Chapter VI

Summary & Conclusion
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Corrosion is the gradual destruction of metals by chemical or electrochemical reaction with its environment. It degrades the useful properties of metals like appearance, strength and rigidity, etc. It causes severe damages in cooling water system, petroleum refineries and high pressure boilers, etc. The corrosion is much extensive in marine environment due to the presence of high chloride ion. Among the various available methods to control corrosion, the use of inhibitor is one of the methods. It has been known that corrosion inhibitor is a chemical compound which is added to the corrosive environment at an optimum concentration, decreases the corrosion rate of metals by forming a protective layer.

In the present study the following compounds were studied as corrosion inhibitors: Ethylenediaminetetraacetic acid (EDTA), Thiourea (TU), Urea (U), Succinic acid (SA) and Oxalic acid (OA). The synergistic effect of EDTA / TU / U / SA / OA with Zn$^{2+}$ on the inhibition of corrosion of carbon steel in sea water collected from Bay of Bengal at Marina Beach which is located at Chennai, Tamil Nadu, India has been evaluated. In addition the influence of biocides such as N-cetyl-N, N, N-trimethylammonium bromide (CTAB) and sodium dodecylsulphate (SDS) has been studied.

The mechanistic aspects of corrosion inhibition has been explained on the basis of the results obtained from the studies such as weight loss study, potentiodynamic polarization study, AC impedance spectra and surface characterization studies such as FTIR spectra, SEM and AFM.

EDTA – Zn$^{2+}$ system

The results of weight loss study show that the formulation consists of 250 ppm of EDTA and 50 ppm of Zn$^{2+}$ has 96% corrosion inhibition efficiency (IE), in controlling corrosion of carbon steel in sea water. A synergistic effect exists between EDTA and Zn$^{2+}$. Polarization study reveals that the formulation functions as a cathodic inhibitor. AC impedance spectra reveal that the formation of protective film
on the metal surface. FTIR spectra reveal that the protective film consists of Fe$^{2+}$ - EDTA complex and Zn(OH)$_2$. The SEM micrographs and AFM images confirm that the formation of protective layer on the metal surface. The effective synergistic formulation consists of 250 ppm of EDTA, 50 ppm of Zn$^{2+}$ and 50 ppm of CTAB show IE 98% and 100 % biocidal efficiency (BE). Also the effective synergistic formulation consists of 250 ppm of EDTA, 50 ppm of Zn$^{2+}$ and 50 ppm of SDS show IE 97% and 100 % BE.

Thiourea (TU) – Zn$^{2+}$ system

The results of weight loss study show that the formulation consists of 200 ppm of TU and 50 ppm of Zn$^{2+}$ has 95% IE, in controlling corrosion of carbon steel in sea water. A synergistic effect exists between TU and Zn$^{2+}$. Polarization study reveals that the formulation functions as a cathodic inhibitor. AC impedance spectra reveal that the formation of protective film on the metal surface. FTIR spectra reveal that the protective film consists of Fe$^{2+}$ - TU complex and Zn(OH)$_2$. The SEM micrographs and AFM images confirm that the formation of protective layer on the metal surface. The effective synergistic formulation consists of 200 ppm of TU, 50 ppm of Zn$^{2+}$ and 100 ppm of CTAB show IE 97% and 100% BE. Also the effective synergistic formulation consists of 200 ppm of TU, 50 ppm of Zn$^{2+}$ and 100 ppm of SDS show IE 96% and 100% BE.

Urea (U) – Zn$^{2+}$ system

The results of weight loss study show that the formulation consists of 250 ppm of urea and 50 ppm of Zn$^{2+}$ has 94% IE, in controlling corrosion of carbon steel in sea water. A synergistic effect exists between Urea and Zn$^{2+}$. Polarization study reveals that the formulation functions as a cathodic inhibitor. AC impedance spectra reveal that the formation of protective film on the metal surface. FTIR spectra reveal that the protective film consists of Fe$^{2+}$ - Urea complex and Zn(OH)$_2$. The SEM micrographs and AFM images confirm that the formation of protective layer on the metal surface. The effective synergistic formulation consists of 250 ppm of urea, 50 ppm of Zn$^{2+}$ and 50 ppm of CTAB show IE 96% and 100% BE. Also the effective synergistic formulation consists of 250 ppm of urea, 50 ppm of Zn$^{2+}$ and 50 ppm of SDS show IE 90% and 100% BE.
**Succinic acid (SA) – Zn²⁺ system**

The results of weight loss study show that the formulation consists of 250 ppm of SA and 50 ppm of Zn²⁺ has 93% IE, in controlling corrosion of carbon steel in seawater. A synergistic effect exists between SA and Zn²⁺. Polarization study reveals that the formulation functions as a cathodic inhibitor. AC impedance spectra reveal that the formation of protective film on the metal surface. FTIR spectra reveal that the protective film consists of Fe²⁺ - SA complex and Zn(OH)₂. The SEM micrographs and AFM images confirm that the formation of protective layer on the metal surface. The effective synergistic formulation consists of 250 ppm of SA, 50 ppm of Zn²⁺ and 50 ppm of CTAB show IE 94% and 100% BE. Also the synergistic formulation consists of 250 ppm of SA, 50 ppm of Zn²⁺ and 50 ppm of SDS is found to show IE 90% and 100% BE.

