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Analysis of stainless steel shower columns high parts corrosion in bathrooms in Senegal.

El Hadji Aliou Diop
Electromechanical Engineer, Ecole Doctorale Développement Durable et Société, University of Thiès, Senegal, adioping@yahoo.fr; elhadjialiou.diop@univ-thies.sn

Fadel Niang
Enseignant Chercheur, Ecole Doctorale Développement Durable et Société, University of Thiès, Senegal
Diadioly Gassama
Enseignant Chercheur, UFR Sciences & Technologies (SET), University of Thiès, Senegal
Karim Diaw
Enseigant chercheur, Department of Chemistry, Faculty of Sciences and Techniques, University Cheikh Anta DIOP, Dakar-Senegal
Modou Fall
Professor, Department of Chemistry, Faculty of Sciences and Techniques, Uni. Cheikh Anta DIOP, Dakar-Senegal

Abstract — Stainless steel shower columns in bathrooms are marked by fast and special corrosion of the high horizontal parts in the environment context of the region of Dakar. This causes drillings or alterations leading to their constant replacements though the other parts of the shower column usually remain unaffected. The sweating technical permitted to evidence early stage corrosion cases on the shower columns for better observation. Ryznar stability and Langelier saturation indexes were used to evaluate the aqueous environment aggressiveness (corrosiveness). Chronopotentiometry and linear polarization techniques were used to determine free-corrosion potentials as well as Evans diagrams and Tafel data's which allowed studying the shower columns corrosion behavior in the solutions simulating the respective environments. They permitted to compare these various environments aggressiveness and explain the origin of the observed corrosion. The results showed that the corrosion of these stainless steel shower column parts is more pronounced in chlorinated soapy water and seawater solutions (presence of chloride ions). Drinking and soapy waters were less corrosive for these shower columns. The corrosion rates were close when comparing seawater and chlorinated soapy water, but also drinking and soapy waters.

Keyword —, Langelier saturation index, linear polarization, Open circuit potential, Ryznar stability index, scaling pH, Stainless steel.

1. INTRODUCTION

The phenomenon of stainless steel shower columns high parts corrosion is recurrent in bathrooms in Senegal, especially in Dakar. The vertical and leaning parts of the shower column generally remain unaffected. This type of corrosion is particularly severe and alters the shower columns esthetic and sustainability. Shower columns drillings and recurrent replacements then follow.

The corrosivity and potential of scale formation of drinking water have been the subject of many studies during the last years [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]-[13]-[14]-[15]-[16]. In most cases, it was related to the environment composition and geographical position.

Our purpose is to study the corrosion of 316 stainless steel type in various solutions in three places in the region of Dakar, Senegal (Yoff, Rufisque and Sébikhotane) representing different bathroom environments and classify them in order of aggressiveness. The solutions under study are drinking water, soapy water, chlorinated soapy water and sea water (chloride ions presence).

For the purpose, we carried out physical observations through sweating technique, determined the Ryznar stability and Langelier saturation indexes of the solutions under study, monitored free-corrosion potentials, plotted the Evans diagrams and evaluated the Tafel extrapolation data's of a 316 stainless steel shower column in the studied solutions.

2. EXPERIMENTAL

2.1. Equipment

The sample under study is a piece of shower column made of stainless steel type 316, the composition of which is given in Table (1). Figure 1 presents examples of corroded shower columns operating on various sites.

2.2. Solutions under study

The aqueous solutions used in this study are drinking or tap water, cleaning soapy water, chlorinated soapy water and seawater samples. The physicochemical composition of drinking water samples is presented in Table (2).

The shower room atmosphere has a high relative humidity ratio. This air humidity or hygrometry level (H%) is the percentage between water steam partial pressure in air and saturated vapor pressure at the same temperature [17].

Table (1) 316 stainless steel chemical composition (Source: Nouvelle Plomberie Sanitaire, PO. Box. 35701, Dakar, Senegal).

Element	C	Si	Mn	P	S	Ni	Cr	Mo
%	0.05	0.74	2.03	0.02	0.01	10.33	17.19	2.34

(a) (b)

Fig. 1. Corroded shower column's high part; (a): Sebikhotane site; (b): Yoff site (seaside)

Table (2) physicochemical characteristics of drinking water solutions of Yoff Layene (A), Rufisque (B) and Sebikhotane (C).

