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The Use of Iron Counts for Corrosion Rate Prediction in a Seawater Injection System: A Field Study, Offshore Nigeria

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ABSTRACT

As one of the critical parameters for monitoring corrosion protection in the Meren Water Injection System (MWIS), offshore Nigeria, iron counts are obtained daily at the water injection platform and once weekly at the well jackets. Trends in iron counts were monitored along with daily water injection and system changes from 1994 to 2003. This study extended the value of the iron counts data by relating iron production to corrosion rate based on water injection volume, using 10 years of field data. The system corrosion profile was reviewed on the basis of failure history, iron counts, bacteria trends, and biofouling of the deoxygenating equipment. The principle of the Corrosion Rate-Production Rate (COPRA) Correlation method was utilized in predicting the equivalent average corrosion rate in the system. An approximate corrosion rate determination based on iron counts and daily injection data has been demonstrated by the study. The value of iron counts data for corrosion monitoring was enhanced by converting the data to iron production. Observations from this study further justify the use of iron production in preference to iron counts data for corrosion monitoring purposes. Although the COPRA Correlation was applied normally to only gas systems, this study extended the COPRA Correlation technique to water injection systems. The value of this article to the operating oil company has been to allow closer monitoring of corrosion rates by non-invasive methods, thereby ensuring improved flow assurance integrity while minimizing the cost of the monitoring program.

Keywords: corrosion, Freshwater, Water injection, Flow assurance, Iron counts, Seawater, Rate, and biofouling

INTRODUCTION

As already established, iron counts data can be converted to iron production. This study attempted to extend the value of the iron counts data by relating iron production to corrosion rate based on water injection volume. The principle of the COPRA Correlation method was utilized in predicting the equivalent average corrosion rate in the system.

The water injection facility is located 14 km (8.8 miles) from the nearest shoreline offshore Nigeria, in the Niger Delta area. The ocean depth at this location is about 14 m (46 feet) of water. There are 12 injection wells that provide water to support nine reservoirs in the Meren Field. The injection wells are located on seven well jackets situated between 1.6 km (1.0 mile) and 5.2 km (3.2 miles) away from the injection platform. Injection water is distributed to the well jackets via two 14-inch lines and one 16-inch line. The MWIS is designed to produce treated seawater of 1 .04 specific gravity in the flow range of 24,000 to 200,000 BWPD maximum at a pressure of 3,500 psig (34,132 kPa) at the seawater injection pump discharge. Water treatment program comprises chlorination, filtration, deaeration, biocide, scale and corrosion inhibitor treatments.

This study extended the value of the iron counts data by relating iron production to corrosion rate based on water injection volume.

METHODS

Data Collection and Analysis

For the study, data collection covered the period 1994 to 2003, and included the following: Iron Counts, Bacteria Counts, Corrosion/Leak History, and Failure Analysis Reports. Historically, the Meren Water Injection System has a corrosion profile of <1 to 5 mpy, depending on the effectiveness of chemical treatment, oxygen control and system dynamics. A 0.8-mis (2.3- ft/sec) flow velocity was measured in May 2009 at Jacket 5, situated 3.3 kilometers from the injection platform. Table 1 presents the history of leaks reported as number of barge jobs to repair leaks at the well jackets and injection platform.

Table 1: Meren Water Injection System Leak History

Year	Number of Leaks
1994	25
1996	9
1998	5
2000	4
2003	3
Reduction in # Leaks (1994-2003)	22

From 1994 to 2003 the cost to fix leaks was estimated at about $50,000 per leak based on 3- day barge charges, labor and material costs. Therefore, the 22 leaks reduction could translate into approximately $1.1 million savings between 1994 and 2003. Reduction in leaks was drastic between 1994 and 1995. Pre-1994 performance of the deaeration and chlorination units was not acceptable. Moreover, water quality and corrosion monitoring were not effective until mid 1994.

A 2003 failure analysis report of corroded downhole tubing indicated a combination of MIC and oxygen corrosion. Microorganism Influenced Corrosion (MIC) was due to sulfate reducing bacteria (SRB) attack. Before 1994, the deaerator packings had collapsed due to heavy buildup of biomass. During that period, the electrochlorinator had not performed satisfactorily. The use of biocides could not effectively replace chlorine treatment for microbiological growth .control.

Typical iron counts profile across the system is presented in Table 2. Based on plant history, iron and bacteria data were analyzed for correlations and corrosion trends. Iron determination was by the colorimetric method, employing the HACH's DR-2000 Spectrophotometer. Bacteria monitoring was by the API RP 38 serial dilution method.

