CORROSION AND MICROBIOLOGICAL GROWTH PREVENTION OF SURFACTANT IN THE PRESENCE OF DICARBOXYLICACIDS AND Zn^{2+} FOR CARBON STEEL IN GROUND WATER

K.Lawrence Mary[1], M.Jebastin Sonia Jas[2]

Department of chemistry, IFET College of engineering, Villupuram

Abbreviation

OA –Oxalic acid

MA – Malonic acid

SA – Succinic acid

GA – Glutaric acid

AA – Adipic acid

SDS – Sodium dodecyl sulphate

IE – Inhibition Efficiency

CR – Corrosion Rate

ABSTRACT

We investigate the influence of SDS on the inhibition efficiency of OA-Zn^{2+}, MA-Zn^2, SA-Zn^2, GA-Zn^2, AA-Zn^2 system. We examine the nature of the protective film formed on the surface of carbon steel by surface analysis techniques such as Fourier Transform Infra Red spectra (FTIR).

Key words: SDS, Inhibition, corrosion,biocides

INTRODUCTION

The efficiency of Schiff base derived from 4-aminoantipyrine, namely 2-(1,5-dimethyl-4-(2-methylbenzylidene)amino)-2-phenyl-1H-pyrazol-3(2H)-ylidene) hydrazinecarbothioamide as a corrosion inhibitor on mild steel in 1.0 M H2SO4 was investigated using electrochemical impedance spectroscopy (EIS), potentiodynamic polarization (PD) and electrochemical frequently modulation (EFM) in addition to the adsorption isotherm, corrosion kinetic parameters and scanning electron microscopy (SEM). The results showed that this inhibitor behaved as a good corrosion inhibitor, even at low concentration, with a mean efficiency of 93% and, also, a reduction of the inhibition efficiency as the solution temperature increases. A polarization technique and EIS were tested for different concentrations and different temperatures to reveal that this compound is adsorbed on the mild steel, therefore blocking the active sites, and the adsorption follows the Langmuir adsorption isotherm model. The excellent inhibition effectiveness of 2-(1,5-dimethyl-4-(2-methylbenzylidene)amino)-2-phenyl-1H-pyrazol-3(2H)ylidene)hydrazinecarbothioamide was also verified by scanning electron microscope (SEM)[1]. Ruthenium complexes containing chiral Schiff base ligand are successfully used in asymmetric epoxidation of unfunctionalised olefins, oxidation, aziridination, amidation, Michael reaction[2].

The effect of acetic acid on the corrosion behavior of X 65 and C 1018 carbon steel in vapor-water two-phase stratified flow (Vsg: 2m=s; Vsl: 0.1m=s) at 2 bars total pressure, 1.54 bars CO2 partial pressure, pH 5.5, and 80C was studied in a low pressure-high temperature multiphase flow horizontal loop using electrochemical and mass loss techniques. The liquid phase is composed of 1% NaCl aqueous solution containing different concentrations of acetic acid (500 to 5000ppm total acetic acid), and the gas phase is composed of CO2-acetic acid-water vapor mixture. The corrosion rates, on both the top and bottom of the line, increase with increase in acetic acid concentration, which was attributed to the contribution of hydrogen ions by the free acetic acid to the cathodic reaction. Partial coverage of the metal surface by FeCO3 on both the top and bottom of the line is reported to be responsible for the observed localized corrosion. Surface analysis investigated with SEM and XRD is reported. A vapor-liquid equilibrium model was developed for the system studied[3].

The corrosion inhibition properties of ceftadizime (CZD) for mild steel corrosion in H_2SO_4 solution were analysed by electrochemical impedance spectroscopy (EIS), potentiodynamic polarization and gravimetric methods. Mixed mode of adsorption (Physisorption and chemisorption) is proposed for the inhibition and the process followed the Langmuir adsorption isotherm. The mechanism of adsorption inhibition and type of adsorption isotherm were proposed from the trend of inhibition efficiency with temperature . Potentiodynamic polarization study clearly revealed that CZD acted as mixed type inhibitor. The experimental data showed a frequency distribution and therefore a modelling element with frequency dispersion behaviour and a constant phase element (CPE) have been used [4].

Alizarin yellow GG (AYGG) is a natural dye used as a corrosion inhibitor. The inhibitive action of this compound against corrosion of carbon steel in hydrochloric acid solution (1M concentration), has been tested using the weight loss measurements and electrochemical measurements techniques. The results indicates this compound is a good inhibitor for carbon steel in hydrochloric acid solution, and the inhibition efficiency increased as the concentration of this compound increased. Also the results revealed as the temperature increased, efficiency and corrosion activation energies are increased. On the basis of the experimentally determined activation energy values, the addition of this compound can be considered chemisorption adsorbed[5].

The present work sheds some light on the inhibition effect of acidic extract of Haloxylon Scoparium pommel on the corrosion of steel (X52) in acid solution of hydrogen chloride (1M) using the electrochemical measurements (electrochemical polarization resistance, electrochemical impedance spectrum, and scanning electron microscopic studies). The results revealed that the extract could serve as an effective mixed mode inhibitor for mild steel in HCl media. The electrochemical impedance spectroscopy findings showed that the change in the impedance parameters, charge transfer resistance and double layer capacitance, with the variation in extract concentration is due to the adsorption of active molecules leading to the formation of a protective layer on the surface of mild steel. This could be observed on the image obtained by electron microscopic scanning [6].

Diverse types of steels have found application in industry owing to their ability to form passive films resistant to the electrochemical corrosion. However, the presence of microorganisms in the production environment can cause undesired corrosion of metals. Therefore, any information on the chemical structure of corrosion products and microbiological deposits, as well as the estimation of the biocorrosion level can be extremely useful in applications. To prevent or reduce biocorrosion the initial selection of the materials and design of the technological equipment are of crucial importance. At later stages it is shown that proper and regular cleaning of the equipment is a necessity. This would significantly lower cost for reparation of the equipment damaged by the microbial action. Key words: Biocorrosion, Steel, Sulfate reducing bacteria [7].

Most engineering systems experience unexpected problems, premature failures and costly repairs due to damages wrecked by Microbiologically Influenced Corrosion (MIC). This research is aim at establishing the influence of certain microorganisms in increasing corrosion rate in steel coupons, characterizing and isolating the microbial strains associated with the accelerated corrosion in waterlogged clay soil area and determining the corrosion inhibitors that can effectively reduce the MIC, acting as a biocide instead of a nutrient source. Microbial count tests in both dry and waterlogged soils and Biochemical tests on isolates were conducted. Results show that effective prevention and control of MIC can be achieved through proper characterization of the microorganisms involved and understanding their specific roles in the clay soil environment. The Inhibitive Efficiency of the three inhibitors used in this study decreased in the following order: Copper (II) Chloride, Glutaraldehyde and sodium molybdate with $CuCl_2$ giving 78.9% efficiency. The effective use of biocides helps reduce the equipment damage by lowering the rate of corrosion attack and thereby saving maintenance cost such as repair costs, lost production and lost sales[8].

The present study enlightens the role of *Bacillus cereus* ACE4 on biodegradation of commercial corrosion inhibitors (CCI) and the corrosion process on API 5LX steel.*Bacillus cereus* ACE4, a dominant facultative aerobic species was identified by 16S rDNA sequence analysis, which was isolated from the corrosion products of refined diesel-transporting pipeline in North West India. The effect of CCI on the growth of bacterium and its corrosion inhibition efficiency were investigated. Corrosion inhibition efficiency was studied by rotating cage test and the nature of biodegradation of corrosion inhibitors was also analyzed. This isolate has the capacity to degrade the aromatic and aliphatic hydrocarbon present in the corrosion inhibitors. The degraded products of corrosion inhibitors and bacterial activity determine the electrochemical behavior of API 5LX steel[9]. The rate of the reaction was increased by increasing the ionic strength of the reaction [10].