	Drinking water (A)	Drinking water (B)	Drinking water (C)
pH	7.1	7.1	7
Temperature	26	26	26
Conductivity (µs cm^{-1})	441	450	650
Total hardness (10^{-4} mol L^{-1})	16	17.6	31.2
Ca hardness (10^{-4} mol L^{-1})	12	12.8	28
Mg hardness (10^{-4} mol L^{-1})	4	4.8	3.2
Total alkalinity (10^{-4} mol L^{-1})	13.6	15. 6	33.6
Cl^- (mg L^{-1})	8	6	5
NO_3^- (mg L^{-1})	3,4	1,5	2
SO_4^{2-} (mg L^{-1})	21	22	-
Na^+ (mg L^{-1})	35	27	14
K^+ (mg L^{-1})	12.2	21.7	8.3

This moisture content was measured by a hygrometer type Fluke 975V maintained 1 m above the floor. The results of relative humidity measurements were: 77% ± 3 (Yoff), 79% ± 3 (Rufisque), 70% ± 2 (Sébikhotane). Figure 2 shows the localizations of study sites in Dakar.

Fig. 2. Map of the region of Dakar, Senegal.

2.3. Experimental methods

2.3.1. Physical observation through sweating-penetrant testing

The sweating-penetrating testing is an industrial process for welds quality checking. It consists in cleaning the welds surfaces with a solvent, penetrating the cracks or weld defects with a coloring initial treatment product. After a certain time, the color revealing agent permitted to trace the weld defaults or surface defects [18]. In our case the surface defects noticed correspond to corroded zones noted on Fig. 1. We cleaned the shower column's surface with a clean cloth while making sure that the corrosion products were not removed. Then we applied on the surface during 5 minutes a cloth soaked with a DR60 type solvent (Sherwin Inc.), thus permitting a removal of the fats. After cleaning, the alloy was attacked by a penetrating purple coloring type DP55 (Sherwin Inc.) during 15 minutes to enable the entrance of the dye in all the surface defects. The surface was again cleaned with a dry cloth, then with water before sun drying for 2-3 minutes. Finally, we applied a white DR100 type revealing product (Sherwin Inc.) and observed after 10 minutes, surface defects (corrosion) characterized by a revelation in purple of the incursions absorbing the colorant, the not corroded parts were not penetrated by the dye and remained white (color of the tracer product). The sweating-penetrant testing results are presented on Fig. 3.

Fig. 3. Revelation of corrosion pitting through sweating-penetrant testing.

The purple-colored points represent the corrosion pittings locations on the shower column. The unaffected parts of the metal were identifiable by the white color of the indicative product. We could therefore locate and underline the corrosion pittings.

The sweating-penetrant testing was thus suitable for better finding defects areas and work directly on the considered parts for repair or replacement.

2.3.2. Ryznar and Langelier aggressiveness indexes.

The Langelier stability (LSI) and Ryznar stability (RSI) indexes permitted to characterize the solutions through the analytical criterion of under saturation or super-saturation in calcium carbonate ($CaCO_3$) [19].

These indexes indicate a water tendency to corrosion, to equilibrium or to $CaCO_3$ precipitation (insulating protective layer) depending on the saturation pH level and the actual pH [11]-[19]. The saturation pH (pH_S) as well as LSI and RSI indexes are calculated using the LPLWIN V5 software based on the aqueous solution physicochemical composition(temperature, dissolved salts mass concentration, hardness, alkalinity, pH) [12]. The RSI and LSI as functions of pH and pH_S are represented by (1) and (2).

$$RSI = 2pH_S - pH \qquad (1)$$

$$LSI = pH - pH_S \qquad (2)$$

pH_S is calculated according to the formula of Langelier in (3) [19]:

$$pH_S = pK_2 - pK_S - \log [Ca^{2+}] - \log [HCO_3^-] \qquad (3)$$

K_S, Solubility constant of $CaCO_3$.

K_2, 2nd acidity constant of carbonic acid.

$[Ca^{2+}]$, molar concentration in calcium ion (mol L^{-1}).

$[HCO_3^-]$, molar concentration in hydrogenocarbonate ion (mol L^{-1}).

2.3.3. Chronopotentiometry.

The metallic samples external surfaces were cleaned with abrasive papers (P300 and P800 successively) in order to remove the surface oxides layers before rinsing them using a squeeze bottle of distilled water. A sampling of the solutions was then carried out in the selected sites. Ag/AgCl electrode (+198 mV relative to normal hydrogen electrode) was used as the reference. The working electrode was constituted by the shower column and the counter-electrode was a stainless steel grid with a large surface. The electrochemical measurements were performed with a µAutolab III + FRA II, potentiostat/galvanaostat, controlled by the GPES software. The open-circuit potential vs. time (2 hours) were recorded after 30 minutes of stabilization.