**Oxalic acid (OA) – Zn²⁺ system**

The results of weight loss study show that the formulation consists of 250 ppm of SA and 50 ppm of Zn²⁺ has 89% IE, in controlling corrosion of carbon steel in seawater. A synergistic effect exists between OA and Zn²⁺. Polarization study reveals that the formulation functions as a cathodic inhibitor. AC impedance spectra reveal that the formation of protective film on the metal surface. FTIR spectra reveal that the protective film consists of Fe²⁺ - OA complex and Zn(OH)₂. The SEM micrographs and AFM images confirm that the formation of protective layer on the metal surface. The effective synergistic formulation consists of 250 ppm of OA, 50 ppm of Zn²⁺ and 100 ppm of CTAB has IE 92% and 100% BE. Also the effective synergistic formulation consists of 250 ppm of OA, 50 ppm of Zn²⁺ and 50 ppm of SDS is found to show IE 90% and 100% BE.
The present study leads to the following conclusions.

- All the five inhibitors exhibit synergism with Zn$^{2+}$ ion at specific concentration in the inhibition of corrosion of carbon steel in sea water.

- The order of IE of the inhibitors used in the study as follows: EDTA > TU > U > SA > OA

- The order of IE of the carboxylic acids in the study as follows: EDTA > SA > OA

- The order of IE of amides used in the study as follows: TU > U

- All the inhibitor formulations are effective in neutral aqueous medium and also in slight basic medium.

- The stability of the film formed on the surface of the carbon steel immersed in sea water in the presence of synergistic inhibitors decreases, as the immersion period increases.

- As the pH of the medium increases, inhibition efficiency increases.

- The synergism parameter ($S_i$) and F-Test (ANOVA) confirm the existence of synergistic effect between inhibitor and Zn$^{2+}$ ion.

- Polarization study reveals that the inhibitor – Zn$^{2+}$ system controls cathodic reaction predominantly and to some extent the anodic reaction.

- AC impedance spectra reveals that the formation of protective film on the metal surface.
• FTIR spectra reveal that the protective film formed on the metal surface consists of Fe$^{2+}$-inhibitor complex and Zn(OH)$_2$.

• The SEM micrographs and AFM images confirm the formation of protective layer on the metal surface.

• The IE and BE of the biocides such as CTAB and SDS for all the effective synergistic inhibitor – Zn$^{2+}$ system has been studied.

• The addition of CTAB to the inhibitor – Zn$^{2+}$ system enhances the IE at lower concentration, but decreases at higher concentration.

• The IE of CTAB with various inhibitor in presence of Zn$^{2+}$ is in the order of EDTA > TU > U > SA > OA.

• The addition of SDS to the inhibitor – Zn$^{2+}$ system enhances the IE at lower concentration, but decreases at higher concentration in the case of EDTA, TU and SA, whereas the IE decreases in the case of Urea and OA at all concentrations of SDS.

• The IE of SDS with various inhibitor in presence of Zn$^{2+}$ is in the order of EDTA > TU > U = SA = OA.

• Based on the weight loss study, electrochemical studies and surface characterization studies, a suitable mechanism has been proposed for the corrosion control of all the efficient inhibitor and Zn$^{2+}$ systems.
SCOPE FOR FURTHER STUDY

- The corrosion inhibition efficiency (IE) of carbon steel immersed in synthetic sea water may be evaluated.

- The IE of carbon steel in sea water may be studied using derivatives of EDTA, TU, Urea, SA and OA as inhibitors.

- The IE and BE of carbon steel in sea water may be studied using biocides such as N-cetyl pyridinium chloride (CPC), Dodecylguanidine hydrochloride (DGH), derivatives of CTAB and SDS, etc.

- The IE of carbon steel in sea water collected from Bay of Bengal at Marina Beach which is located at Chennai, Tamil Nadu, India, may be studied at different temperature and thermodynamic conditions.

- The duration of the stability of the protective film formed on the carbon steel surface can be increased with further synergism.

- The structural elucidation of the Fe$^{2+}$ - inhibitor complex formed on the metal surface may be studied.

- The Fe$^{2+}$ - inhibitor complex formed on the metal surface may be characterized by ESCA, TEM and EDAX.

- The nature of adsorption of inhibitor molecules on the carbon steel surface may be studied.

- The IE of inhibitors may be evaluated in combination with other synergistic such as Mg$^{2+}$, Ca$^{2+}$, Mn$^{2+}$, Ba$^{2+}$, polymers and composites, etc.

- The specific roughness properties of AFM images may be investigated in detail through spectral roughness analysis.
Publications & Conferences
RESEARCH PUBLICATIONS:

International:


15. N. Manimaran, S. Rajendran, M. Manivannan and R. Saranya, “Inhibitive action of polyvinyl alcohol – Zn(II) system in corrosion inhibition of


National:


Conference Proceedings:

CONFERENCES / SEMINARS / WORKSHOPS PRESENTED:

International:


National:

1. **M. Manivannan** and S. Rajendran, “Corrosion behaviour of carbon steel in sea water in presence of Urea and Zn\(^{2+}\) ion”, Recent Trends in Chemistry (RTC-4) held at Jayaraj Annapackiam College for Women, Periyakulam on 18\(^{th}\) and 19\(^{th}\) February 2010.

2. **M. Manivannan** and S. Rajendran, “Thiourea – Zn\(^{2+}\) system as corrosion inhibitor for carbon steel in sea water”, 15\(^{th}\) National congress on Corrosion control, held at The Accord Metropolitan, Chennai on 16\(^{th}\) – 18\(^{th}\) September 2010.


CONFERENCES ATTENDED:

National:

1. Faculty Development Programme under TEQIP on “Environmental Technology” held at Govt. College of Engineering, Salem on 3rd March 2009.


8. Workshop on “Marine Corrosion and Surface Engineering” held at the Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai on 24th to 26th November 2011.

9. National Symposium on “Recent Developments in Chemistry” held at Srinivasan College of Arts and Science, Permbalur on 25th February 2012.