



## *Ocimum sanctum* (Tulasi) as Corrosion Inhibitor on Mild Steel in Hydrochloric Acid

M. Shyamala and A. Arulanantham

Department of Chemistry, Government College of Technology, Coimbatore-641 013, T.N., India

### Key Words:

Corrosion inhibition  
*Ocimum sanctum*  
Plant extract  
Mild steel corrosion  
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### ABSTRACT

The aqueous extract of *Ocimum sanctum* as corrosion inhibitor on mild steel in 1 N hydrochloric acid was studied using the weight loss method, gasometric, potentiodynamic polarization and impedance method. The maximum inhibition efficiency was 99.6 % in the optimum concentration of the extract 6 % in v/v. Similarly, in gasometric method, maximum efficiency was 98.6% in the same concentration. It was confirmed by potentiodynamic polarization and impedance methods, which showed a maximum efficiency of 99.7% and 97.9% respectively in the same concentration. The effect of immersion time from 3 hrs to 24 hrs at 30°C on corrosion inhibition of mild steel in 1N HCl in the presence of the optimum concentration of the inhibitor (6 % in v/v) revealed that the extract of *Ocimum sanctum* has maximum efficiency of 99.6% in 3 hours immersion time. Potentiodynamic polarization studies indicated that the plant extract behaves as mixed type inhibitor. The results show that 6% in v/v aqueous extract of the leaves of *Ocimum sanctum* could serve as an effective inhibitor on the corrosion of mild steel in 1 N hydrochloric acid medium.

### INTRODUCTION

*Ocimum sanctum* (Tulasi) is a sacred plant and has various medicinal properties. In this study the corrosion inhibition action of the aqueous extract of *Ocimum sanctum* in hydrochloric acid solution has been investigated using weight loss, gasometric, hydrogen permeation, potentiodynamic polarization and impedance methods. There has been a growing trend in the use of natural products as corrosion inhibitor as they are environmentally safe, less toxic and readily available such as extracts of plant leaves for metals in acid cleaning process. Some plant extracts like *Mentha pulegium* (Bouyanzer et al. 2006), *Opuntia* (El-Etre 2003), *Azadiracta indica* (Valek & Martinez 2006), Killah extract (El-Etre. 2005), *Nypa fruticans* (Orubite et al. 2004), Berberine (Yan Li et al. 2005), *Lawsonia* (El-Etre et al. 2005), *Ocimum viridis* (Emeka 2005), etc. have been found to be very efficient corrosion inhibitors for the protection of mild steel in acidic media.

### MATERIALS AND METHODS

**Material preparation:** Mild steel strips of size 4.5cm × 2cm × 0.2cm containing 0.14% C, 0.35% Mn, 0.17% Si, 0.025% S, 0.03% P and the remainder Fe were used for weight loss and gasometric methods. For electrochemical studies, mild steel strips of the same composition coated with lacquer with an exposed area of 1 cm<sup>2</sup> were used. Mild steel strips were polished mechanically with emery papers of 1/0 to 4/0 grades and subsequently degreased with trichloroethylene before use. Analytical reagent grade HCl and double distilled water were used for preparing test solutions for all the experiments.

**Solution preparation:** The leaves of *Ocimum sanctum* were cut into small pieces, dried in a hot air oven at 80°C for 2 hrs and ground into powder. From this 10g sample was refluxed in 100mL

distilled water for 1 h, filtered carefully and made to 100 mL using double distilled water. The concentration of the stock solution is expressed in terms of % (v/v).

**Weight loss method:** The specimens were hanged into the experimental solution with the help of glass hooks. The volume of solution used was 100mL. The experimental solution used was 1N HCl in the absence and presence of different concentrations of inhibitor. The initial weight of the specimens was noted and then they were completely immersed into the experimental solution at 30°C for three hours. After three hours, the specimens were taken out, washed thoroughly with distilled water, dried completely and their final weights were noted. From the initial and final weights of the specimen, the loss in weight was calculated. The corrosion rate (mmpy) and the efficiency of inhibitors was calculated using the formula,

$$\text{Corrosion rate (mmpy)} = \frac{KW}{ATD}$$

Where,  $K = 8.76 \times 10^4$  (constant),  $W$  = weight loss in g,  $A$  = area in sq. cm and  $D$  = density in g/cu. cm (7.86).