2.3.4. Linear polarization (Evans diagram and Tafel extrapolation).

The method consists in linearly varying the potential in a suitable range, including the equilibrium potential, so that the metal or the alloy behaves as a cathode then an anode. We noted that in its anodic behavior, a slight degradation of the metal was observed. The measurements were done just after the free-corrosion potential measurements. The scanning rate was 1 mV/s in the explored potential domain for a cycle. The potential scanning ranged from -336 to 501.3 mV/Ag/AgCl for drinking water, from -798 to 202.3 mV/Ag/AgCl for soapy water, from -1118 to -27 mV/Ag/AgCl for chlorinated soapy water, and from -1073 to -72.3 mV/Ag/AgCl for seawater.

3. RESULTS AND DISCUSSIONS

3.1. Ryznar and Langelier aggressiveness indexes.

The RSI and LSI were determined on 6 water samples: 3 drinking water samples from 'Sénégalaise Des Eaux (SDE)' public water supply network, collected in Yoff Layene (A), Rufisque (B) and Sebikhotane (C) sites, chlorinated soapy water, soapy water and a seawater. The results are summarized in Table (3). The scaling or corrosion tendencies of aqueous samples can be predicted by combining LSI and RSI results interpretations according to Tables (4) and (5).

Table (3) Langelier and Ryznar indexes for drinking water samples from Yoff Layene (A), Rufisque (B) and Sebikhotane (C) sites and for chlorinated soapy water, soapy water and seawater samples.

Samples	(A)	(B)	(C)	Chlorinated soapy water	Soapy water	Sea water
pHs	7.5	7.4	6.9	7.6	8.2	8.9
pH	7.1	7.1	7.0	7.4	7.8	8.5
Temperature (°C)	20	20	20	20	20	20
LSI	-0.4	-0.3	0.1	-0.2	-0.4	-0.4
RSI	7.9	7.7	6.8	7.8	8.6	9.3

Table 4: Interpretation of Riznar stability index (RSI) values [15].

RSI	Tendances
4 - 5	Important scaling
5 - 6	Low scaling
6 - 7	Balance
7 - 7.5	Slight corrosiveness
7.5 – 8.5	Significant corrosiveness
> 8.5	Important corrosiveness

Table (5) Interpretation of Langelier saturation index (LSI) values [15].

LSI	Tendency
< -2	Important corrosion
-2 < LSI < -0,5	Significant corrosion
-0.5 < LSI < 0	Slightly corrosive but non-scale forming
0	Balanced but pitting
0 < LSI < 0.5	Slightly scale forming and corrosive
0.5 < LSI < 2	Scale forming but non corrosive

The Ryznar stability indexes on drinking water samples (A, B, C) are comprised between 7.5 and 8.5 for Yoff Layene (A) and Rufisque cities in Table (3). Indeed, their Langelier indexes are slightly negative (between -0.5 and 0). These results are indicative of a significant corrosiveness but without noticeable scaling [15] of these samples. In contrast, for Sebikhotane the slightly positive value of the Langelier index combined with a Ryznar index comprised between 6 and 7 suggest an equilibrium tendency with a low scale formation [15].

Regarding the 3 water samples of the environment, the Ryznar stability index values Table (3) indicated an important corrosion on soapy water and seawater and a significant corrosion on chlorinated soapy water. The Langelier saturation index values comprised between -0.5 and 0 for the three samples were compatible with a non-scale formation.

The important corrosiveness in seawater sample explains the apparently higher corrosion observed in stainless column of a coastal city (Yoff) compared to a non-coastal one (Sébikhotane) for the same duration of exposure (4 years) (Fig. 1).

The equilibrium tendency with a low scale formation on Sébikhotane drinking water samples is a quality factor consistent with works reported by Beaulieu et al. [16], which specify that drinking water (intended to human consumption) must have a calcium and carbonate balance or slightly scaling.

These aggressiveness indexes processing remain empirical and limited [20], which requires the study of the stainless steel shower column electrochemical behavior through electrochemical and computing polarization methods in each of those environments to better understand corrosion presence or absence and the kinetics (in a corrosion case).

3.2. Open-circuit potentials (OCP).

Fig. 4 represents the curves of potential vs. time for a stainless steel shower column sample in the following electrolytes: drinking water, soapy water, chlorinated soapy water and sea water. The potential decreased in the first few minutes and this may be due to the dissolution of an oxide film that was formed on the surface [21, 22]. For all the samples, the potential seemed to stabilize to virtually constant values which were assumed to correspond to the OCP. The results also showed free-corrosion potentials stability in drinking and soapy waters, which is not the case with chlorinated soapy water and sea water. This explains why the stainless steel OCP measurements could need a longer equilibrium time, ranging from 1-2 h to gain stability.