The use of heavy metal-based corrosion inhibitors is increasingly being curtailed by recent environmental restrictions. In many parts of the world, high levels of inorganic phosphates are also restricted by law. In response to these environmental guidelines, this paper presents the results of a 'green' chemicals study that was undertaken to investigate the ability of a new inhibitor to inhibit the corrosion, scale and microorganism problems found in open

recirculating cooling systems. This study used a new all-organic multi-component inhibitor blend composed of citric acid/phosphonates (hydroxy ethylidene diphosphonic acid, HEDP)/acrylate copolymer/isothiazolone. The effects of the inhibitor on carbon steel dissolution in synthetic cooling water were studied through weight loss measurements and electrochemical, scale, and microorganism tests. The results obtained from this study show that the new inhibitor can decrease corrosion, scale build-up and microbial growth under the conditions tested. Potentiodynamic polarization curves indicate that the blended inhibitor acted as an anodic inhibitor, reducing metal dissolution. The nature of protective films formed on the carbon steel was studied by scanning electron microscopy (SEM) and auger electron spectroscopy (AES). The inhibition effects are due to the formation of protective films which might contain calcium phosphonates and iron oxide. The inhibitor used in this study appears to have an excellent crystal modification effect on calcium carbonate scale. The various microorganisms used in this study were inhibited effectively in the planktonic state [11].

Microorganisms are able to drastically change the electrochemical conditions at the metal/solution interface by biofilm formation. These changes can range from the induction or acceleration of corrosion to corrosion inhibition. Any inhibitory action developed by bacteria may be accomplished within the varied and complex biofilm/corrosion products interactions occurring on a biofouled metal surface.Biocorrosion and its counter process, microbial inhibition of corrosion, are rarely linked to a single mechanism or to a single species of microorganisms. Microorganisms can induce corrosion inhibition according to two general mechanisms or their combination: i) neutralizing the action of corrosive substances present in the environment; ii) forming protective films or stabilizing pre-existing protective films on a metal. Different practical cases illustrating these mechanisms are presented in this overview.It must be stressed that some times the inhibitory action of bacteria can be reversed to a corrosive action in bacterial consortia located within biofilm thickness [12].

EXPERIMENTAL METHODS

There are two important problems encountered in cooling water system, they are corrosion and bio fouling due to microbes. The most efficient corrosion inhibitors known are based upon the elements carbon, phosphorus, Nitrogen and Sulphur. Bacteria on the other hand are completely dependent on their elements for their metabolism and survival.Sudden and apparently unjustified breaks down of inhibitors in technical water based systems are observed due to bacterial activity in the waters. Bacteria also induce corrosion by the formation of biofilms. Hence, it is important to add a chemical which function as biocide as well as corrosion inhibitors. As it is difficult to control both corrosion and microbial growth by a single chemical, it is important to develop an inhibitor system which includes a biocide. Review of literature reveals that SDS in combination with other organic chemicals are effective in controlling the corrosion of many metals in various environment and also functions as an excellent biocide. Hence, the present study investigate the possibility of using SDS as a second synergist along with few well known dicarboxilic acids and Zn^{2+} combinations and also as a biocide for the corrosion of carbon steel in ground water.

This study is confined to a single metal species, namely, carbon steel specimens of the following composition.

Carbon - 0.1%

Sulphur – 0.026%

Phosphorus – 0.06%

Manganese – 0.4%

And the rest is Iron

Methods and materials

Preparation of the carbon steel specimens:

Carbon steel specimens were chosen from the same sheet of the following composition:0.1 cent C, 0.026 percent P, 0.04 Percent Mn and balance Fe. Carbon steel specimens of the dimensions 1.0*4.0*0.2 cm were polished to mirror finish, degreased with acetone and used for mass-loss and surface examination studies.

Preparation of the stock solution:

Zinc sulphate solution:

Exactly 1.1 g of zinc sulphate was dissolved in double distilled water and made up to 250 ml in a 250 ml in a 250 ml standard flask. A hundred- fold dilution yields exactly 10 ppm of Zn^{2+} concentration.

Preparation if OA/MA/SA/GA/AA solution:

Stock solution of OA/MA/SA/GA/AA were prepared in double distilled water by weighing 1 g of the chemical and making up to 100 ml in a 100 ml standard flask. A hundred fold dilutions yields exactly 100 ppm of the chemical.

isrjournals

International Journal of Advanced Research in Civil,Structural,Environmental and Infrastructure Engineering and Developing

Volume: 3 Issue: 1 Jul,2016,ISSN_NO: 2320-723X

SDS SOLUTION:

A stock solution of SDS was prepared by dissolving 1 g of SDS in 100 ml of double distilled water. A hundred fold dilutions yields exactly 100 ppm of SDS concentration.

Zobell medium:

Zobell medium was prepared by dissolving 5g of peptone, 1g of yeast extract, 0.1g potassium dihydrogen phosphate and 15g of agar-agar in 1 liter of double distilled water. The medium was sterilized by applying 15 pounds per square inch for 15 minutes in an autoclave.

Mass- Loss Method:

Determination of surface area of the specimens:

The length, breadth and the thickness of carbon steel specimens and the radius of the holes were determined with the help of vernier calipers of high precision and the surface areas of the specimens were calculated.

Weighing the specimens before and after corrosion:

All the weighing of the carbon steel specimens before and after corrosion were carried out using ACCULAB Electronic top loading balance, with readability/ sensitivity of 0.1 mg in 210 g range. This balance has reproducibility (standard deviation) of 0.02 mg in 40g range and 0.1 mg in 200 g range.

Determination of corrosion rate:

The weighed specimens in duplicate, were suspended by means of glass hooks in 100 ml beakers containing 100 ml of various test solutions. After 24 hours of immersion, the specimens were taken out, washed in running water, dried and weighed. From the change in weights of the specimens, corrosion rates were calculated using the following relationship:

Corrosion rate = Loss in weight (mg) / surface area of the specimen (dm^2) * Period of immersion (days)

Corrosion inhibition efficiency (IE) was then calculated using the equation

$$IE = 100 [1 ---(W_2 / W_1)] \% .$$

Where W_1 = corrosion rate in the absence of inhibitor and

W_2 = corrosion rate in the presence of inhibitor.

Surface Analysis by FTIR spectroscopic study:

After the immersion period of 72 hours in various environments, the specimens were taken out of the test solutions and dried. The film formed on the surface was scratched carefully and it was thoroughly mixed so as to make it uniform throughout. FTIR spectrum of the power (KB_r pellet) was recorded using perkin -Elmer 1600 FTIR spectrophotometer with a resolving power of 4 cm^{-1}

Determination of Biocidal efficiency of the system:

Inhibitor – Zn^{2+} formulation that offered the best corrosive inhibition efficiency was selected. The Biocidal efficiency of SDS in the presence and absence of these formulations and also the effect of SDS on the corrosion inhibition efficiency of these systems were determined.