$$\text{Inhibition efficiency (\%)} = \frac{W_B - W_1}{W_B} \times 100$$

Where  $W_B$  and  $W_1$  are weight loss per unit time in the absence and presence of inhibitors. The degree of surface coverage ( $\theta$ ) was calculated from the weight loss measurement using the formula,

$$\text{Surface coverage (\theta)} = \frac{W_B - W_1}{W_B}$$

Where,  $W_B$  is the weight loss in the absence of inhibitor and  $W_1$  is the weight loss in the presence of inhibitor.

**Gasometric method:** The size of the specimen used was identical with that used for weight loss method. This technique gives accurate results compared to that of conventional weight loss method provided the inhibitor does not react with hydrogen and the hydrogen penetration into the metal is small compared to the total volume of hydrogen gas. The gasometric method consists of three parts, (i) Reaction cell (ii) Vertical graduated burette (iii) Reservoir bulb

**(i) Reaction cell:** It consists of a cylindrical glass vessel of 150mL capacity with a ground joint opening through which the metal specimen can be inserted into the cell by means of a glass stopper provided with a hook. The stopper exactly fits into the central ground glass joint so that there is no leakage of hydrogen gas. It is also provided with a gas release stopper on one side through which excess gas pressure over the atmospheric pressure, which builds up when the stopper carrying the metal strip is introduced, can be released.

**(ii) Vertical graduated burette:** A 50 mL graduated burette with 0.1 mL accuracy is used to collect the gas evolved during the reaction. The top end of the burette is connected to the reaction cell through a side tube.

The vertical column tubes are filled with 20-25% sodium chloride solution, acidified with HCl and coloured with methyl orange or methyl red. The gas is collected over this solution. The colour

makes observation of the meniscus easy. The solubility of gases like CO<sub>2</sub>, H<sub>2</sub>, etc. is very low in sodium chloride solution. Hence, the measurement is more accurate.

**(iii) Reservoir bulb:** A reservoir bulb is attached to the other end of the graduated burette to adjust the liquid level in the burette to be equal to that in the reservoir bulb so that the pressure of the gas inside the tube is the same as atmospheric pressure. As the liquid level inside and outside the burette are kept same from the beginning of the experiment, any pressure correction due to aqueous tension is not necessary. The specimen was suspended from the hook of the glass stopper and introduced into the cell containing 100 mL of the experimental solution. The temperature was maintained constant throughout these experiments at 30°C at constant atmospheric pressure. Volume measurements were made for a period of two hours in all the cases. From the volume of hydrogen gas liberated, the inhibition efficiency was calculated using the formula,

$$\text{Inhibition efficiency (\%)} = \frac{V_0 - V_1}{V_0} \times 100$$

Where,  $V_0$  is the volume of hydrogen evolved in the absence of inhibitor and  $V_1$  is the volume of hydrogen evolved in the presence of inhibitor.

**Potentiodynamic polarization method:** Potentiodynamic polarization measurements were carried out using Solartron Electrochemical analyzer (Model-1280). The polarization measurements were made to evaluate the corrosion current, corrosion potential and Tafel slopes. Experiments were carried out in a conventional three-electrode cell assembly. The working electrode was mild steel specimen of 1 sq. cm area which is exposed and the rest being covered with red lacquer. A rectangular Pt foil was used as the counter electrode. To exert uniform potential on the working electrode, it is designed in such a way that the counter electrode is much larger in area compared to the working electrode. The reference electrode used was SCE. Instead of salt bridge, a luggin capillary arrangement was used to connect the working electrode to SCE. To avoid the ohmic contribution, the luggin capillary was kept close to the working electrode. A time interval of 10-15 minutes is given for each experiment to attain the steady state open circuit potential. The polarization was carried from a cathodic potential of -800mV (vs SCE) to an anodic potential of -200mV (vs SCE) at a sweep rate of 1 mV per second. From the polarization curves, Tafel slopes, corrosion potential and corrosion current were calculated. The inhibitor efficiency was calculated using the formula,

$$\text{IE (\%)} = \frac{I_{\text{Corr}} - I_{\text{Corr}}^*}{I_{\text{Corr}}} \times 100$$

Where,  $I_{\text{corr}}$  and  $I_{\text{corr}}^*$  are corrosion current in absence and presence of the inhibitor.