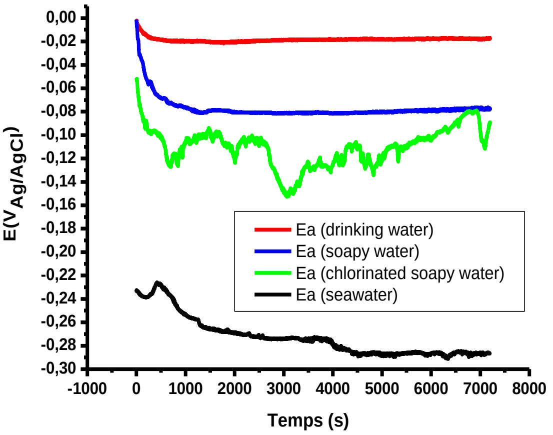

Fig. 4. Variations of the open-circuit potential with time in various electrolytes for the stainless steel shower column.

OCP values obtained from Fig. 4 were (V/Ag/AgCl) -0.018 for drinking water, -0.078 for soapy water, -0.091 for chlorinated soapy water and -0.286 for sea water. This showed that the stainless steel OCP was more cathodic (-286 mV/Ag/AgCl) in sea water and that the most anodic value was obtained in drinking water (-18 mV/Ag/AgCl).

3.3. Current density– voltage curve, Evans diagram and Tafel extrapolation.

Fig. 5 represents the polarization curves of the stainless steel shower column in the following electrolytes: drinking water, soapy water, chlorinated soapy water and sea water. The corrosion potentials (E_{corr}) recorded in Fig. 4 were -0.324 V (drinking water), -0.534 V (soapy water), -0.751 V (chlorinated soapy water) and -0.967 V/Ag/AgCl (sea water). The OPC recorded in Fig. 4 were respectively -0,018, -0,078, -0.091 and -0.286 V/Ag/AgCl. Those OCP values are relatively very distant the ones from the others, which explains why this stainless steel type free potential corrosion study needs a measuring time longer than 2 hours.

The polarization curves include a cathodic branch where we can note an overall reduction of the charge quantity or current density when the potential increases. The main corresponding reaction (4) in our case (neutral or close to neutrality and ventilated aqueous solution) would be the following:

$$O_2 + 2H_2O + 4\,e^- \longrightarrow 4OH^- \qquad (4)$$

The anodic curves branches present an attack of the stainless steel varying from -0,3 to -0.24 V/Ag/AgCl in drinking water, from -0.53 to -0.44 V/Ag/AgCl in soapy water, from -0.74 to -0.67 V/Ag/AgCl in chlorinated soapy water and from -0.95 to -0.52 V/Ag/AgCl in sea water. This corrosion phase corresponds to alloy dissolution in all the environments under study (even corrosion) [23].

The attack is followed by quite stationary level for the current density values between -0.24 and -0,08 V/Ag/AgCl for drinking water and between -0.44 and -0.17 V/Ag/AgCl for soapy water. These low current density increases correspond to the passivity or creation of thin protective layers on the stainless steel surface. This phase is followed by a transpassivity or loss of passivity for a continuous or uniform corrosion starting from -0.085 V/Ag/AgCl for drinking water and -0.17 V/Ag/AgCl for soapy water until the polarization ends.

A fast pitting corrosion is noted in soapy chlorinated water and seawater since the respective potentials of -0.67 and -0.52 V/Ag/AgCl until the polarization ends. This indication is confirmed by the free-corrosion potential curves in Fig. 3 which clearly show a continuous decrease consistent with an attack of the steel. The presence of chloride ions in those solutions could justify this important corrosion. In fact, the chloride ions would disperse the stainless steel passivity products. The chloride ions aggressiveness is caused by their small size (small diameter), their polarity nature and their mobility [24]. This is testified by the shower column observation in seaside Fig. 1 (b) dwellings (presence of chloride in the humid air) which present more accentuated corrosion degrees than in the other areas.

The Tafel extrapolation data summarized in Table (6) show that the shower column corrosion speeds are relatively similar in the solutions of sea water (209.4×10^{-5} mm/year) and chlorinated soapy water (186.7×10^{-5} mm/year) on one hand, and in the solutions of drinking water (1.318×10^{-5} mm/year) and soapy water ($1{,}96.10^{-5}$mm/year) on the other.