Various concentrations of SDS, viz 50 ppm, 100 ppm, 150 ppm, 200 ppm, 250 ppm, 300 ppm were added to the formulation consisting of the inhibitor system. Polished and degreased carbon steel specimens in duplicate were immersed in these environments for a period of 72 hours. After 72 hours one ml each of test solution from environments was pipetted out into sterile petri dishes containing about 20 ml of the sterilized Zobell medium kept in asterilized environment inside the laminar flow system fabricated and supplied by CEERI-pilani. The petri dishes were then kept for 48 hours. The total viable hetorpic bacterial colonies were counted using a bacterial colony counter.

RESULTS AND DISCUSSION

Table-V.1

Influence of on the IE of oxalic acid (OA)-Zn^{2+} system.

Corrosion rates of carbon steel in ground water in the presence and absence of the inhibitor and inhibiting efficiencies are obtained by the Mass-loss method.

Inhibition system : Zn^{2+} +OA+SDS.

S.NO	Zn^{2+}, ppm	OA, Ppm	SDS, ppm	CR, mdd	IE, %
1	0	0	0	27.22	-
2	50	0	0	15.75	42
3	0	50	0	10.38	62

isrjournals

International Journal of Advanced Research in Civil,Structural,Environmental and Infrastructure Engineering and Developing

Volume: 3 Issue: 1 Jul,2016,ISSN_NO: 2320-723X

4	50	50	0	2.81	90
5	50	50	50	4.21	85
6	50	50	100	3.19	88
7	50	50	150	2.01	93
8	50	50	200	1.43	95
9	50	50	250	3.64	87
10	50	50	300	7.09	74

Figure – V.1

Influence of SDS on the CR of carbon steel in the presence of OA-Zn^{2+}

$(Zn^{2+} 50\ ppm + OA\ 50\ ppm)$
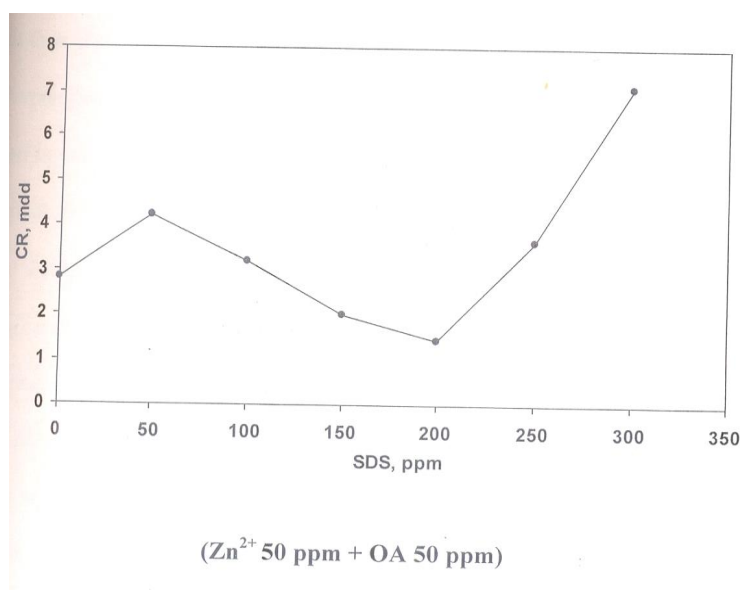
The IE of Zn^{2+}, OA and Zn^{2+}+OA and Zn^{2+}+OA and various concentration of SDS are presented in table V .1 CR as a function of the concentration of SDS are presented in Figure V .1. Table shows that 50 ppm of Zn^{2+} alone gives an IE of 42% and 50 ppm of OA gives an IE of 61.87%, but their combination exhibits 90% of IE. This clearly shows the existence of synergism between OA and Zn^{2+} in controlling the corrosion by carbon steel in ground water. The role of Zn is to carry the OA molecules from the bulk of the solution to the surface of the metal.

Addition of 50ppm of SDS lowers the IE of the inhibition system. This may due to the reaction between OA and SDS. However, further addition increases the IE and the IE reaches 95% at 200ppm of SDS beyond which the IE again decreases. The increase in IE with increase in consent of SDS may be due to the inhibiting property of SDS, which gives maximum IE near critical micelle concentration (CMC). Above CMC, however the number of monomers decrease due to micelle formation hence the IE decreases.

able-V.2

Influence of SDS on the IE of MA+Zn2+ system. Corrosion rates of the carbon steel in ground water in the presence and absence of the inhibitor and IE obtained by the mass-loss method.

Inhibition system : Zn^{2+} +MA+SDS.

S.NO	Zn^{2+}, ppm	MA, ppm	SDS, ppm	CR, ppm	IE, %

1	0	0	0	27.22	-
2	50	0	0	15.75	42
3	0	50	0	15.48	43
4	50	50	0	4.05	85
5	50	50	50	9.60	65
6	50	50	100	6.40	76
7	50	50	150	6.00	78
8	50	50	200	6.00	78
9	50	50	250	3.60	87
10	50	50	300	3.60	87

Figure – V.2   Influence of SDS on the CR of carbon steel in the presence of MA-Zn^{2+}·

The IE of Zn^{2+}, MA, Zn^{2+}+MA and Zn^{2+}+MA and various concentration of SDS are presented in table V .2 CR as a function of the concentration of SDS are presented in Figure V .2. Table V-2 shows that 50 ppm of Zn^{2+} alone gives an IE of 42% and 50 ppm of OA gives an IE of 43%, but their combination exhibits 85% of IE. This clearly shows the existence of synergism between MA and Zn^{2+} in controlling the corrosion by carbon steel in ground water. The role of Zn is to carry the MA molecules from the bulk of the solution to the surface of the metal.

Addition of 50ppm of SDS to MA + Zn^{2+} system reduces the IE from 85% to 65%. However, further addition increases the IE and at 300ppm of SDS, the IE of the formulation is found to be 87%. The decrease in IE on the addition of 50ppm of SDS may be due to the reaction between SDS and inhibitor formulation. However, further addition increases the IE. This may be due to the inhibiting property of SDS.

Table-V.3:   Influence of SDS on the IE of SA+Zn2+ system.

Corrosion rates of the carbon steel in ground water in the presence and absence of the inhibitor and IE obtained by the mass-loss method.

Inhibition system : Zn^{2+} +SA+SDS.

S.NO	Zn^{2+}, ppm	SA, ppm	SDS, ppm	CR, ppm	IE, %
1	0	0	0	27.22	-
2	50	0	0	15.75	42
3	0	50	0	14.66	46
4	50	50	0	3.76	86
5	50	50	50	2.41	91
6	50	50	100	2.35	91
7	50	50	150	2.26	92
8	50	50	200	1.20	96
9	50	50	250	0.79	97
10	50	50	300	0.93	97

Figure – V.3   Influence of SDS on the CR of carbon steel in the presence of SA-Zn^{2+}·

Influence of SDS on the CR of carbon steel in the presence of SA+Zn^{2+}·

(Zn^{2+} 50 ppm + SA 50 ppm)
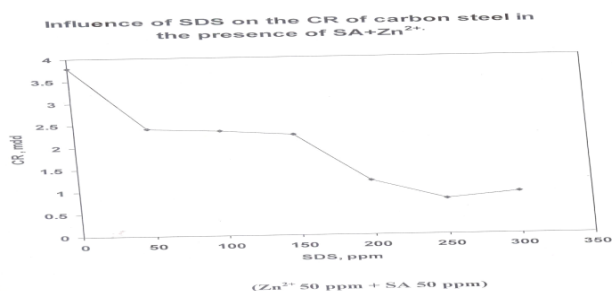
The IE of Zn^{2+}, SA, Zn^{2+}+SA and Zn^{2+}+SA and various concentration of SDS are presented in table V .3 CR as a function of the concentration of SDS are presented in Figure V .3. Table V-3 shows that 50 ppm of Zn^{2+} alone gives an IE of 42% and 50 ppm of SA gives an IE of 46%, but their combination exhibits 86% of IE. This clearly shows the existence of synergism between SA and Zn^{2+} in controlling the corrosion by carbon steel in ground water. The role of Zn is to carry the SA molecules from the bulk of the solution to the surface of the metal.

