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Studies on Scaling and Corrosion Characteristics of Ground Water

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Scale formation and corrosion affect the performance of an open recirculating cooling system, which is considered as an important component in most of the industries. This article deals with the evaluation of scaling and corrosion tendency of groundwater samples collected from various locations in Chennai city. The evaluating procedures include determination of water quality parameters like pH, alkalinity, Total dissolved solids (TDS) and hardness. This article also deals with the evaluation of scale and corrosion inhibition efficiency of some of the inhibitors.

Key Words: Groundwater, Scaling, Scale inhibition, Corrosion, Corrosion inhibition.

INTRODUCTION

In industrial water treatment, the major emphasis is on preventing corrosion and scale formation. Scale and corrosion related problems pose severe economic losses to the industries. Hence scale and corrosion control is of great significance in every cooling water system. While corrosion has caused great concern in the past, interest has been focussed increasingly on the prevention of scaling. Scale is a hard, adherent mineral deposit that usually precipitates from solution and grows in place. It is a crystalline form of deposit. In cooling water systems, a part of the pure water evaporates resulting in increased dissolved solid content in the remaining water. If this increase continues, a state of saturation would reach wherein the water cannot hold any more solids at that temperature. When saturation is reached, the dissolved solids drop out of the solution and deposit as scale on the condenser tubes, tower fill and pipings[1–3]. Scale formation is maximum when the temperature is at its highest. Typical scales which form on any heat transfer surfaces are $CaCO_3$, magnesium silicate, $Ca_3(PO_4)_2$ or $CaSO_4$.[4] The scaling tendency is a result of the reverse solubility of these salts with temperature, *i.e.*, at high temperature their solubility decreases and they tend to precipitate on a surface. Scale formation is influenced by a number of factors including surface temperature on heat transfer surface, hardness (dissolved Ca and Mg content), alkalinity (CO_3^{2-} and HCO_3^- content), TDS and pH. Scale deposition is a complex crystallisation process. The time taken for the formation of initial scale and its subsequent rate of growth, are determined by the interaction of several rate processes (*e.g.*, supersaturation, nucleation, diffusion, chemical reaction and molecular arrangement of the scale crystal lattices). Scale control has been carried out by different methods, the most accepted being the addition of antiscalant chemicals (scale inhibitors).

Corrosion is defined as the loss and eventual failure of metals and alloys caused by an electrochemical reaction between the system surfaces and water[5]. The various factors influencing the rate of corrosion are presence of dissolved oxygen, amount of dissolved and suspended solids, degree of alkalinity or acidity, water velocity, temperature and presence of microbes. Corrosion often leads to premature failure of the system. Numerous corrosion inhibitors such as chromate based, Zn based and Mo based formulations were used to control corrosion. Due to the environmental problems associated with each of these, organic based formulations have taken over the inorganic ones.

EXPERIMENTAL

Water Sample Collection: The ground water samples were collected from various parts of Chennai city. The water samples were collected in clean one-litre polythene containers as per the procedure described[6]. The places of sample collection are shown in Fig. 1.

Prediction of scaling/corrosion tendency of water samples

Langelier Saturation Index (LSI): The scaling tendency of cooling water is dependent upon the alkalinity, calcium hardness, temperature and dissolved salts. These parameters define the pH at which $CaCO_3$ will become saturated in the system. This pH is called the pH_s for $CaCO_3$. Langelier[7] derived the pH_s from solubility data and defined the Langelier index as (LSI).

$$LSI = pH - pH_s$$

where $pH_s = (0.3 + A + B) - (C + D)$

where factor A represents total dissolved solids, B represents temperature, C represents calcium hardness and D represents total alkalinity. If the Langelier index is positive, water is said to be scaling. If it is negative, water is said to be corrosive.

Ryznar Saturation Index (RSI): It is possible for a low-hardness water and a high hardness water to have the same LSI value. Using operational data and experience with scale and corrosion in a large number of systems, Ryznar refined the Langelier index. The Ryznar[8] equation is:

$$RSI = 2pH_s - pH.$$

Determination of Water Quality Parameters: Water quality parameters like pH, alkalinity, hardness and TDS in the context of prediction of scaling/corrosion tendencies of water sample were determined. pH of the samples was estimated using pH-meter, hardness and alkalinity were evaluated in the laboratory by analytical procedures and TDS was estimated by the standard methods[6].

