CHAPTER V
SUMMARY AND CONCLUSION

Findings of the present investigation entitled “Selected natural plants extracts and a synthesised compound as corrosion inhibitors of mild steel in acid media “are summarized in this section.

Leaves extracts of the plants studied , Abutilon indicum (ABI), Hyptis suaveolens (HYP) and Sida rhombifolia (SR) in 1 M HCl ,0.5 M H₂SO₄ and 1 M H₃PO₄ and the synthetic compound, 4-(N, N- dimethylamino) benzylidine acetone (DMABA) in 1 M H₃PO₄ have been found to be effective in inhibiting mild steel corrosion. The inhibition efficiencies of the plant extracts as well as the synthetic compound DMABA were found to vary with concentration, immersion period and temperature.

5.1: Plant extracts as mild steel corrosion inhibitors in different acid media

- The inhibition efficiency of studied plant extracts, ABI, HYP and SR increases with increasing concentration at room temperature. Maximum %IE was obtained at 10 % (v/v) concentration for each plant extract.
- The inhibition efficiencies of 92.98%, 95.51% and 95.49% were obtained for ABI in 1M HCl, 0.5 M H₂SO₄ and 1 M H₃PO₄ respectively for one hour immersion period.
- The inhibition efficiencies of 91.86,% 94.32 % and 93.76 % were obtained for HYP in 1M HCl, 0.5 M H₂SO₄ and 1 M H₃PO₄ respectively for one hour immersion period.
- The inhibition efficiencies of 97.08 %, 96.59 % and 96.10% were obtained for SR in 1M HCl ,0.5 M H₂SO₄ and 1 M H₃PO₄ respectively for one hour immersion period.
- Increase in immersion period (1, 3, 5, 7, and 12 h) increases the inhibitive action the extracts, ABI, HYP, and SR extracts.
- Maximum %IE of 97.8% and 97.46 % were obtained for 7h immersion period for ABI extract in 1M HCl and 1 M H₃PO₄ respectively. Inhibition efficiency of
98.09 % was obtained for 5 h immersion for ABI in 0.5 M H₂SO₄. Inhibition efficiencies of 96.79% and 97.18 % were obtained for 5 h optimum immersion period in HCl and H₃PO₄ containing HYP and HYP in 0.5 M H₂SO₄ showed the inhibition efficiency of 96.73 % for 3h immersion.

- Inhibition efficiencies of 98.58 and 98.1% were obtained for 5 hour immersion in HCl and H₃PO₄ respectively containing SR extracts and 98.65% for 3 hour immersion for SR extract in 0.5 M H₂SO₄.

- In general corrosion inhibitive behaviour of each plant extract with respect to rise in temperature from 303 to 343 K is not uniform.

- ABI in HCl and H₂SO₄ showed maximum inhibition efficiency of 96.26% and 95.88 % at 313 K respectively and ABI in H₃PO₄ showed 96.6 %. at 323 K.

- HYP extract showed maximum %IE of 96.26, 96.52 and 94.93 at 313 K in HCl, H₂SO₄ and H₃PO₄ respectively.

- Maximum Inhibition efficiency of 96.77% and 96.52 % were obtained for SR in HCl, and H₃PO₄ respectively at 313 K and 98.86% in H₂SO₄ at 323 K.

- Multiple variance analysis reveals that rise in solution temperature has no significant effect on inhibition efficiency (except at 0.1 %v/v concentration) of three plant extracts for mild steel corrosion in 1 M HCl ,0.5 M H₂SO₄ and 1 M H₃PO₄.

- Activation energy (Ea) was found higher for the plant inhibitors in each acid solution than that of the blank, suggests physical adsorption.

- The change in enthalpy of activation (ΔH*) was negative for mild steel corrosion in the presence of all the plant inhibitors, indicating dissolution of metal or adsorption of inhibitor as exothermic process.

- The negative value for change in Gibbs’ free energy of adsorption (ΔG_{ads}) indicates adsorption process as spontaneous.
• Negative values for change in entropy of activation (ΔS*) for mild steel corrosion in the presence of the plant inhibitors in HCl and H₃PO₄, showed association of species at rate determining step.

• Positive values for change in entropy of activation (ΔS*) for mild steel corrosion in the presence of all the plant inhibitors in H₂SO₄ is attributed to increase of disorder due to desorption of some water molecules from the iron surface.

• Positive as well as negative values were obtained for heat of adsorption (Q_{ads}) in the presence of all the plant inhibitors in acid solutions depending on the temperature. Positive values of (Q_{ads}) indicate adsorption of the extract as endothermic and negative values of Q_{ads} indicate adsorption of the extract as exothermic.

• ABI, HYP and SR extracts fit well in Langmuir adsorption isotherm which reveals the mono layer adsorption of the phytochemical constituents from the plant extracts.

• Modified Langmuir adsorption isotherms for all the plant inhibitors, ABI, HYP and SR in acid solutions reveal that two of the adsorbed water molecules on the metal surface have been replaced by the adsorbed inhibitor molecule.