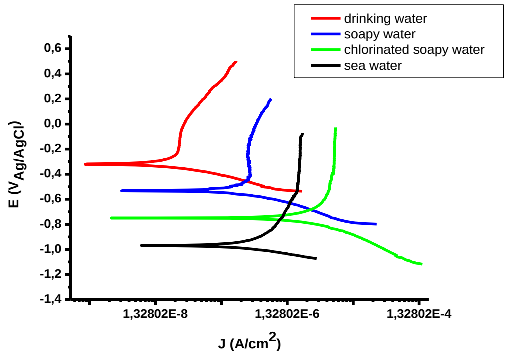

Fig. 5. The Evans diagrams of the stainless steel shower column in various electrolytes.

The corrosion speeds for seawater and chlorinated soapy water are at least 95 times more important than in drinking water and soapy water solutions.

Likewise the polarization resistances are more important in drinking water ($5.4x10^{+4}$ ohm) and soapy water ($4.2x10^{+4}$ ohm) solutions than in chlorinated soapy water ($1.1x10^{+3}$ ohm) and sea water ($5.5x10^{+2}$ ohm) solutions. This is in accordance with the corrosion speeds tendencies discussed above.The corrosion currents and their densities substantiate the analyses based on the corrosion speed and polarization resistance. Thus most important currents or current densities correspond to a most important corrosion in general case.

The corrosion potentials observed and calculated according to Tafel extrapolations datas are very close for each solution under study.

The higher ions concentrations in seawater chlorinated soapy are responsible for the existence of "critical" electrochemical corrosion potentials by pitting on the stainless steel. The hypochlorite ions (ClO^-) intervene as

Table (6) Tafel data summary

Aqueous solutions	Drinking water	Soapy water	Chlorinated soapy water	Sea water
Observed E_{corr} (V/Ag/AgCl)	-0.32	-0.53	-0.75	-0.969
Calculated E_{corr} (V/Ag/AgCl)	-0.32	-0.53	-0.74	-0.978
J_{corr} (µA/cm^2)	0.009656	0.01436	1.367	1.534
I_{corr} (µA)	0.0728	0.1083	10.31	12
R_p (□/cm^2)	$1.828x10^{+5}$	$1.263x10^{+5}$	$0 .024x10^{+5}$	$0 .015x10^{+5}$
R_p (□)	$5.429x10^{+4}$	$4.204x10^{+4}$	$0.106x10^{+4}$	$0.055x10^{+4}$
Corrosion rate (mm/year)	$1.318x10^{-5}$	$1.96x10^{-5}$	$186.7x10^{-5}$	$209.4x10^{-5}$
βa (V/dec.)	0.143	0.133	0.172	0.215
βc (V/dec.)	0.06	0.79	0.15	0.07
Samples surface (cm^2)	7.53	7.53	7.53	7.53

oxidizing agents which increases the free-corrosion potential until values equal or superior to critical values, thus causing a natural corrosion of the steel and therefore an increase its corrosion speed [25]. Besides, the stainless steel corrosion by the hypochlorite ions is corroborated by other studies [26]-[27]-[28].

The relatively low corrosion speeds are explained by the presence of calcium carbonate ($CaCO_3$) in drinking water according to the conclusions of the Ryznar and Langelier indexes, and also soap presence. Glue and soap cause no difficulty to corrosion which explains close corrosion speeds between drinking water and soapy water, whereas calcium carbonate is a corrosion inhibiting substance [29].

9. CONCLUSION

This study showed that stainless steel shower column corrosion is more emphasized in seawater and chlorinated soapy water. The chloride presence in both media would be the cause, through the destructive attack of stainless steel passivity layers. Moreover, corroded samples observation shows that Yoff Layene site, closed to the sea, therefore probably more rich in chloride ions in the air, presents more important corrosiveness than Sébikhotane site. The material (stainless steel 316 column) is not appropriate for seaside use or cleaning with chlorinated soapy water. The results permit to establish that the stainless steel 316 behavior in seawater is nearly the same in chlorinated soapy water. This testifies that this material is neither adapted to marine atmosphere (moist and rich in chloride), nor to cleaning methods using chlorinated soapy water.
Drinking water and soapy water solutions are not very corrosive (very slow speed) towards stainless steel.
That is consistent with the absence of visual corrosion on the shower columns vertical parts in contact with city water and soapy water during shower and washing.
The sweating-penetrant testing as an observation method can help better locate corrosion pitting and their density however as it does not indicate the pitting depth.
This work creates prospects for further study on dust deposits impact and the surface condition, thus, of the internal microstructure related to stainless steel 316 shower column thermal treatments on the results submitted in this study.

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AUTHOR’S PROFILE


Image of Author

El Hadji Aliou DIOP, electromechanical engineer,
Candidate of Phd
Ecole Doctorale Développement Durable et Société.
University of Thies, Senegal.