**Impedance measurements:** The electrochemical AC impedance measurements were performed using Solartron electrochemical analyzer (Model-1280). Experiments were carried out in a conventional three-electrode cell assembly as that used for potentiodynamic polarization studies. The working electrode was carbon steel specimen of 1 sq. cm area which is exposed and the rest being covered with red lacquer. A rectangular Pt foil was used as the counter electrode. A sine wave with amplitude of 10 mV was superimposed on the steady open circuit potential. The real part ( $Z'$ ) and the imaginary part ( $Z''$ ) were measured at various frequencies in the range of 100 kHz to 10 mHz. A plot of  $Z'$  vs  $Z''$  were made. From the plots the charge transfer resistance ( $R_t$ ) were calculated and the double layer capacitance were then calculated using the equation.

$$C_{dl} = 1/2pf_{\max} R_t$$

Where  $R_t$  is charge transfer resistance and  $C_{dl}$  is double layer capacitance.

The experiments were carried out in the absence and presence of different concentrations of inhibitors. The percentage of inhibition efficiency was calculated using the equation.

$$IF (\%) = \frac{R_t^* - R_t}{R_t^*} \times 100$$

Where  $R_t^*$  and  $R_t$  are the charge transfer resistance in the presence and absence of inhibitors.

## RESULTS AND DISCUSSION

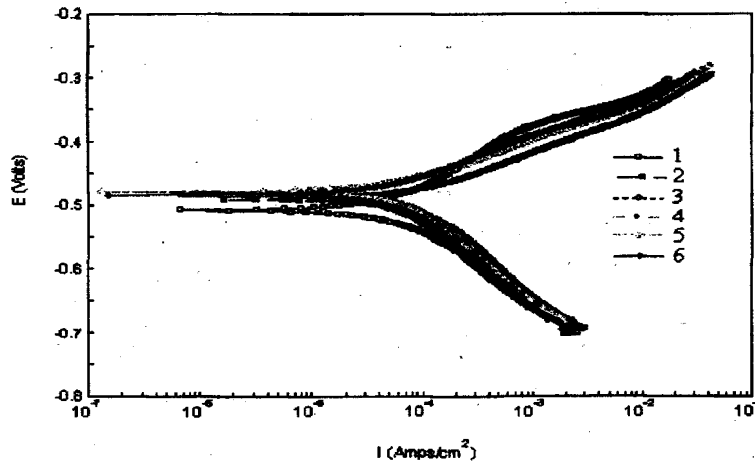
**Weight loss method:** The weight loss method was done with concentrations ranging from 2% to 10% v/v. The weight loss data are given in Table 1. It was found that with the rise in concentration of the *Ocimum sanctum* extract from 2.0 to 8% v/v, the weight loss of mild steel decreased. The corrosion rate also decreased while the inhibition efficiency increased. At the optimum concentration of 6.0 % in v/v, *Ocimum sanctum* has a highest inhibition efficiency of about 99.6%. The effect of immersion time from 3 hours to 24 hours at 30°C on the corrosion inhibition of mild steel in 1N HCl in the presence of the optimum concentration of the inhibitor revealed that the extract has maximum efficiency of 99.6% in 3 hours immersion time. It slightly decreased from 99.6% to 94.8% as immersion time was increased from 3 hours to 24 hours (Table 2). The results indicate that *Ocimum sanctum* could act as an excellent corrosion inhibitor.

**Gasometric method:** Table 3 shows the inhibition efficiency by gasometric method for mild steel in 1N HCl for different concentrations of *Ocimum sanctum* extract. It was observed that with increase in concentration of *Ocimum sanctum* extract from 2 % to 10 % v/v, the volume of hydrogen gas evolved at 30±1°C decreased, and with optimum concentration of 6 % v/v, the volume of hydrogen gas evolved was only 0.1 mL showing 98.6 % inhibition efficiency.