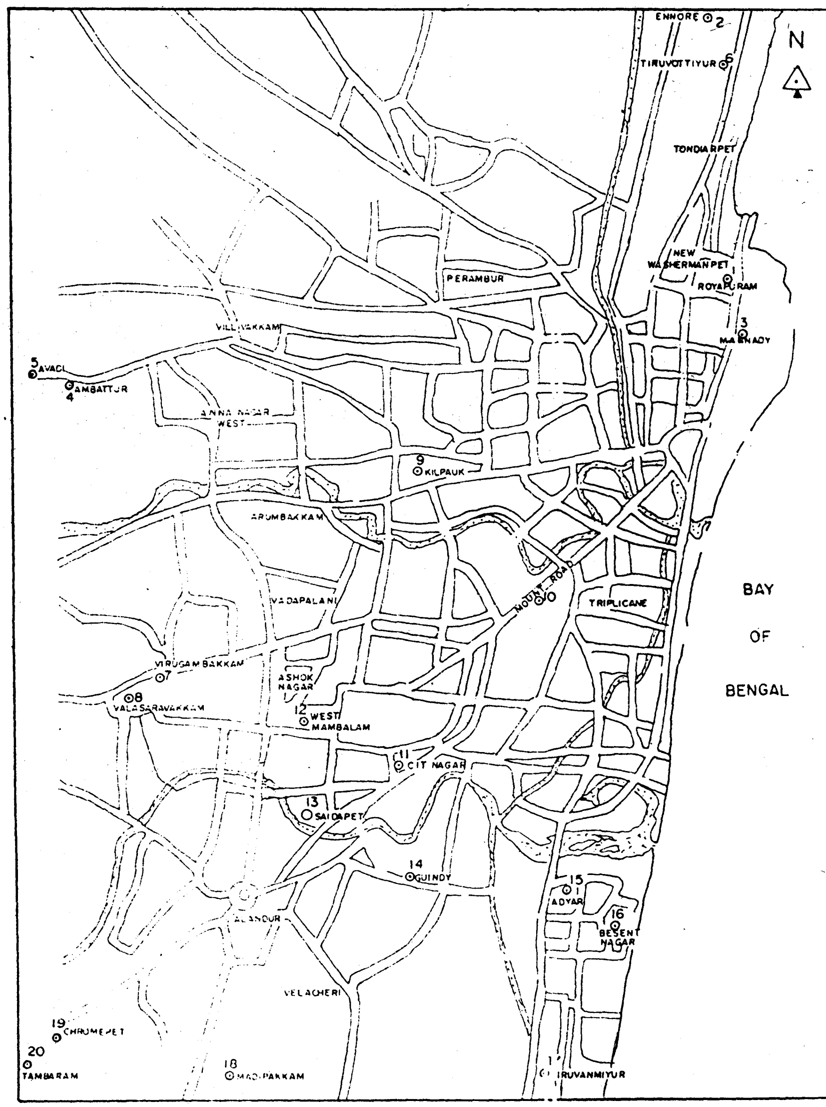


Fig. 1 The city map showing the sites of sample collection

All the parameters (TDS, alkalinity and hardness) are expressed in mg/L (ppm).

Scale Inhibition Studies: The scale inhibition efficiency of inhibitors like 3-phosphonopropionic acid (3-PPA) and triton X-100 were determined by standard methods[9]. The inhibition efficiency is calculated from the equation[10]

$$\% \text{ Inhibition} = \frac{Ca_i - Ca_b}{Ca_c - Ca_b} \times 100$$

Ca_i = Calcium ion concentration with the inhibitor

Ca_b = Calcium ion concentration in the blank

Ca_c = Calcium ion concentration before the test.

The scale inhibition study was carried out for two of the scaling water samples (site nos. 14 and 18).

Corrosion Inhibition Studies: Potentiodynamic polarisation studies were carried out using Vibrant Potentiostat (model no VSM/CS/30) interfaced with a computer. The experiment was carried out with 3-PPA and triton X-100.

The corrosion behaviour of mild steel was studied for one of the corrosive water samples (Table-4).

