	Mixed inhibitor. Surface film is composed of iron oxides/hydroxides, zinc hydroxide, heteropolynuclear complex [Fe(III), Zn(II)-BPMG] and WO_3.	14
15	Carbon Steel	Chloride Solution	Zn^{2+}	HEDP	-	The protective film consists of Fe^{2+} - HEDP complex and $Zn(OH)_2$.	15
16	Carbon Steel	Neutral Medium	Zn^{2+}	DTPMP	Voltammetric, Gravimetric, and Electrochemical methods.	The corrosion inhibition efficiency of DTPMP+ Zn^{2+} is found to be 80% after 24 hours.	16
17	Mild Steel	60 ppm chloride	Zn^{2+}	Sodium salt of HEDP	UV-visible, FTIR, and Luminescence spectroscopy.	Presence of Zn^{2+} facilitates the transport of HEDP from the bulk of the solution to the metal surface both the anodic reaction and cathodic reaction are controlled effectively.	17
18	Carbon steel	Chloride ions	Zinc ions	HEDP & Sodium molybdate	-	Pressure of more than 1,200 ppm of chloride ions, temperatures greater than or equal to 4.5°C, the combination of HEDP, molybdate and zinc could not control the corrosion in a cooling water system.	18

Table 1 (cont.). The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
19	Carbon Steel	60 ppm chloride ion	Zn^{2+}	Phosphonates	Polarization and weight loss method.	Inhibition efficiency increases when the phosphonate- Zn^{2+} complex remains in solution in soluble form. Inhibition efficiency decreased when the phosphonate- Zn^{2+} complex was precipitated in the bulk of the solution.	19
20	304 Stainless steel	Ground water	Zn^{2+}	100 ppm of 3-phosphonopropionic acid and 150 ppm of Tween 80 (polyoxyethylene sorbitan monooleate)	Luminescence, XRD, FTIR spectra, pit morphology and Scanning electron microscopy.	Mixed inhibitor.	20
21	304 Stainless steel	Ground water	Zn^{2+}	3-phospho-nopropionic acid (3-PPA) and Triton X-100	Open circuit potential-time, Polarization, Impedance and Luminescence measurements.	The nature of the film formed and the mechanistic aspects of film formation has been analysed.	21
22	Mild Steel	Oxygen containing aqueous solutions	Zn^{2+}	HEDP	-	Anionic complex can behave as an anodic, passivating inhibitor at a concentration as low as 0.00015M (20 ppm zinc-32 ppm HEDP mixture).	22
23	Steel	Oxygen saturated environment	Zinc	Tartrate with organophosphonic acid (2-carboxyethylphos-phonic acid)	Weight change method, polarization, AC impedance technique, UV-VIS reflectance, UV-VIS luminescence and ESCA techniques.	The protective film has been analysed.	23
24	Carbon Steel	60ppm Cl^-	Zn^{2+}	Carboxymethylphos-phonic acid (CMPA) and 2-carboxyethyl-phosphonic acid (2-CEPA)	Weight loss method, X-ray diffraction, Fourier transform infrared and Luminescence spectroscopy.	The protective film is found to consist of Fe^{2+}-phosphonate complex and $Zn(OH)_2$. It is found to be luminescent.	24
25	Mild Steel	60ppm Cl^-	Zn^{2+}	Ethylphosphonic acid(EPA)	Weight loss method, Polarization study and X-ray diffraction.	Mixed inhibitor.	25
26	Mild Steel	60ppm Cl^-	Zn^{2+}	Ethyl and 2-carboxy-ethyl phosphonic acid (EPA and 2-CEPA, resp.)	Polarization study and Fluorescence Spectra.	Mixed inhibitor.	26
27	Carbon Steel	60ppm Cl^-	Zn^{2+}	2-chloroethyl phosphonic acid (2Cl EPA)	UV-luminescent.	The protective film consists of Fe^{2+}-2-Cl EPA complex and $Zn(OH)_2$.	27
28	Mild Steel	60ppm Cl^-	Zn^{2+}	HEDP	Weight-loss study, UV-visible reflectance spectroscopy and X-ray diffraction.	Mixed inhibitor.	28
29	Carbon Steel	60ppm Cl^-	Zn^{2+}	2-chloroethyl phosphonic acid (2Cl EPA)	Weight-loss, Electrochemical methods, Polarization study, UV-visible absorption and Reflectance spectra.	Mixed inhibitor. The protective film consisted of Fe^{2+}-2-Cl EPA complex, $Zn(OH)_2$ and oxides of ions. The film was found to be semiconducting in nature.	29