**Potentiodynamic polarization Method:** Fig. 1 shows the polarization curves for mild steel in 1N HCl with different additions of *Ocimum sanctum* extract. Inspection of the figure reveals that the polarization curves shift towards less negative potential and lower current density values upon addition of the extract. This behaviour reflects the inhibitive action of the extract. The potentiodynamic polarization parameters for mild steel in 1N HCl containing different concentrations of *Ocimum sanctum* extract obtained from the curves of Fig. 1 are given in Table 4. The data show that the corrosion potential shifts to less negative values as the concentration of added extract is increased. On the other hand, the corrosion current density ( $I_{\text{corr}}$ ) is markedly decreased upon addition of the extract. The extent of its decrease increases with increased extract concentration. At 6 % v/v, the  $I_{\text{corr}}$  value was 0.01 mA/cm. The maximum inhibition efficiency by *Ocimum sanctum* extract was observed in the optimum concentration of 6% in v/v with 99.7% efficiency.

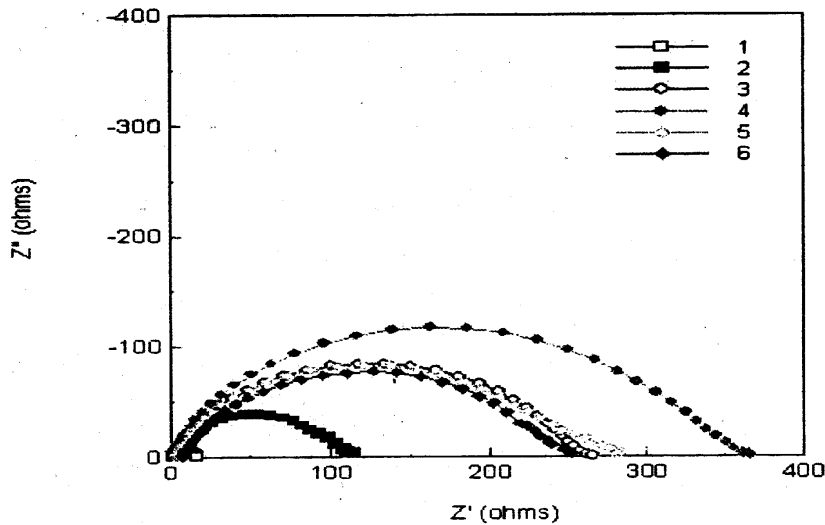
**Impedance measurement:** Impedance measurements were studied to evaluate the charge transfer resistance ( $R_t$ ) and double layer capacitance ( $C_{dl}$ ) and through these parameters the inhibition efficiency was calculated. Fig. 2 shows the impedance diagrams for mild steel in 1N HCl with different concentrations of *Ocimum sanctum* extract and the impedance parameters derived from these investigations are given in Table 5.

The obtained impedance diagrams are almost in a semi-circular appearance, indicating that the charge-transfer process mainly controls the corrosion of mild steel. Deviations of perfect circular



(1) Blank, (2) 2.0 %v/v, (3) 4.0 % v/v, (4) 6.0 % v v, (5) 8.0 % v/v, (6) 10.0 % v/v

Fig. 1: Potentiodynamic polarization curves for mild steel in 1N HCl solution in the absence and presence of different concentrations of *Ocimum sanctum* extract.



(1) Blank, (2) 2.0 %v/v, (3) 4.0 % v/v, (4) 6.0 % v v, (5) 8.0 % v/v, (6) 10.0 % v/v

Fig. 2: Impedance diagrams (Nyquist plot) for mild steel in 1N HCl solution in the absence and presence of different concentrations of *Ocimum sanctum* extract.

shape are often referred to the frequency dispersion of interfacial impedance. This anomalous phenomenon may be attributed to the inhomogeneity of the electrode surface arising from surface roughness or interfacial phenomena. In fact, the presence of *Ocimum sanctum* extract enhances the value of  $R_p$  in acidic solution. Values of double layer capacitance are also brought down to the maximum extent in the presence of inhibitor and the decrease in the values of  $C_{dl}$  follows the order similar to

Table 1: Corrosion parameters obtained from weight loss measurements for mild steel in 1N HCl containing different concentrations of *Ocimum sanctum* extract.