Details of the bacterial test method are contained in NACE Standard TM 0194-94g.

Table 2: MWIS Typical Iron Counts Profile

Location	mg/I Total Iron, Typical
Filter Inlet	0.0-0.5
Filter Outlet	0.0-0.1
Deaerator Outlet	0.0 -0.1
Well Jacket #34	0.2 - 1.2
Well Jacket #59	0.3 - 0.6
Well Jacket #61	0.2- 1.7

RESULTS AND DISCUSSION

Figures 1 and 2 show the SRB data for the period 1994 through 2003. Note that Figures 1 and 2 illustrate the bacteria trend across the system. Bacteria measurements were carried out across the system. For the period under review, SRB counts ranged between 0 and 10 colonies per milliliter at the Filter Outlet location. At the Deaerator Outlet the SRB counts had ranged between 0 and 1000 colonies per milliliter, with an average maintained around 100 bacteria/ml. The observed trend could be explained in terms of the effectiveness of chlorine treatment.

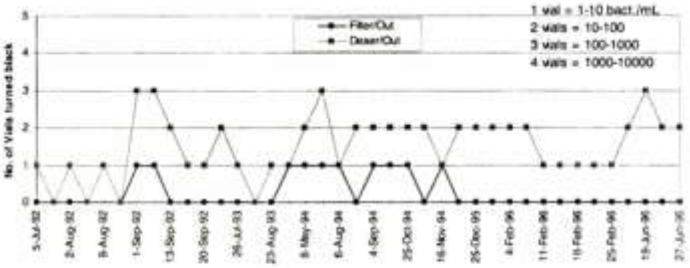

Figure 1: MWIS SRB COUNTS AT THE PLATFORM

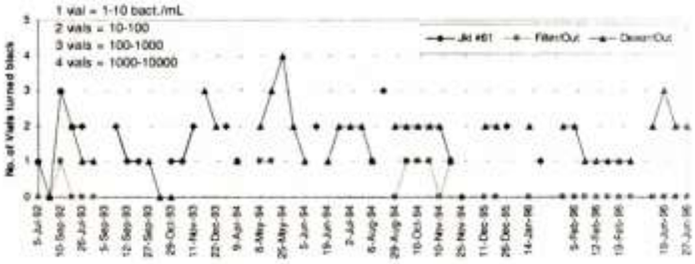

Figure 2: MWIS SRB COUNTS ACROSS THE SYSTEM

Typical chlorine concentration at the Filter Outlet is 0.5-1 .25 ppm. Residual chlorine at the Deaerator Outlet is usually zero due to gas stripping and removal of chlorine with the oxygen scavenger chemical. Zero-chlorine condition at this location is desirable in order to prevent chlorine corrosion of the injection flowlines and well tubings. Control of microbiological growth is therefore more difficult at the deaerators than at the filters.

Figure 2 compares bacteria control between the water injection platform and the farthest wellhead platform, Jacket 61. Jacket 61 is about 5.2 km from the water injection plant. Control of microorganisms downstream of the deaerators and into the reservoir is by use of organic biocides, otherwise known as secondary or supplementary bactericides. The primary bactericide is chlorine, which has proved to be most effective biocide for controlling microorganisms in seawater injection system Figure 2 indicates identical trends in SRB counts at the deaerators and the amounts measured at the well jackets. The bacteria charts reveal up- and-down trends in the bacteria counts. This is typical of microbial growth in batch treated systems. Biocide protocol for this system required twice weekly batch treatments with alternate biocides injected at a batch rate of 150-200 ppm for four hours. Most of the data reported were collected just before repeat shock treatments.

Monitoring was by the API serial dilution method3. Therefore only planktonic SRB bacteria populations were measured. The correlation between planktonic and sessile bacteria has not been well established in the published literature. Sessile bacterial population depends on system dynamics and cleanliness. While few investigators believe in some kind of relationship between sessile and planktonic population4 most nave shown that such a correlauor S ‘or and could lead to costly mistakes in the interpretation of monitoring data5. It should be emphasized here that bacterial eradication is practically impossible, and the zero numbers shown in the charts are as indicated by the planktonic monitoring of SRB. This could represent between 10% and 50% of the total bacteria present in the system. Therefore the bacteria trend is more important than actual numbers in monitoring the biological corrosion or the effectiveness of the biocide program.