The corrosion rate was calculated using the equation[11],

$$\text{Corrosion rate (mpy)} = \frac{0.129 \times i_{corr} \times EW}{D \times A}$$

where

i_{corr} = corrosion current density ($\mu A/cm^2$),

EW = equivalent weight (g),

A = area (cm^2),

D = density (g/cm^3)

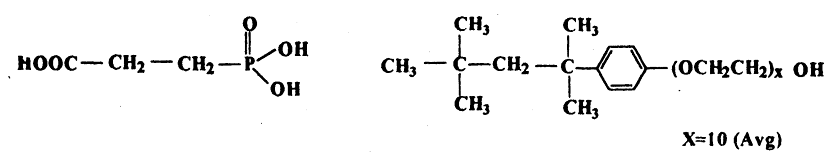
The inhibition efficiency was also calculated from the following equation[12]:

$$\text{Inhibition Efficiency (\%)} = \frac{I'_{corr} - I_{corr}}{I'_{corr}} \times 100$$

I'_{corr} = Corrosion current density of uninhibited system

I_{corr} = Corrosion current density of inhibited system

The structures of the inhibitor compounds used in the study are given in Fig. 2.



3 - PPA

Triton X - 100

Fig. 2 The structure of inhibitor compounds (a) 3-Phosphonopropionic acid, (b) Triton X-100

RESULTS AND DISCUSSION

The water quality parameters (pH, alkalinity, TDS and hardness) are listed in Table-1 and the LSI/RSI indices are listed in Table-2. The LSI/RSI indices listed in Table-2 revealed that in the zone I, water samples from site nos. 1 and 2 exhibited moderate scaling tendency while site nos. 3 and 5 are of moderately corrosive nature.

TABLE-1
WATER QUALITY PARAMETERS OF THE GROUNDWATER SAMPLES

Site No.	Area	pH	TDS (ppm)	Hardness (ppm)	Alkalinity (ppm)
			ZONE I		
1.	Royapuram	7.50	709.3	361.8	225.2
2.	Ennore	7.30	1200.0	400.5	203.5
3.	Mannady	6.27	677.4	270.0	207.8
4.	Ambattur	6.48	1100.0	482.0	170.2
5.	Avadi	7.70	359.1	82.8	88.8
6.	Tiruvottiyur	7.29	993.2	405.0	185.4
			ZONE II		
7.	Virugambakkam	6.56	1138.0	144.0	252.2
8.	Valasaravakkam	6.48	841.1	236.7	286.7
9.	Kilpauk	7.03	700.0	204.7	305.3
10.	Mount Road	7.03	1700.0	432.0	388.5
			ZONE III		
11.	C.I.T. Nagar	7.45	823.0	226.1	308.90
12.	West Mambalam	7.50	1022.0	26.7	407.00
13.	Saidapet	6.91	234.3	76.5	75.85
14.	Guindy	7.02	1002.0	623.0	251.60
15.	Adyar	7.68	2800.0	82.0	560.00
16.	Besant Nagar	7.60	400.0	188.6	172.05
17.	Tiruvanmiyur	7.20	900.0	90.0	281.20
			ZONE IV		
18.	Madipakkam	7.09	1862.0	1242.0	114.7
19.	Chromepet	6.89	1300.0	812.0	209.1
20.	Tambaram	7.10	608.2	258.1	260.8

TABLE-2
SCALING/CORROSIVE TENDENCY OF THE GROUND WATER SAMPLES

Site No.	Area	LSI	RSI	Tendency of water
		ZONE I		
1.	Royapuram	+0.5	6.50	Moderate scaling
2.	Ennore	+0.4	6.50	Moderate scaling
3.	Mannady	−0.8	7.93	No scaling, moderate tendency to dissolve scale
4.	Ambattur	−0.4	7.32	No scaling, slight tendency to dissolve scale
5.	Avadi	−0.2	8.10	No scaling, moderate tendency to dissolve scale
6.	Tiruvottiyur	+0.6	6.30	No scaling, slight tendency to dissolve scale
		ZONE II		
7.	Virugambakkam	−0.64	7.80	No scaling, moderate tendency to dissolve scale
8.	Valasaravakkam	−0.40	7.30	No scaling, slight tendency to dissolve scale
9.	Kilpauk	+0.80	5.40	Moderate scaling
10.	Mount Road	+0.50	5.90	Slight scaling
		ZONE III		
11.	C.I.T. Nagar	+0.5	6.35	Stable water
12.	West Mambalam	−0.3	8.10	No scaling, moderate tendency to dissolve scale
13.	Saidapet	−0.2	8.90	No scaling, moderate tendency to dissolve scale
14.	Guindy	+0.4	6.20	Slight scaling
15.	Adyar	+0.6	6.50	Moderate scaling
16.	Besant Nagar	+1.3	5.00	Severe scaling
17.	Tiruvanmiyur	+0.9	5.90	Moderate scaling
		ZONE IV		
18.	Madipakkam	+0.4	6.30	Slight scaling
19.	Chromepet	+0.3	6.30	Slight scaling
20.	Tambaram	+0.1	6.90	No scaling, very slight tendency to dissolve scale

In the case of zone II, samples from site nos. 7 and 8 are of corrosive nature while that of 9 and 10 are of scaling nature.