Addition of various concentrations of SDS to SA + Zn^{2+} system, exhances the IE at all concentrations of SDS. This shows that SDS behave synergistically with SA+, Zn^{2+} system.

Figure – V.4   Influence of SDS on the IE of GA+ Zn^{2}

Corrosion rates of the carbon steel in ground water in the presence and absence of the inhibitor and IE obtained by the mass-loss method

Inhibition system : Zn^{2+} +GA+SDS.

S.NO	Zn^{2+}, ppm	GA, ppm	SDS, ppm	CR, ppm	IE, %
1	0	0	0	27.22	-
2	50	0	0	15.75	42
3	0	50	0	13.31	51
4	50	50	0	3.51	87
5	50	50	50	8.57	69
6	50	50	100	8.13	70
7	50	50	150	7.77	71
8	50	50	200	6.97	74
9	50	50	250	6.17	77
10	50	50	300	8.90	67

Figure – V.4   Influence of SDS on the CR of carbon steel in the presence pf GA+ Zn^{2+}.

Influences of SDS on the CR of carbon steel in the presence of GA-Zn^{2+}
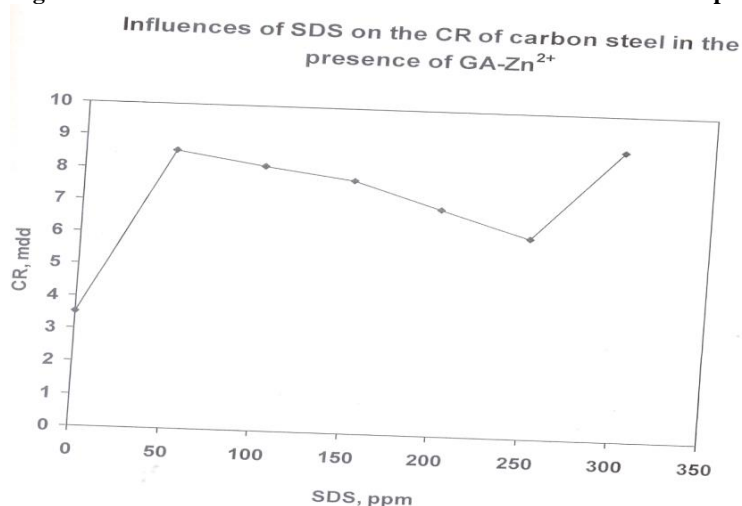
(Zn^{2+} 50 ppm + GA 50 ppm)

The IE of Zn^{2+}, GA, Zn^{2+}+GA and Zn^{2+}+GA and various concentration of SDS are presented in table V .4 CR as a function of the concentration of SDS are presented in Figure V .4. Table V-4 shows that 50 ppm of Zn^{2+} alone gives an IE of 42% and 50 ppm of GA gives an IE of 51%, but their combination exhibits 87% of IE. This clearly shows the existence of synergism between GA and Zn^{2+} in controlling the corrosion by carbon steel in ground water. The role of Zn is to carry the GA molecules from the bulk of the solution to the surface of the metal.

Addition of 50ppm of SDS to GA + Zn^{2+} system, reduces the IE from 87% to 69%. However, further addition increases the IE and the maximum value of 77% IE IS obtained for 250ppm of SDS. The decrease in IE may be due to the reaction between SDS and GA + Zn^{2+}.The increase in IE an further addition of SDS increases with increase in concentration of SDS.

Figure – V.5   Influence of SDS on the IE of AA+ Zn^{2+}system .

Corrosion rates of the carbon steel in ground water in the presence and absence of the inhibitor and IE obtained by the mass-loss method.
Inhibition system : Zn^{2+} +AA+SDS.

S.NO	Zn^{2+}, ppm	GA, Ppm	SDS, ppm	CR, ppm	IE, %
1	0	0	0	27.22	-
2	50	0	0	15.75	42
3	0	50	0	16.55	39
4	50	50	0	5.93	78
5	50	50	50	9.37	66
6	50	50	100	8.57	69
7	50	50	150	8.11	70
8	50	50	200	6.97	74
9	50	50	250	6.57	76
10	50	50	300	7.37	73

Figure – V.5   Influence of SDS on the CR of carbon steel in the presence of aA-Zn^{2+}·

Influence of SDS on the CR of carbon steel in the presence of AA-Zn^{2+}

(Zn^{2+} 50 ppm + AA 50 ppm)
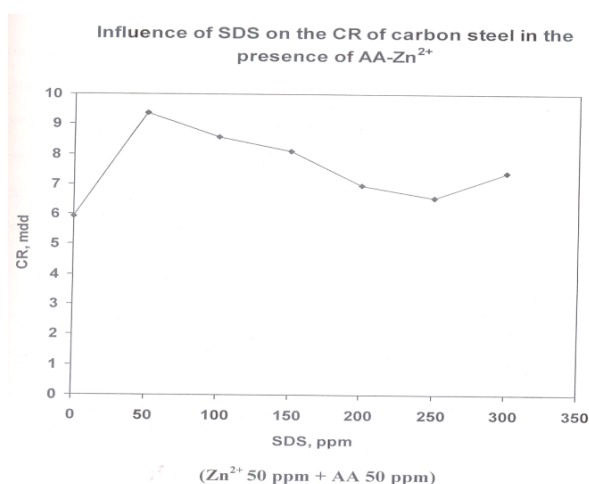
The IE of Zn^{2+} , AA, Zn^{2+}+AA and Zn^{2+}+AA and various concentration of SDS are presented in table V .5 CR as a function of the concentration of SDS are presented in Figure V .5. Table V-5 shows that 50 ppm of Zn^{2+} alone gives an IE of 42% and 50 ppm of AA gives an IE of 39%, but their combination exhibits 78% of IE. This clearly

shows the existence of synergism between AA and Zn^{2+} in controlling the corrosion by carbon steel in ground water. The role of Zn is to carry the AA molecules from the bulk of the solution to the surface of the metal.

Addition of 50ppm of SDS to AA + Zn^{2+} system, reduces the IE from 78% to 66%. However, further addition increases the IE and the maximum value of 76% IE is obtained for 250ppm of SDS. The decrease in IE may be due to the reaction between SDS and AA + Zn^{2+} .The increase in IE an further addition of SDS inhibiting property of SDS with increases with in concentration of SDS. The FTIR spectra of the thin film formed on the surface of the metal after immersing the specimens in ground water containing the inhibitor formulation, 1.50 ppm of Zn^{2+} , 50 ppm of OA, 200ppm of SDS.

FTIR spectrum of 50 ppm Zn^{2+} , 50ppm OA, 150 ppm SDS.