Cone. of Extract (% v/v)	Corrosion Rate (mmpy)	Inhibition Efficiency (%)	Surface Coverage ( $\theta$ )
Blank	30.67	-	-
2.0	2.39	92.2	0.92
4.0	1.10	96.4	0.96
6.0	0.12	99.6	1.00
8.0	1.08	96.5	0.97
10.0	1.32	95.7	0.96

Table 2: Effect of immersion time on percentage inhibition efficiency of mild steel in 1N HCl at 30°C in the presence of an optimum concentration 6% v/v of the extract of *Ocimum sanctum*.

Name of the natural inhibitor	Inhibition efficiency (%)							
	3h	6h	9h	12h	15h	18h	21h	24h
<i>Ocimum sanctum</i>	99.6	98.5	98.0	97.3	96.5	96.0	95.3	94.8

Table 3: Inhibition efficiency obtained from gasometric method for mild steel in 1N HCl for different concentrations of *Ocimum sanctum* extract.

Cone. of extract (% v/v)	Volume of hydrogen gas evolved at 30 $\pm$ °C	Inhibition Efficiency
Blank	7.0	-
2.0	0.6	91.4
4.0	0.3	95.7
6.0	0.1	98.6
8.0	0.3	95.7
10.0	0.4	94.3

Table 4: Potentiodynamic polarization parameters for mild steel in 1N HCl containing different concentrations of *Ocimum sanctum* extract.

Conc. of extract (% v/v)	$E_{\text{corr}}$ (V)	$I_{\text{corr}}$ (mA/cm <sup>2</sup> )	Tafel Slope mV/decade		Inhibition Efficiency (%)
			$b_a$	$b_c$	
Blank	-0.4826	3.57	78	122	-
Tulasi					
2.0	-0.4917	0.24	74	126	93.3
4.0	-0.4802	0.12	76	124	96.6
6.0	-0.4806	0.01	78	124	99.7
8.0	-0.4777	0.09	74	122	97.5
10.0	-0.4847	0.12	76	124	96.6

Table 5: Impedance parameters for the corrosion of mild steel in 1N HCl in the absence and presence of different concentrations of *Ocimum sanctum* extract at 30°C.

Conc. of extract (% v/v)	$R_t$ ( $\Omega \text{ cm}^2$ )	$C_{dl}$ ( $\mu\text{F}/\text{cm}^2$ )	Inhibition Efficiency (%)
Blank	7.58	285.34	-
Tulasi			
2.0	110.91	19.34	93.2
4.0	253.86	8.44	97.0
6.0	358.80	6.00	97.9
8.0	274.99	7.95	97.2
10.0	239.25	9.02	96.8

that obtained for  $I_{corr}$  in this study. The decrease in  $C_{dl}$  shows that the adsorption of the inhibitor takes place on the metal surface in acidic solution.

Moreover, the increase in the value of  $R_t$  with the inhibitor concentration leading to the increase in the corrosion inhibition efficiency. The maximum  $R_t$  value of  $358.80 \Omega \text{ cm}^2$  and minimum  $C_{dl}$  value of  $6.00 \mu\text{F}/\text{cm}^2$  is obtained for the optimum concentration 6 % v/v with a maximum inhibition efficiency of 97.9%. A good agreement is observed between results obtained in non-electrochemical methods (weight loss method and gasometric method) and electrochemical methods (potentiodynamic polarization method and impedance method).

## CONCLUSIONS

1. *Ocimum sanctum* acts as a good and efficient inhibitor for corrosion of mild steel in 1N hydrochloric acid.
2. The maximum inhibition efficiency was found to be 99.6 % in the optimum concentration of the extract 6 % v/v.
3. The effect of immersion time from 3 hours to 24 hours at 30°C on the corrosion inhibition of mild steel in 1N HCl in presence of the optimum concentration of the inhibitor (6 % v/v) revealed that the extract of *Ocimum sanctum* has maximum efficiency of 99.6% in 3 hours immersion time.
4. Results obtained in non-electrochemical methods (weight loss method and gasometric method) were in good agreement with the electrochemical methods (potentiodynamic polarization method and impedance method).
5. The use of *Ocimum sanctum* as corrosion inhibitor is environmentally safe, less toxic, ecofriendly, cost effective, and easily and readily available.

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