The sample from Besant Nagar (site no. 16) of zone III demonstrated severe scaling tendency. The sample from site no. 11 of the same zone was found to be a stable one. Water samples from site no. 18 and 19 of zone IV are of scaling nature.

Scaling and corrosion inhibition studies were carried out with different concentrations of the inhibitors (3-PPA and triton X-100). Each inhibitor was studied at eight different concentration levels, for example, 25, 50, 75, 100, 125, 150, 175 and 200 ppm levels in the case of 3-PPA and 50, 100, 150, 200, 250, 300, 350 and 400 in the case of triton X-100. The efficiency was found to increase with the concentration of the inhibitor up to a certain concentration level after which it decreases. The concentration at which maximum inhibition obtained is chosen as the optimum concentration is presented in Tables 3 and 4. Scale inhibition study revealed that both 3-PPA and triton X-100 showed better inhibition efficiencies. Scale inhibition by organic phosphates takes place by the adsorption of the inhibitor on the active crystal growth site and this tends to distort bond angles, so that crystals do not develop.

TABLE-3
SCALE INHIBITION EFFICIENCY

Inhibitor	Concentration (ppm)	Inhibition Efficiency (%) for area 1*	Inhibition Efficiency (%) for area 2†
3-PPA	200	34.2	92.8
Triton X-100	200	42.9	72.4

*Area 1—Madipakkam, *Area 2—Guindy

The polarisation curves of mild steel in groundwater in the presence of various concentrations of inhibitors were recorded. Polarisation studies showed that both 3-PPA and triton X-100 gave better corrosion inhibition efficiencies as shown in Table-4. The corresponding polarisation curves of the optimised concentrations of the inhibitors are given in Fig. 3. It can be inferred that both 3-PPA as well as triton X-100 are capable of inhibiting the corrosion of mild steel in groundwater.

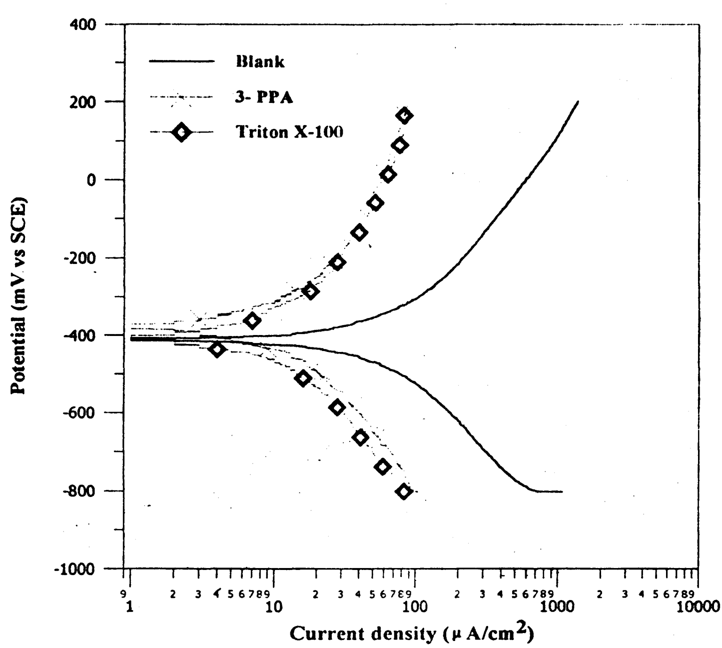


Fig. 3 Polarisation curves of Mild steel at optimum concentration of inhibitors in Valasaravakkam groundwater

TABLE-4
CORROSION INHIBITION EFFICIENCY FOR VALASARAVAKKAM GROUNDWATER

Inhibitor	Concentration (ppm)	i_{corr} ($\mu A/cm^2$)	Corrosion rate (mpy)	Inhibition efficiency (%)
Blank	–	12.0	5.48	–
3-PPA	100	3.2	1.50	73.3
Triton X-100	250	3.0	1.40	75.0

The mechanistic aspect of corrosion inhibition by 3-PPA and triton X-100 can be explained in terms of complexation and adsorption[13,14].

Conclusion

- The scaling/corrosion characteristics are found to be greatly affected by pH, TDS, alkalinity and hardness.
- It has been found that both 3-PPA and triton X-100 revealed almost equal performance both as scale/corrosion inhibitors.

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