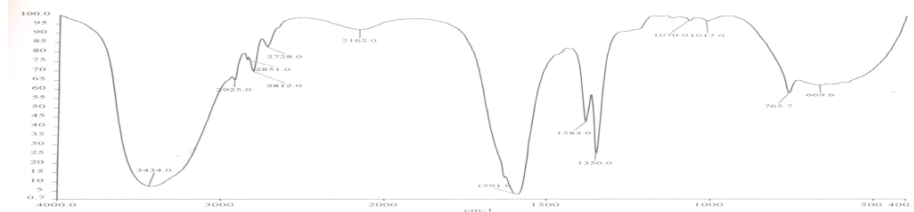
FTIR spectrum of 50 ppm Zn^{2+}, 50 ppm OA, 150 ppm SDS.
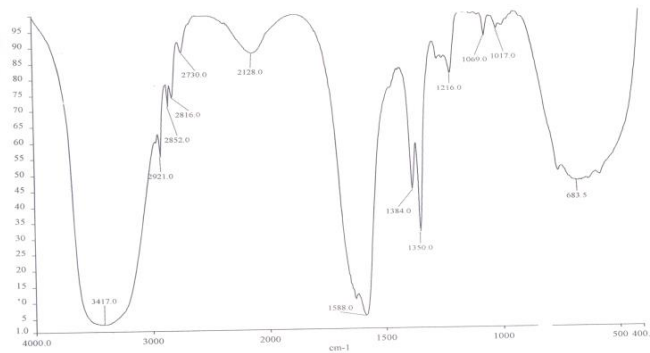
The peak at 3417 cm^{-1} is due to –OH symmetrical stretching. The peaks around 2800 cm^{-1} are due to C-H stretching. The peak at 2128 cm^{-1} is due to CO_2 stretching. The C=O stretching frequency occurs at 1588 cm^{-1}. The in-plane bending vibration of the –COOH group occurs at 1384 cm^{-1} and the peak at 1350 cm^{-1} is due to the in-plane bending vibration of the   –OH group attached to zinc ions. The peak at 1216 cm^{-1} ,1069 cm^{-1} and 1017 cm^{-1} are due to the S=O stretching in the SDS. The peak at 683 cm^{-1} due to MO stretching. This clearly shows the presence of OA,SDS and Zinc hydroxide on the metal surface. This shows the possibility of the formation of complexes with the metal ion.

The FTIR spectra of the thin film formed on the surface of the metal after immersing the specimens in ground water containing the inhibitor formulation, 2.50 ppm of **Zn^{2+}**,50 ppm of MA, 250ppm of SDS for three days are given in Figure -V.7

FTIR spectrum of 50 ppm Zn^{2+} , 50 ppm MA , 250 ppm SDS.

FTIR spectrum of 50 ppm Zn^{2+}, 50 ppm MA, 250 ppm SDS.

The peak at 3434 cm^{-1} is due to –OH symmetrical stretching. The peaks around 2800 cm^{-1} are due to C-H stretching. The peak at 2162 cm^{-1} is due to CO_2 stretching. The C=O stretching frequency occurs at 1591 cm^{-1}. The in-plane bending vibration of the –COOH group occurs at 1384 cm^{-1} and the peak at 1350 cm^{-1} is due to the in-plane bending vibration of the -OH group attached to zinc ions. The peak at 1070 cm^{-1} and 1017 cm^{-1} are due to the S=O stretching in the SDS. The group of peaks at 765 cm^{-1} and 669 cm^{-1} are due to MO bond. This shows the possibility of the formation of complexes with the metal ion. The FTIR spectra of the thin film formed on the surface of the metal after immersing the specimens in ground water containing the inhibitor formulation, 3. 50 ppm of Zn^{2+}, 50 ppm of SA, 250 ppm of SDS for three days are given in figure – V.8

FTIR spectrum of 50 ppm Zn^{2+} , 50 ppm SA, 250 ppm SDS

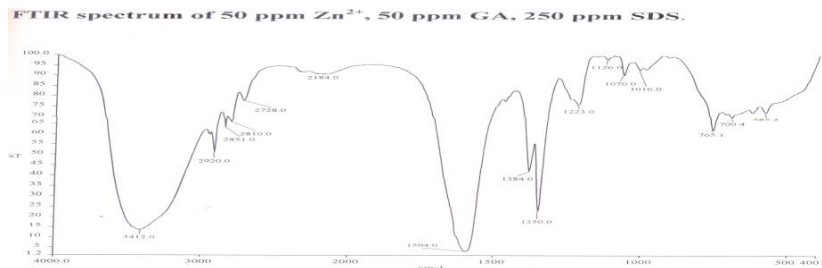FTIR spectrum of 50 ppm Zn^{2+}, 50 ppm SA, 250 ppm SDS
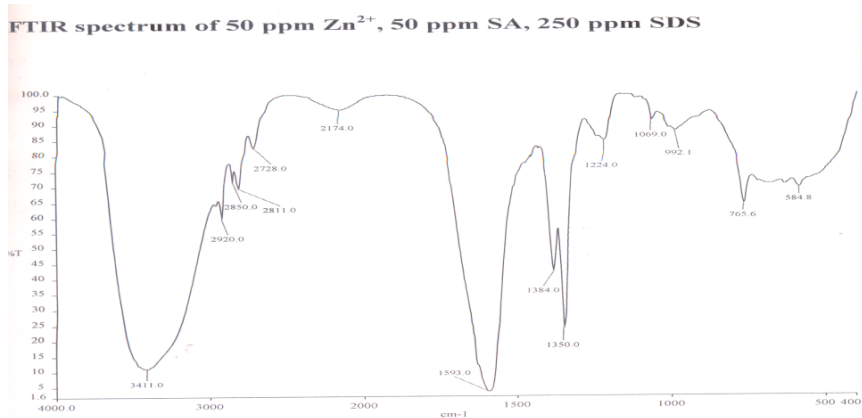
The peak at 3411 cm^{-1} is due to –OH symmetrical stretching. The peaks around 2800 cm^{-1} are due to C-H stretching. The peak at 2174 cm^{-1} is due to CO_2 stretching. The C=O stretching frequency occurs at 1593 cm^{-1}. The in-plane bending vibration of the –COOH group occurs at 1384 cm^{-1} and the peak at 1350 cm^{-1} is due to the in-plane bending vibration of the -OH group attached to zinc ions. The peak at 1224 cm^{-1} and 1069 cm^{-1} and 992 cm^{-1} are due to the S=O stretching in the SDS. The group of peaks at 765 cm^{-1} and 584 cm^{-1} are due to MO stretching . This clearly shows the presence of SA, SDS and Zinc hydroxide on the metal surface. This shows the possibility of the formation of complexes with the metal ion.

The FTIR spectra of the thin film formed on the surface of the metal after immersing the specimens in ground water containing the inhibitor formulation,
4. 50 ppm of Zn^{2+}, 50 ppm of GA, 250 ppm of SDS for three days are given in figure – V.9

**FTIR spectrum of 50 ppm Zn^{2+} , 50 ppm GA, 250 ppm SDS.**

FTIR spectrum of 50 ppm Zn^{2+}, 50 ppm GA, 250 ppm SDS.

The peak at 3412 cm^{-1} is due to –OH symmetrical stretching. The peaks around 2800 cm^{-1} are due to C-H stretching. The peak at 2184 cm^{-1} is due to CO_2 stretching. The C=O stretching frequency occurs at 1594 cm^{-1}. The in-plane bending vibration of the –COOH group occurs at 1384 cm^{-1} and the peak at 1350 cm^{-1} is

---

due to the in-plane bending vibration of the   -OH group attached to zinc ions. The peak at 1223 cm^{-1} , 1126 cm^{-1} ,   1070 cm^{-1} and 1016 cm^{-1} are due to the S=O stretching in the SDS. The group of peaks around   765 cm^{-1} 700 cm^{-1} and 585 cm^{-1} are due to MO stretching . This clearly shows the presence of GA, SDS and Zinc hydroxide on the metal surface. This shows the possibility of the formation of complexes with the metal ion.   The FTIR spectra of the thin film formed on the surface of the metal after immersing the specimens in ground water containing the inhibitor formulation, 5. 50 ppm of Zn^{2+}, 50 ppm of AA, 250 ppm of SDS for three days are given in figure – V.10

FTIR spectrum of 50 ppm $Zn^{2+,}$ 50 ppm AA, 250 ppm SDS.

