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# Corrosion of surface facilities of an industrial concern in the niger delta area of Nigeria splased by produced water

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**Abstract**

A study of uniform corrosion of carbon steel pipeline by produced water that splashed continuously on it is presented. The predominantly uniform attack was essentially the conventional corrosion mechanism that was accelerated by chloride-assisted $CO_2$ corrosion additive. The high $Cl^-$ and $HCO_3^-$ contents of the produced water were additional corrosion drivers. The paint was rapidly destroyed by the $Cl^-$ ions of the produced water, thus exposing the metal predominantly to uniform corrosion. Attempts to wire-brush the corroded steel, preparatory to repainting them led to leakages. The corrosion incidence was remedied by the abatement of discharge of the produced water from the line and replacement of the lines that developed sporadic leaks at different intervals and different points. Insulation of the facilities from contact with the produced water could also suffice to stop the attack. The importance of ensuring that produced water does not splash or come into contact with the external surface of any facility during drainage, is underscored.

*Keywords:* Produced water; Corrosion; Surface facilities; Industrial concern

## 1. Introduction

Flowlines and pipelines transporting fluids like crude oil and natural gas from one location to the other, in some instances covering distances of thousands of kilometers, are subject to external and internal corrosion. If the corrosion processes are not mitigated or stopped, the pipelines could be eaten through. Ruptures thereby result, often leading to fire outbreak and serious environmental pollution. Human lives and high economic tolls are direct consequences of such disasters. Regular and stringent monitoring of such facilities is therefore instituted to obviate the occurrence of such ugly incidents. Any presentation of corrosion incidence is therefore a candidate for thorough investigation with the aim of establishing the corrosion drivers and the corrosion mechanism so that mitigating and abatement measures could be carried out promptly. Figure 1 show typical extensive corrosion of some facilities of industrial concerns in the Niger Delta area of Nigeria.

## 2. Materials and method

In situ inspection revealed that the facilities were splashed with produced water that was discharged from one of the lines. The corroded parts were extensive and uniform in most of the cases with some pitting presentations in some of the depressions and crevices where water stagnated. The facilities around which were not contacted by the produced water did not corrode. The produced water was therefore queried. Produced water associated with oil and gas production depending on the location has varying concentrations of elements that are corrosive to steel pipelines. Samples of the produced water were analyzed using the atomic absorption spectrophotometric method for the determination of the concentration of iron and the standard wet chemical analytical method for the determination of the concentration of other species (Vogel, 2006).



a.



b.



c.

Fig.1. Corrosion caused by the produced water splashing on the facility.

## 3. Results and discussion

The results of the analyses are presented in table 1. The low iron content of the water attests to very low internal corrosion of the line because of an effective corrosion inhibition regime coupled with the formation of a protective carbonate scale. Furthermore the low concentration of $SO_4^{2-}$ anions indicates the absence of sulphate reducing bacteria microbial corrosion incidence. Differential aeration corrosion occasioned by the differential concentrations of oxygen was not indited because few stagnant droplets or pools of the water were present. The presence of $H_2S$ a powerful corrosion agent is not indicated in the water analyses. The anodic depolarizers could well be the, $Cl^-$ and $HCO_3^-$ anions.

Table 1
Produced water concentration

| S/N | SPECIE | CONCENTRATION |
|---|---|---|
| 1 | $Na^+$ | 5179.85 ($mgl^{-1}$) |
| 2 | $Cl^-$ | 6977.28 ($mgl^{-1}$) |
| 3 | $Mg^{2+}$ | 31.40 ($mgl^{-1}$) |
| 4 | $HCO_3^-$ | 1976.40 ($mgl^{-1}$) |
| 5 | Fe | 0.34 ($mgl^{-1}$) |
| 6 | $SO_4^{2-}$ | $\angle$ 1.00 ($mgl^{-1}$) |
| 7 | $CaCO_3$ | 1620 ($mgl^{-1}$) |
| 8 | pH | 7.94 |

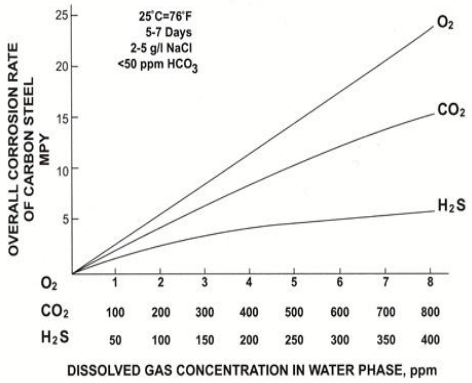


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Fig. 2. Dissolved gas concentration in water phase, ppm.