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
30	Carbon Steel	Low chloride aqueous environment	Zinc ions	N,N-bis(Phosphono-methyl) glycine (BPMG)	Potentiodynamic polarization, X-ray photoelectron spectroscopic analysis(XPS), Deconvolution, FTIR spectroscopy and SEM.	Film showed the presence of the elements iron, phosphorus, nitrogen, oxygen, carbon, and zinc. Deconvolution spectra of these elements in the surface film showed the presence of oxides/hydroxides of iron(III),$Zn(OH)_2$, and [Zn(II)-BPMG] complex.	30
31	Carbon steel	Well water	Zn^{2+}	Resorcinol	Weight loss method, FTIR spectra, SEM and AFM analysis.	Mixed inhibitor. Protective film is formed on the metal surface consists of Fe^{2+}-resorcinol complex and $Zn(OH)_2$.	31
32	Mild Steel	Aqueous Chloride Media Containing Cupric Ions	Zn^{2+}	Molybdate, Nitrite	Thiocyanate method at 480 nm using a WPA S104 spectrophotometer.	Zinc ion inhibits mild steel corrosion in low acidic and near neutral media containing chloride and cupric ions. However, it cannot inhibit mild steel corrosion in neutral and alkaline solution.	32
33	Carbon steel	Neutral aqueous environment containing 100 ppm chloride	Zn^{2+}	ATMP	Weight-loss method, FTIR, UV-luminescence spectroscopy and Potentiostatic polarisation method .	Protective film, Corrosion inhibition , FTIR spectroscopy, UV luminescence spectroscopy and Electron chemical method like Potentiostatic polarisation have been used.	33
34	Carbon steel	Low chloride aqueous environment	Zn^{2+}	1-Hydroxyethane-1,1-diphosphonic acid (HEDP) , Ascorbic acid (AA), Nitrilotris(methylenephosphonic acid) (NTMP) and ascorbic acid (AA)	Gravimetric studies.	Ternary inhibitor. The synergistic action of ascorbic acid in combination with phosphonate-Zn^{2+} is proved. The uniqueness of the inhibitor system, HEDP-Zn^{2+}-AA is that it requires only 5 ppm of Zn^{2+} in order to maintain the protective nature of the surface film. Both the formulations are effective in corrosion control in a wide pH range that includes pH range maintained in cooling water systems.	34
35	Carbon steel	Low chloride environments	Zn^{2+}	Tertiary butyl phosphonate and Citrate	Weight loss method,AC impedance, Potentiostatic polarization study, X-ray diffraction, X-ray photoelectron spectroscopy, and Fourier transform infrared spectroscopy.	The inhibitor combination was determined to function as a "mixed"-type inhibitor, though being predominantly cathodic.	35
36	Mild steel	Neutral aqueous environment containing 60ppm chloride	Zn^{2+}	Phenyl Phosphonate	-	In solution, both the phosphonate group and the phenyl group of PPA are involved in the formation of the complex with both Zn^{2+} and Fe^{2+}, whereas in the solid state, only the phosphonate group is involved.	36