FTIR spectrum of 50 ppm Zn^{2+}, 50 ppm AA, 250 ppm SDS.
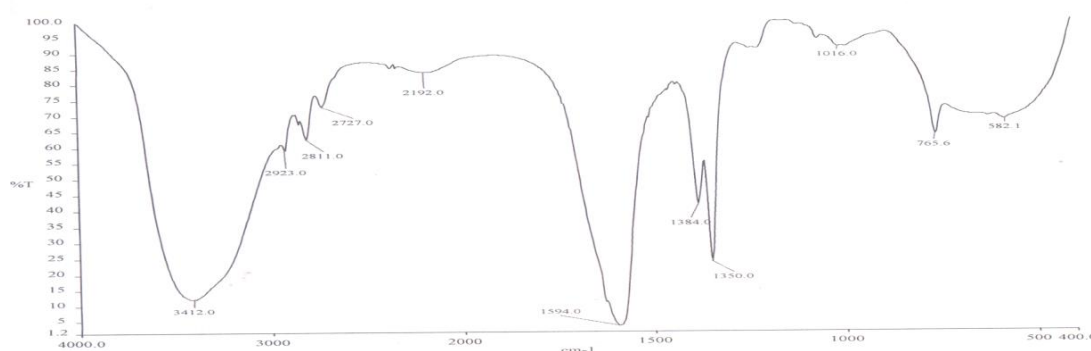
The peak at 3412 cm^{-1} is due to –OH symmetrical stretching. The peaks around 2800 cm^{-1} are due to C-H stretching. The peak at 2192 cm^{-1} is due to CO_2 stretching. The C=O stretching frequency occurs at 1594 cm^{-1}. The in-plane bending vibration of the –COOH group occurs at 1384 cm^{-1} and the peak at 1350 cm^{-1} is due to the in-plane bending vibration of the -OH group attached to zinc ions. The peak at 1016 cm^{-1} 1126 cm^{-1} is due to the S=O stretching in the SDS. The group of peaks around   600 cm^{-1} and 582 cm^{-1} are due to MO stretching . This clearly shows the presence of AA, SDS and Zinc hydroxide on the metal surface. This shows the possibility of the formation of complexes with the metal ion.

Table – V.6 Biocidal efficiencies of SDS in the presence and absence of OA- Zn^{2+} system in ground water.

S.NO	Zn^{2+}, ppm	OA, Ppm	SDS, ppm	Colony forming min/ml	Biocidal efficiencies %
1	0	0	0	962	-
2	0	0	10	873	9.25
3	0	0	50	83	91.37
4	0	0	100	3	99.68
5	0	0	150	0	100
6	50	50	0	4	99.58
7	50	50	50	140	85.44
8	50	50	100	21	97.81
9	50	50	150	2	99.79
10	50	50	200	0	100

The biocidal efficiency of SDS in the presence and absence of OA- Zn^{2+} formulation in ground water after suspending the metal pieces for 72 hours presented in table-V.6

Biocidal efficiency as a function of the concentration of SDS are presented in   Figure V.11
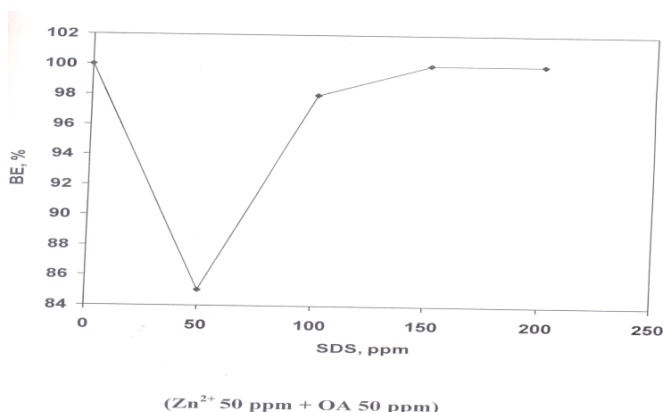
$(Zn^{2+}$ 50 ppm + OA 50 ppm)
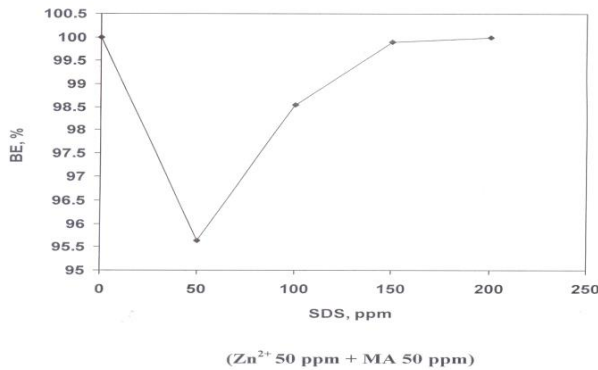
$(Zn^{2+}$ 50 ppm +OA 50 ppm)

150 ppm of SDS is required to completely eradicate the bacterial activity in ground water in which the carbon steel specimens were immersed for 3 days. However, a slight higher concentration of SDS(200 ppm) is required to control the bacterial activity. This again enhances the fact that the reaction between SDS and OA- Zn^{2+} system. Hence a combination of 50 ppm of Zn^{2+} , 50 ppm of OA, 200 ppm of SDS offers 100% BE and 95% of IE.

Table – V.7   Biocidal efficiencies of SDS in the presence and absence of MA- Zn^{2+} system in ground water.

S.NO	Zn^{2+}, ppm	MA, Ppm	SDS, ppm	Colony forming min/ml	Biocidal efficiencies %
1	0	0	0	962	-
2	0	0	10	873	9.25
3	0	0	50	83	91.37
4	0	0	100	3	99.68
5	0	0	150	0	100
6	50	50	0	6	99.37
7	50	50	50	42	95.63
8	50	50	100	14	98.54
9	50	50	150	1	99.89
10	50	50	200	0	100

The biocidal efficiency of SDS in the presence and absence of MA- Zn^{2+} formulation in ground water after suspending the metal pieces for 72 hours presented in table-V.7

Biocidal efficiency as a function of the concentration of SDS are presented in   Figure V.12
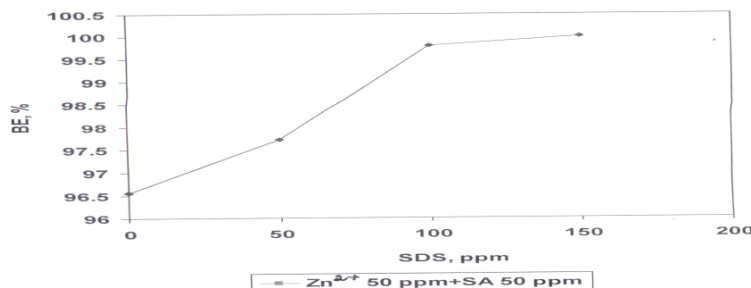
(Zn^{2+} 50 ppm +MA 50 ppm)

150 ppm of SDS is required to completely eradicate the bacterial activity in ground water in which the carbon steel specimens were immersed for 3 days. However, a slight higher concentration of SDS (200 ppm) is required to control the bacterial activity. This again enhances the fact that the reaction between SDS and MA- Zn^{2+} system. Hence a combination of 50 ppm of Zn^{2+}, 50 ppm of ,MA, 200 ppm of SDS offers 100% BE and 78% of IE.