### *3.1. Effect of $HCO_3^-$*

Fig. 4. was generated for 2-5$gl^{-1}$ of NaCl at 25°C. The NaCl content of the produced water (table 1) is close to that of Fig. 2. The splashing action however, lingered for many more days and the ambient temperature was well above 32 °C and the concentration of the bicarbonate anion, $HCO_3^-$ of 1976.40 $gl^{-1}$ is well above the maximum limit shown in Fig. 4. The combination of these three factors should cause the bicarbonate ion to accelerate the corrosion of the carbon steel facilities. Furthermore the relatively high $HCO_3^-$ concentration attests to the preponderance of $CO_2$ corrosion mechanism. The high $Cl^-$ anion concentration is indicative of high chloride content that is balanced by the relatively high $Na^+$ cation concentration. The preferential close

association of the $Cl^-$ anions with the $Na^+$ cations rather than with the $H^+$ cations maintains the pH of the produced water at the near neutrality value of 7.94. According to (Nesis et al., 1995; Waard and Milliams, 1975; Shmidt and Rothman, 1977), $CO_2$ corrosion is given by reaction (1) because it is thought that the process is associated with the formation of $FeCO_3$ which may or may not passivate the surface of the metal.

$$Fe + CO_2 + H_2O = FeCO_3 + H_2 . \quad (1)$$

Reaction (1) shows that the anodic reaction involves the anodic dissolution of iron and a cathodic evolution of hydrogen. This reaction takes place through a series of stages proposed by researchers (Waard and Milliams, 1975, Schmidt and Rothman, 1977; Bonis and Crolet, 1989) as follows:

$$CO_2 + H_2O = H_2CO_3 \quad (2)$$

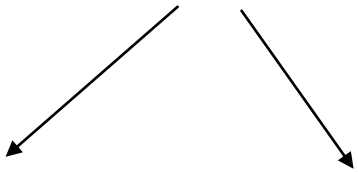
$$H_2CO_3 = H^+ + HCO_3^- \quad (3)$$

$$HCO_3^- = H^+ + CO_3^{2-} \quad (4)$$

Carbonic acid provides a reservoir of $H^+$ ions at a given pH. Hydrogen evolution is therefore assumed to be the most dominant cathodic reaction.

When hydrogen ions $H^+$, diffuse through the diffusion boundary layer to the metal surface, hydrogen evolution involving intermediate adsorbed hydrogen atom will take place as shown below:

$$H^+ + e^- = H_{ads} \quad (5)$$



$$H_{ads} + H^+ + e^- = H_{2_{ads}} \quad (6) \qquad H_{ads} + H_{ads} = H_{2_{ads}} \quad (7)$$

i.e. as the hydrogen ion is being reduced (5), the resulting adsorbed hydrogen atom $H_{ads}$ can either recombine with another adsorbed hydrogen atom to form $H_{2ads}$ (7), or it has the possibility to undergo another charge transfer step by reacting with a hydrogen ion and an electron to form $H_{2ads}$ (6). This additional charge transfer reaction (6) is first proposed by (Heyrovsky, 1925) and is also known as Heyrovsky's reaction. On the other hand, the slow recombination reaction (7) assumed by Tafel (1905) is the best-known rate determining chemical reaction.

The anodic reaction:

$$Fe = Fe^{2+} + 2e^- \quad (8)$$

is therefore sustained by :

- The steady evolution of hydrogen gas that is provided by carbonic acid dissociation.
- The steady diffusion of the adsorbed hydrogen atoms into the metal with a probable "burrowing" effect.
- The corrosion product detachment or peeling by the formed adsorbed hydrogen gas (see arrow in Fig. 2).

These three mechanisms resulted in accelerated and severe corrosion of the facilities and produced leaks until the drainage of the produced water was discontinued from the line.

### *3.2. Effect of $Cl^-$*

The high content of the $Cl^-$ ion of the produced water would indicate its reaction with Fe to assist the anodic iron dissolution according to reaction (9).

$$Fe^{2+} + 2Cl^- = FeCl_2 \quad .(9)$$

It must however, be pointed out that the traditional aqueous corrosion involving the following reactions must be active.

$$Fe = Fe^{2+} + 2e^- \quad (10)$$

$$O_2 + 2H_2O + 4e^- = 4OH^- \quad (11)$$

$$2H_2O + 2e^- = H_2 + 2OH^- \quad .(12)$$

The effect of the $HCO_3^-$ anion is to further corrosion acceleration additive. The above hypothesis was tested in the laboratory by immersing carbon steel coupons in the distilled water and in produced water for five days at ambient temperature of 32 $^oC$. The corrosion of the coupons immersed in the produced water was very severe and the corrosion rates were as high as 40mpy (Fig. 3) while those immersed in distilled water (Fig. 4.) had corrosion rates of about 5mpy.

## 4. Conclusion

The corrosion rate was essentially the conventional aqueous corrosion mechanism that was accelerated by chloride-assisted $CO_2$ corrosion additive. The corrosion incidence was remedied by the discontinuation of produced water discharge from the line. The affected lines and those

that developed sporadic leaks, at different time intervals, and at different points, were subsequently replaced.



Fig. 3. Coupon immersed in produced water, corr. rate =40mpy.



Fig. 4. Coupon immersed in distilled water, corr. rate=supply.

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