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
37	Carbon steel	Neutral oxygen-containing chloride solutions	Zn^{2+}	1, hydroxyethylidene-1,1 diphosphonic acid	-	HEDP concentration appeared to be crucial where good inhibition was not achieved at low concentrations and aggressive nature is observed at high HEDP levels. The predominant corrosion control mechanism of the zinc-HEDP mixture was on the anodic (metal dissolution) reaction, but it also affected the rate and mechanism of the oxygen reduction reaction.	37
38	Carbon steel	Neutral aqueous environments containing 60-ppm Cl.	Zn^{2+}	Phosphonates	Polarisation study and weight loss study.	Inhibition efficiency increases when the phosphonate-Zn^{2+} complex remains in solution in soluble form. Inhibition efficiency decreased when the phosphonate-Zn^{2+} complex was precipitated in the bulk of the solution.	38
39	Iron	Aqueous environments	Zn^{2+}	Tungstate, Nitrite	Long-term open circuit potential measurements.	The passive layer formed on the metal surface retained its protective capability for several weeks, even after test coupons were transferred into a depleted inhibitor solution.	39
40	Carbon steel	Aqueous media containing chloride ions	Zn^{2+}	HEDP, Sodium molybdate	-	In the presence of more than 1,200 ppm of chloride ions, and temperatures greater than or equal to 42.5°C, the combination could not control the corrosion in a cooling water system.	40
41	Mild steel	Stimulated cooling water	Zn^{2+}	Molybdate, Nitrite, Nitroethane,	Potentiodynamic polarization study, AC impedance study, Scanning electron microscopy (SEM) and X-ray energy dispersive spectrometry (EDS) .	A new optimized inhibitor could form a relatively steady, compact, and uniform film on the surface of mild steel.	41
42.	Carbon steel	Dam water	Zn^{2+}	Hexanesulphonic acid	Weight loss, Potentiodynamic polarization methods, FTIR spectra, SEM and AFM analyses.	AC impedance spectra revealed that a protective film was formed on the metal surface.	42.
43.	Carbon steel	Sea water	Zn^{2+}	Sodium Gluconate	Weight-loss method, Polarization study and AC impedance spectra.	The protective film consists of Fe^{2+}-SG complex and $Zn(OH)_2$. It is found to be UV-fluorescent.	43.
44.	Carbon steel	Rainwater	Zn^{2+}	Sodium potassium tartrate	Weight loss, Polarization study, AC impedance spectra and FTIR spectra.	Mixed inhibitor. the protective film consists of Fe^{2+}-SPT complex and $Zn(OH)_2$	44.
45.	Mild steel	Neutral aqueous environment	Zn^{2+}	Carboxymethyl cellulose	FTIR spectra, XRD and Polarization study.	The protective film consists of Fe^{2+} - HEDP complex, Fe^{2+} -CMC complex and $Zn(OH)_2$.	45.