Table – V.8 Biocidal efficiencies of SDS in the presence and absence of SA- Zn^{2+} system in ground water.

S.NO	Zn^{2+}, ppm	SA, Ppm	SDS, ppm	Colony forming min/ml	Biocidal efficiencies %
1	0	0	0	962	-
2	0	0	10	873	9.25
3	0	0	50	83	91.37
4	0	0	100	3	99.68
5	0	0	150	0	100
6	50	50	0	33	96.56
7	50	50	50	22	97.71
8	50	50	100	2	99.79
9	50	50	150	0	100

The biocidal efficiency of SDS in the presence and absence of SA- Zn^{2+} formulation in ground water after suspending the metal pieces for 72 hours presented in table-V.8

Biocidal efficiency as a function of the concentration of SDS are presented in   Figure V.13
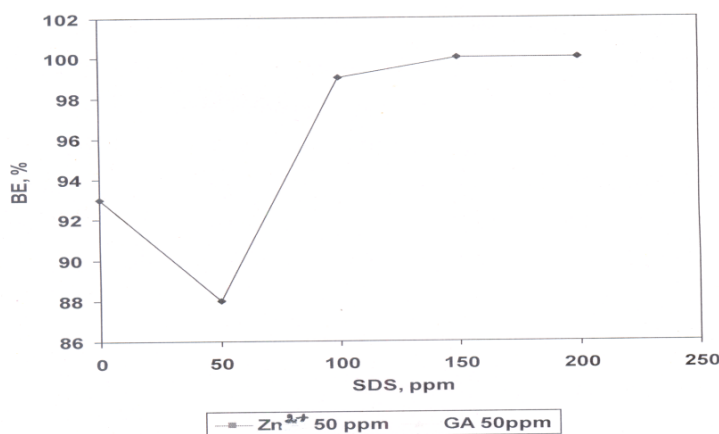

(Zn^{2+} 50 ppm +SA 50 ppm)

Both SA and SDS complement each other in controlling the bacterial growth which is evident from the fact that 50 ppm of SDS alone gives BE of 97.71% and 50 ppm   SA- Zn^{2+} system gives the BE of 96.57% but on adding 50 ppm of SDS to the above mention system gives 97.7% of BE. It is noted from the table- V.8. 150 ppm of SDS is required to eradicate the microbes that are present in ground water in the presence of SA-- Zn^{2+} system . so the combination of 50 ppm of Zn^{2+} ,50 ppm of SA, 150 ppm of SDS offers 100% of BE and 92% of IE .

 Table – V.9   Biocidal efficiencies of SDS in the presence and absence of GA- Zn^{2+} system in ground water.

S.NO	Zn^{2+}, ppm	MA, Ppm	SDS, ppm	Colony forming min/ml	Biocidal efficiencies %
1	0	0	0	962	-
2	0	0	10	873	9.25
3	0	0	50	83	91.37
4	0	0	100	3	99.68
5	0	0	150	0	100
6	50	50	0	69	92.82
7	50	50	50	119	87.62
8	50	50	100	10	98.96
9	50	50	150	2	99.79
10	50	50	200	0	100

The biocidal efficiency of SDS in the presence and absence of GA- Zn^{2+} formulation in ground water after suspending the metal pieces for 72 hours presented in table-V.9

Biocidal efficiency as a function of the concentration of SDS are presented in Figure V.**14**

(Zn^{2+} 50 ppm +GA 50 ppm)

150 ppm of SDS is required to completely eradicate the bacterial activity in ground water in which the carbon steel specimens were immersed for 3 days. However ,a slight higher concentration of SDS(200 ppm) is required to control the bacterial activity. This again enhances the fact that the reaction between SDS and GA- Zn^{2+} system.

Hence a combination of 50 ppm of Zn^{2+}, 50 ppm of ,GA, 200 ppm of SDS offers 100% BE and 74% of IE.

Table – V.10

Biocidal efficiencies of SDS in the presence and absence of AA- Zn^{2+} system in ground water.

S.NO	Zn^{2+}, ppm	AA, Ppm	SDS, ppm	Colony forming min/ml	Biocidal efficiencies %
1	0	0	0	962	-
2	0	0	10	873	9.25
3	0	0	50	83	91.37
4	0	0	100	3	99.68
5	0	0	150	0	100
6	50	50	0	12	98.75
7	50	50	50	108	88.77
8	50	50	100	29	98.98
9	50	50	150	3	99.68
10	50	50	200	0	100

The biocidal efficiency of SDS in the presence and absence of AA- Zn^{2+} formulation in ground water after suspending the metal pieces for 72 hours presented in table-V.10.

Biocidal efficiencies as a function of the concentration of SDS are presented in Figure V.15
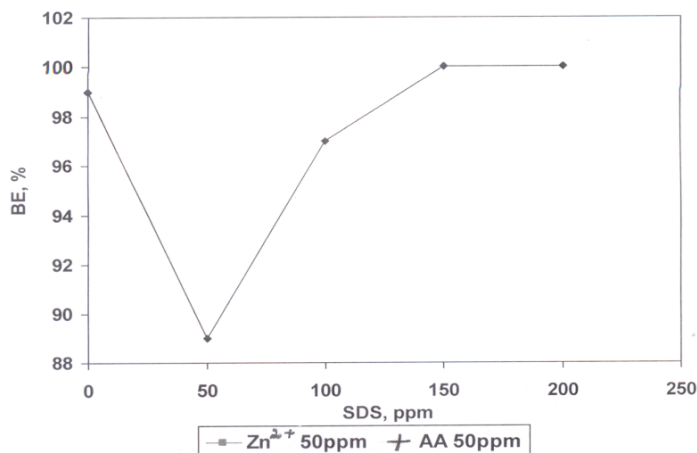
(Zn^{2+} 50 ppm +AA 50 ppm)

150 ppm of SDS is required to completely eradicate the bacterial activity in ground water in which the carbon steel specimens were immersed for 3 days. However ,a slight higher concentration of SDS(200 ppm) is required to control the bacterial activity. This again enhances the fact that the reaction between SDS and AA- Zn^{2+} system.

Hence a combination of 50 ppm of Zn^{2+} , 50 ppm of ,GA, 200 ppm of SDS offers 100% BE and 74% of IE.

CONCLUSION

1. OA and Zn^{2+} mutually enhance the IE of each other in controlling the corrosion of carbon steel in ground water .

- Addition of lower concentration of SDS exhibits antagonistic effect with OA- Zn^{2+} system. However , higher concentration of SDS behaves synergistically with OA - Zn^{2+} system. A combination of 50 ppm of Zn^{2+} , 50ppm of OA and 200 ppm of SDS shows a maximum IE of 95% for carbon steel in ground water.
- FTIR spectrum shows the presence of OA, SDS and Zinc hydroxide on the metal surface. This shows the formation of a film containing the complexes of SDS with iron.
- 150 ppm of SDS is required to completely arrest the growth of microbes in ground water in which the metal pieces were suspended for 3 days in the absence of OA - Zn^{2+} system .
- However, in the presence of OA - Zn^{2+} system 200 ppm of SDS is needed to control the bacterial activity. A combination of 50 ppm of Zn^{2+} , 50 ppm of OA and 200 ppm of SDS offers 100% BE and 95% IE.