• The molecular interaction parameters ('a') calculated from Temkin adsorption isotherm plots are found positive and high, showing strong molecular interaction between the phytochemical constituents of all the plant inhibitors, ABI, HYP and SR, and the metal surface.

• Corrosion current density (I_{corr}) decreases with increasing concentration of ABI in HCl, H₂SO₄ and H₃PO₄ and HYP in H₃PO₄ upto 5 % (v/v) showing inhibitive effect on corrosion reaction.

• All the plant inhibitors in all the three acid solutions are found to be mixed type.

• The polarisation resistance (R_p) increases with increasing concentration of extracts in all the three acid media up to 5% (v/v) reveals high resistance offered by the extract due to adsorption of active constituents.
• EIS studies reveal that charge transfer resistance (R<sub>ct</sub>) increases with increasing concentration of plant extracts in all the three acid media up to 5% (v/v) revealing high resistance offered by the extract.

• Double layer capacitance (C<sub>dl</sub>) decreases with increasing concentration of ABI, in all the three acid media up to 5% (v/v) showing increase in the thickness of double layer.

• The inhibition of corrosion of mild steel in the presence of the extract was due to the adsorption of the phytochemical constituents present in the extract on the mild steel surface was confirmed by FTIR studies.

• SEM images reveal the formation of protective film on the mild steel immersed in the inhibitor solutions

• Durability tests revealed that the three plant inhibitors could be stored at room temperature and may be used upto six months.

• Pickling bath monitoring test showed that the same bath can be used for five new sets of mild steel specimen and thereby reducing acid consumption during pickling process.

5.2: Synthetic compound as mild steel corrosion inhibitor in H<sub>3</sub>PO<sub>4</sub>

• The synthesized compound, DMABA was found be to effective inhibitor in H<sub>3</sub>PO<sub>4</sub> for which optimum period of immersion is 12 h with inhibition efficiency (%IE) of 94.9 at optimum concentration of 0.04 % (w/v).

• The maximum %IE of 84.59 % obtained for 0.04 % DMABA at 333 K.

• DMAB was found to obey Langmuir and Temkin adsorption isotherms.

• Positive as well as negative values were obtained for heat of adsorption (Q<sub>ads</sub>) in the presence of DMABA. Positive values of (Q<sub>ads</sub>) indicate adsorption of the extract as endothermic and negative values of Q<sub>ads</sub> indicate adsorption of the extract as exothermic.
• The negative value for change in Gibbs’ free energy ($\Delta G_{\text{ads}}$) indicates adsorption process as spontaneous.

• Potentiodynamic studies revealed its behaviour to be of mixed type. Decrease in $I_{\text{corr}}$ and increase in $R_p$ shows inhibitive effect of adsorbed inhibitor on corrosion reactions.

• From EIS study, it is found that charge transfer mechanism is involved in controlling corrosion. Increasing values of $R_{\text{ct}}$ and decreasing values of $C_{\text{dl}}$ in the presence of inhibitor, DMABA show effective adsorption of the same on the substrate.

• FTIR spectra reveals the interaction between the nitrogen atom of dimethyl amino group and C=C of olefinic carbon and aromatic ring.

• SEM analysis confirms formation of protective film on the mild steel surface immersed in 0.04 % DMABA.

### 5.3: Synergistic study

• The combination of DMABA and CTAB seemed to be effective in controlling mild steel corrosion in $H_3PO_4$. Though there was an increase in %IE of the mixture containing 0.005 % DMABA and various concentration of CTAB in the range of 0.002 to 0.01%CTAB, synergistic factor was found to be greater than unity at lower concentrations of CTAB. Antagonistic effect was observed at higher concentrations of CTAB, for which synergistic factor was found lesser than unity.

• Potentiodynamic polarisation studies revealed the mixture as of mixed type.

• FTIR study reveal the shift in the band position associated with C-N stretching, showing the effective participation of CTAB and DMABA in controlling mild steel corrosion.

• SEM image indicated that, the inhibitors molecules formed a good protective film on the mild steel surface and confirms the active participation of CTAB which can be understood from different grain structure of protective coating.
5.4: Cost effective study

- Cost effective study revealed the use of plant inhibitor as economical

5.5: Field test

- Though the time taken for pickling in the HCl medium in the presence of plant inhibitors was longer than that of free acid, a positive result of reduction in hydrogen evolution with better corrosion resistance was observed in field testing.

SUGGESTIONS

- Plant extracts studied may be tested for their inhibiting effects on different metals like aluminium, copper, zinc etc.
- Similar studies could be carried out in other medium like nitric acid, NaCl etc.
- Studies may be carried out for DMABA in HCl and H$_2$SO$_4$.
- Cost effectiveness of studied plant inhibitors may be carried out with commercial corrosion inhibitors.
- Studies may be carried out to find the utility of the plant extracts in protective coating and as primers for coating.
- The composition of the electrolytic bath after the corrosion study may be analyzed.
- Field test may be carried out in industries where H$_2$SO$_4$ and H$_3$PO$_4$ acids are used as pickling baths.