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
46.	Mild steel	Water containing 60ppm of Chloride ion	Zn^{2+}	2-Carboxyethylphosphonic acid	Weight loss, Potentiostatic polarization methods, XRD technique,UV-Vis-NIR Spectra and Luminescence spectra.	Obeys Langmuir adsorption isotherm.Acts as a mixed inhibitor.Iron-2CEPA complex is formed on the surface.	46.
47.	Mild steel	Rain water	Zn^{2+}	Diethylenetriaminepenta(methylenephosphonic acid)	Weight loss method and electrochemical impedance spectroscopy, FTIR spectra, atomic force microscopy (AFM) and Fluorescence spectral analysis.	Formation of more stable and compact protective film on the metal surface.	47.
48.	Carbon steel	Well water	Zn^{2+}	Sodium Tungstate,N-(Phosphenomethyl) Iminodiaceticacid	Electrochemical studies. FTIR spectral studies. Weight loss study, AC Impedance and Polarization methods.	The protective film consists of $Zn(OH_2)$ and complexes of $Fe^{2+}Fe^{3+}$ and Zn^{2+} with NPMIDA.	48.
49.	Carbon steel	Well water containing 665 pm of Cl-	Zn^{2+}	Malachite green	Weight loss method, Polarization study, AC impedance spectra, FTIR spectra, UV-visible spectra and fluorescence spectra.	The FTIR spectra show that the protective film consists of the Fe^{2+}- MG complex.	49.
50	Carbon steel	120 ppm chloride solution	Zn^{2+}	Caffeine	Mass – los method, Potentiodynamic polarization study and AC impedance spectra, AFM and FTIR spectrum.	AC impedance spectra and AFM studies reveal the formation of a protective film on the metal surface. FTIR spectrum shows the presence of Fe^{2+}- caffeine complex and $Zn(OH)_2$ in the film.	50
51	Carbon steel	Well water	Zn^{2+}	Fluorescein	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	The protective film consists of Fe^{2+}-FN complex and $Zn(OH)_2$.	51
52.	Carbon steel	River water	Zn^{2+}	Calcium propionate	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	Synergistic effect is noticed between calcium propionate and Zn^{2+}. the protective film consists of Fe^{2+} - CP complex $Zn(OH)_2$. and $Ca(OH)_2$	52.
53.	Carbon steel	Well water	Zn^{2+}	Phenolphthalein	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	A synergistic effect exists between phenolphthalein (PN) and Zn^{2+}. The protective film consists of Fe^{2+}-PN complex and $Zn(OH)_2$.	53.
54	Carbon steel	Well water	Zn^{2+}	Methyl orange	Weight loss method, Polarization study and FTIR spectra.	A synergistic effect exists between Methyl orange (MO) and Zn^{2+}. Mixed inhibitor the protective film consists of Fe^{2+}-MO complex and $Zn(OH)_2$.	54
55	Carbon steel	Well water	Zn^{2+}	Malonic acid	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	A synergistic effect exists between Malonic acid (MA) and Zn^{2+}. Mixed inhibitor. The protective film consists of Fe^{2+}-MA complex and $Zn(OH)_2$.	55
56.	Carbon steel	Sea water	Zn^{2+}	Urea	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	A synergistic effect exists between Urea and Zn^{2+}. Mixed inhibitor. The protective film consists of Fe^{2+}-Urea complex and $Zn(OH)_2$.	56.

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
57.	Carbon steel	Dam water	Zn^{2+}	Octanesulfonic acid as its sodium salt (SOS)	Weight loss method, Polarization study, AC impedance spectra, FTIR spectra, UV-visible spectra, Fluorescence spectra, Scanning electron microscopy (SEM), Energy dispersive X-ray detection and (EDAX) measurements.	Protective film is formed on the metal surface.	57.
58.	Carbon steel	60 ppm of Cl^-	Zn^{2+}	Phyllanthus amarus extract (PAE)	Weight loss method, Polarization study and AC impedance spectra.	A synergistic effect exists between PAE and Zn^{2+}. This system functions as mixed type of inhibitor controlling the cathodic reaction and anodic reaction to an equal extend. a protective film is formed on the metal surface consists of Fe^{2+}-phyllanthus complex.	58.
59	Carbon steel	Dam water	Zn^{2+}	Pentane sulphonic acid as its sodium salt (SPS)	Weight loss method, Polarization study, AC impedance spectra, FTIR spectra and AFM analysis.	Polarization study reveals that SPS-Zn^{2+} system functions as a cathodic inhibitor. The protective film consists of SPS– Fe^{2+} complex and $Zn(OH)_2$.This account for the synergistic effect of SPS – Zn^{2+} system.	59
60	Copper	0.5 M HCl	Zinc ions	Methionine	Cyclic voltammetry, Electrochemical impedance spectroscopy (EIS) and Potentiodynamic polarization.	The adsorption of methionine on copper surface follows Langmuir isotherm. The adsorption free energy of methionine on copper (~−26 kJ mol^{-1}) reveals a strong physical adsorption of the inhibition on the copper surface.	60
61	Mild steel	60 ppm of Cl^- ion	Zinc ions	Metronidazole (MZ)	Weight loss method, Polarization study, AC impedance spectra and FTIR spectra.	Mixed type of inhibitor. protective film is formed on the metal surface consists of Fe(II)-MZ complex.	61
62	Carbon steel	Ground water	Zinc ions	Amino Trimethylene phosphonic acid (ATMP)	Weight loss method, Polarization study and AC impedance spectra	ATMP-Zn^{2+} system functions as a cathodic inhibitor system. Protective film is formed on the metal surface.	62
63	Mild steel	Well water	Zinc ions	Sodium Meta vanadate	Weight loss method, Polarization study and AC impedance spectra.	Mixed type of inhibitor. Protective film is formed on the metal surface. The reactions are diffusion controlled process.	63
64	Carbon Steel	Sea Water	Zinc ions	Glutamic acid (GA)	Weight loss method, Polarization study, AC impedance spectra, FTIR and SEM analysis.	A synergistic effect exists between Glutamic acid and Zn^{2+}. Protective film is formed on the metal surface.	64