2. MA and Zn^{2+} mutually enhances the IE of each other in controlling the corrosion of carbon steel in ground water.

- Addition of lower concentration of SDS exhibits antagonistic effect with MA- Zn^{2+} system. However , higher concentration of SDS behaves synergistically with MA - Zn^{2+} system. A combination of 50 ppm of Zn^{2+} , 50ppm of MA and 250 ppm of SDS shows a maximum IE of 95% for carbo steel in ground water.
- The FTIR spectrum shows the presence of MA, SDS and Zinc hydroxide on the metal surface. This shows the formation of a film containing the complexes of SDS with iron.
- 150 ppm of SDS is required to completely arrest the growth of microbes in ground water in which the metal pieces were suspended for 3 days in the absence of MA - Zn^{2+} system .
- However, in the presence of MA - Zn^{2+} system 200 ppm of SDS is needed to control the bacterial activity. A combination of 50 ppm of Zn^{2+} , 50 ppm of MA and 200 ppm of SDS offers 100% BE and 78% IE.

3. SA and Zn^{2+} mutually enhances the IE of each other in controlling the corrosion of carbon steel in ground water.

- Addition of lower concentration of SDS exhibits antagonistic effect with SA- Zn^{2+} system. However , higher concentration of SDS behaves synergistically with SA - Zn^{2+} system. A combination of 50 ppm of Zn^{2+} , 50ppm of SA and 250 ppm of SDS shows a maximum IE of 97% for carbon steel in ground water.
- The FTIR spectrum shows the presence of SA, SDS and Zinc hydroxide on the metal surface. This shows the formation of a film containing the complexes of SDS with iron.
- 150 ppm of SDS is required to completely arrest the growth of microbes in ground water in which the metal pieces were suspended for 3 days in the absence of SA - Zn^{2+} system .
- However, in the presence of SA - Zn^{2+} system 150 ppm of SDS is needed to control the bacterial activity. A combination of 50 ppm of Zn^{2+} , 50 ppm of SA and 150 ppm of SDS offers 100% BE and 92% IE.

4. GA and Zn^{2+} mutually enhances the IE of each other in controlling the corrosion of carbon steel in ground water.

- Addition of lower concentration of SDS exhibits antagonistic effect with GA- Zn^{2+} system. However , higher concentration of SDS behaves synergistically with GA - Zn^{2+} system. A combination of 50 ppm of Zn^{2+} , 50ppm of GA and 250 ppm of SDS shows a maximum IE of 77% for carbon steel in ground water.
- The FTIR spectrum shows the presence of GA, SDS and Zinc hydroxide on the metal surface. This shows the formation of a film containing the complexes of SDS with iron.
- 150 ppm of SDS is required to completely arrest the growth of microbes in ground water in which the metal pieces were suspended for 3 days in the absence of GA - Zn^{2+} system .
- However, in the presence of GA - Zn^{2+} system 200 ppm of SDS is needed to control the bacterial activity. A combination of 50 ppm of Zn^{2+} , 50 ppm of GA and 200 ppm of SDS offers 100% BE and 74% IE.

5.   AA and Zn^{2+} mutually enhances the IE of each other in controlling the corrosion of carbon steel in ground water.

- Addition of lower concentration of SDS exhibits antagonistic effect with AA- Zn^{2+} system. However , higher concentration of SDS behaves synergistically with AA - Zn^{2+} system. A combination of 50 ppm of Zn^{2+} , 50ppm of AA and 250 ppm of SDS shows a maximum IE of 76% for carbon steel in ground water.
- The FTIR spectrum shows the presence of AA, SDS and Zinc hydroxide on the metal surface. This shows the formation of a film containing the complexes of SDS with iron.
- 150 ppm of SDS is required to completely arrest the growth of microbes in ground water in which the metal pieces were suspended for 3 days in the absence of AA - Zn^{2+} system .
- However, in the presence of AA - Zn^{2+} system 200 ppm of SDS is needed to control the bacterial activity. A combination of 50 ppm of Zn^{2+} , 50 ppm of AA and 200 ppm of SDS offers 100% BE and 74% IE.

REFERENCES:

1.   Ahmed A. Al-Amiery , Abdul Amir H. Kadhum , Abdulhadi Kadihum , Abu Bakar Mohamad , Chong K. How and Sutiana Junaedi " Inhibition of Mild Steel Corrosion in Sulfuric Acid Solution by New Schiff Base " *Materials* 2014, *7*, 787-804

2.   M Jebastin Sonia Jas, K Margandan, R Ramesh, G Marimuthu "Ruthenium(II) Chiral Schiff Base Complexes" International Journal of Advanced Chemical Science and Applications 2 (4), 10-15

3.   P. C. Okafor And S. Nesic "Effect of Acetic Acid on CO2 Corrosion of Carbon Steel in Vapor-Water Two-Phase Horizontal Flow" Chem. Eng. Comm., 194:141–157, 2007

4.   Ashish Kumar Singh , Sudhish Kumar Shukla , M. A. Quraishi "Corrosion Behaviour of Mild Steel in Sulphuric Acid Solution in Presence of Ceftazidime" Int. J. Electrochem. Sci., 6 (2011) 5802 – 5814

5.   Sadeq Hooshmand Zaferani[1]* and Mohammad Reza Shishesaz[2] "Corrosion Inhibition of Carbon Steel in Acidic Solution by Alizarin Yellow GG (AYGG)" J Pet Environ Biotechnol 2014, 5

6.   M. Allaoui , A.Cheriti , N. Gherraf ,*, E. Chebouat , B. Dadamoussa, R. Salhi "Inhibition of Mild Steel Corrosion in 1M HCl Medium by Acid Extract of Haloxylon scoparium Pomel" Int. J. Electrochem. Sci., 8 (2013) 9429 – 9434

7.   Biljana S. Maluckov " Corrosion Of Steels Induced By Microorganisms ""Association of Metallurgical Engineers of Serbia AMES Review paper UDC: 620.193.47:669.14

8.   E.J. Akpabio, E.J. Ekott and M.E. Akpan "Inhibition and Control of Microbiologically Influenced Corrosion in Oilfield Materials" Environmental Research Journal Year: 2011 | Volume: 5 | Issue: 2 | Page No.: 59-65

9.   Aruliah Rajasekar, Sundaram Maruthamuthu, Narayanan Palaniswamy, Annamalai Rajendran "Biodegradation of corrosion inhibitors and their influence on petroleum product pipeline" Microbiological Research Volume 162, Issue 4, 26 September 2007, Pages 355–368.

10.   M. Jebastin Sonia Jas , K. Margandan , S. Parameswari " Studies on in Situ Generation of Chromium(IV) and its Involvement in the Kinetics of Oxidation of L-methionine in Aqueous Medium "International Journal of ChemTech Vol.8, No.12 pp 687-701, 2015

11.   Dong-Jin Choi, Seung-Jae You, Jung-Gu Kim "Development of an environmentally safe corrosion, scale, and microorganism inhibitor for open recirculating cooling systems" Materials Science and Engineering: A Volume 335, Issues 1–2, 25 September 2002, Pages 228–235

12.   Hector A. Videla[a], Liz Karen Herrera[b] "Understanding microbial inhibition of corrosion" International Biodeterioration & Biodegradation Volume 63, Issue 7, October 2009, Pages 896–900