Table 1 (cont.). The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
65.	Aluminium	Well water	Zinc ions	Carboxymethylcellulose	Weight loss method, Polarization study, AC impedance spectra, ,Scanning electron microscope (SEM) and Atomic force microscopy (AFM).	Protective film is formed on the metal surface.	65.
66.	Copper	0.5 M HCl	Zinc ions	Methionine (MTI)	Cyclic voltammetry, Electrochemical impedance spectroscopy (EIS) and Potentiodynamic polarization.	The adsorption of methionine on copper surface follows Langmuir isotherm. The adsorption free energy of methionine on copper (~−26 kJ mol^{-1}) reveals a strong physical adsorption of the inhibition on the copper surface.	66.
67.	Carbon steel	Aqueous Solution	Zinc ions	Thiomalic acid	Gravimetric studies, Potentiodynamic polarization studies, Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy (SEM).	Protective film may consists of [Fe^{3+}/Fe^{2+}/Zn^{2+}-TMA] complex, $Zn(OH)_2$, hydroxides and oxides of iron. This inhibitor formulation consisting of TMA and Zn^{2+} can be used as a potential inhibitor to prevent the corrosion of Carbon steelin aqueous solution.	67.
68	Carbon steel	Groundwater	Zn^{2+}	Thiophenol	Weight loss, Potentiodynamic polarization, AC impedance study, FTIR spectra and Scanning Electron Microscopy.	Productive film shows the presence of Fe_{2+}-thiophenol complex and $Zn(OH)_2$.	68
69	Carbon steel	Soft tap water, hard tap water, sodium chloride solution, sea water, biologically inert sea water and demineralized water.	Zn^{2+}	-	Tafel polarization scanning electron microscopy techniques and EDX analysis.	It shows that substantial corrosion inhibition using zinc gluconate can be obtained with low concentrations in tap waters along with demineralized water and with moderate concentrations in 3.5% sodium chloride solution and sea waters. EDX analysis confirmed the presence of zinc ions which are incorporated in the protective layer of Carbon steelspecimen. The corrosion inhibition is predominately obtained by anodic mechanism.	69
70	Carbon steel	Sea water	Zn^{2+}	L-Arginine	Weight-loss method, Polarization study, AC impedance spectra , Cyclic voltammetry, FTIR, SEM and AFM analysis.	Anodic inhibitor. A more stable and compact protective film formed on the metal surface.	70

Table 1 (cont.).. The uses of zinc ions as corrosion inhibitors

No.	Metal	Medium	Inhibitor	Additive	Method	Findings	Ref
65.	Aluminium	Well water	Zinc ions	Carboxymethylcellulose	Weight loss method, Polarization study, AC impedance spectra, ,Scanning electron microscope (SEM) and Atomic force microscopy (AFM).	Protective film is formed on the metal surface.	65.
66.	Copper	0.5 M HCl	Zinc ions	Methionine (MTI)	Cyclic voltammetry, Electrochemical impedance spectroscopy (EIS) and Potentiodynamic polarization.	The adsorption of methionine on copper surface follows Langmuir isotherm. The adsorption free energy of methionine on copper (~−26 kJ mol^{-1}) reveals a strong physical adsorption of the inhibition on the copper surface.	66.
67.	Carbon steel	Aqueous Solution	Zinc ions	Thiomalic acid	Gravimetric studies, Potentiodynamic polarization studies, Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy (SEM).	Protective film may consists of $[Fe^{3+}/Fe^{2+}/Zn^{2+}$-TMA] complex, $Zn(OH)_2$, hydroxides and oxides of iron. This inhibitor formulation consisting of TMA and Zn^{2+} can be used as a potential inhibitor to prevent the corrosion of Carbon steelin aqueous solution.	67.
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70	Carbon steel	Sea water	Zn^{2+}	L-Arginine	Weight-loss method, Polarization study, AC impedance spectra , Cyclic voltammetry, FTIR, SEM and AFM analysis.	Anodic inhibitor. A more stable and compact protective film formed on the metal surface.	70

Medium

The inhibition efficiency of Zinc ions in controlling corrosion of metals in various environments has been investigated. Acidic medium[66], Alkaline medium[4,7,8,12,14,117,24,25,26,27,28,29,46,50,61] and Neutral medium[1,9,11,16,20,21,31,42,45,47,57,65] have been used for this purpose.

Inhibitor

Zinc ions have been used alone or in combination with other inhibitors such as Sodium molybdate[1,3,18,40,41], Calcium gluconate[2], EPA[4,25,26], HEDP[10,11,13,15,18,22,28,34,37,40], PPA[7,20,21], 2-CIEPA[8,27,29], HEIBMPA[9], NPMG[12], SDS[11], DTPMP[16], CEPA[23,24,26], CMPA[24], Tartrate[23], Resorcinol[31], ATMP[33,62], Ascorbic acid[6,34], Phosphonate[19,36,38], Tungstate[39,48], Hexanesulphonic acid[42], Malachite green[49], Caffeine[50], Fluorescein[51], Phenolphthalein[53], Calcium propionate[52], Methyl orange[54], Malonic acid[55], Urea[56], SOS[57], PAE[58], SPS[59], Metronidazole[61], Sodium meta vanadate[63], GA[64], MTI[66], Thiomalic acid[67], Thiophenol[68] and L-Arginine[70].

Methods

Various methods have been used to evaluate the inhibition efficiency of zinc ions. Weight-loss method[1-4,7,11,19,23-25,28,31,33,35,38,42-44,46-65,68,70], Electrochemical studies (Polarization and AC impedance)[1-4,6-9,11-14,16,19,21,23,25,26,29,30,33,35,38,41-45,46,48-68,70], FTIR spectra[1,4,6-9,11,17,20,24,25,30,31,33,35,44,45,47-57,59-61,64,67,68,70], UV-visible reflectance spectra[1,3,4,17-23,28,49,57], Luminescence spectra[3,17,20,21,23,24,33,46], AES spectra[12], Cyclic voltammetry[16,66,70], Gravimetry[16,34,67], ESCA Techniques[23], EDAX[57], XPS[9,12,30,35], XRD[20,24,35,45,46], EDS[13,41], EDX[69], Fluorescence spectra[26,47,49,57], Surface analysis by SEM[2,13,20,30,31,41,57,60,64,65,67,70] and AFM[2,3,31,47,50,59,60,65,70] have been used.

Findings

Using zinc ions as inhibitor, above studies have been conducted and following findings were reported:

Isotherm: Generally, the adsorption of Zinc ions on metal surface obey Langmuir adsorption isotherm as supported by the studies of Apparao et al and Zhang et al 46,66. Adsorption of Zinc ions on metals like iron, Carbon steel obey adsorption isotherm.

Type of inhibitor: Zinc ions have been used as mixed inhibitor[8,20,25,26,28,29,34,44,54,55,56,61,63], Ternary inhibitor[6,9,], cathodic inhibitor[62], anodic inhibitor [4,22,70].

Nature of protective film: The protective films formed on metal surface when Zinc ions are used as corrosion inhibitors have been analyzed by FTIR, UV, SEM, AFM, and XPS. It is observed that the protective films consists of Fe^{2+} inhibitor complex is formed on anodic sites of the metal surface and $Zn(OH)_2$ formed on the cathodic sites of the metal surface[4,6,8,15,27,31,56].

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