Iron counts data were collected for approximately 8 months' period, namely July 1999 through February 2000. The iron data were analyzed for two systems transmitting injection water to the various' well jackets. Iron concentration in the water was converted to iron production for each system according to the following relationship[1]:

{Fe **(lb/day)**} = (3.5x104}.[Fe (mg/l)].{**BWPD**}
(1)

or:
{Fe(kg/day)}={ 1.5876x1 04}.[Fe(mg/l)j.{BWPD}
(2)

The routine iron counts are reported in mg/I of total iron in the injection water. Water flow rate through each water injection manifold is reported in barrels of water per day (BWPD). Each system or injection manifold delivers water to the wellhead platforms (well jackets) where the water is distributed into the individual injection wells. Iron counts are measured at the well jackets and the BWPD readings are the volumes between the water injection platform and the wellhead platform, i.e., the daily water injection through the well jacket. The farthest well jacket (Jacket 61) is situated at 5.2 km away from the injection platform. The closest well jacket in this study (Jacket 52) is situated about 1 .6 km away from the water injection plant. Jackets 34 and 5 are about 2.4 km and 3.3 km, respectively away from the water injection platform (MWIP). Only data from Jackets 5 and 34 are analyzed in this study. Data from the other well jackets are not analyzed due to low reality of data and/or the need for indirect estimate of flov6rate, which should have an attendant error factor.

Table 3: Line Size and Well Jocket Distance from, Injection Platform

Route		Total Length		Line (in)			Eqvt. Exposed Area
From	To	Km	Miles	Nom, Size	WT	ID	(Sq. In.)
MWIP	JKT	2.425	1.507	14	0.625	12.750	3,826.765
34		3,250	2.020	16	0.688	14.624	5,882,056
MWIP	JKT 5						

From equation 1 and the line data presented in Table 3, an estimate of average general corrosion rate was determined based on iron production. If iron production is considered a general mass loss of the carbon steel injection flowline, then an approximate corrosion rate may be estimated as equivalent corrosion rate (Eqvt CR) using equation 3:

$$\text{Eqvt. CR(mpy)} = \frac{\left\{Fe\left(\frac{kg}{day}\right)\left(2.227x10^{7}\right)\right\}}{\left\{\left[Area\left(in^{2}\right)\right]\left[Density\left(\frac{g}{cm^{3}}\right)\right]\right\}} \tag{3}$$

Equation 3 could be expressed in metric form as:

$$\text{Eqvt. CR}\left(\frac{mm}{yr}\right) = \frac{\left\{Fe\left(\frac{kg}{day}\right)\left(3.649x10^{7}\right)\right\}}{\left\{\left[Area\left(cm^{2}\right)\right]\left[Density\left(\frac{g}{cm^{3}}\right)\right]\right\}} \tag{4}$$

A density of 7.86 g/cm3 is used as generally applied to weightloss corrosion rate calculations for carbon steel6. 2.227x107 and 3.649x106 are unit conversion factors. The exposed surface area as shown in Table 3 is estimated as the internal surface area of pipe, assuming fluid-packed flow condition. Area is given in equation 5 as:

$$\mathbf{A = \{\pi .(ID).(L.63370)\}} \qquad \mathbf{(5)}$$

Where it = 22/7; L is length in miles; ID is pipe internal diameter in inches; and A is the exposed internal surface area of pipe in square inches. 63370 is unit conversion factor from miles to inches.

When equations 1 through 5 are applied to the iron counts data, interesting results were obtained, which show good correlations among iron counts, iron production and equivalent corrosion rate. These results are shown in Figures 3 through 5. The results indicate that, for corrosion protection of < 5 mpy for this system, iron counts of < 0.9 mg/I or < 15-23 lb/day (6.8-10.4 kg/day) iron production will be required under normal plant conditions of chemical treatment and velocity regime. The sensitivity of the calculated corrosion rate to iron production varies depending on the flowline system. For example, iron counts in the Jacket 5 system must be controlled to < 23 lb/day (10.4 kg/day) in order to achieve < 5 mpy corrosion protection. This threshold is lower for the Jacket 34 system, which must be controlled below 15 lb/day. The higher sensitivity of the Jacket 34 system cannot be explained in terms of flowrate or exposed surface area. Jacket 5 flowline is 16-in (406-mm) ID and 2.020 miles (3.250 km) long, resulting in estimated exposed surface area of 5,882,056 sq in (3,795 m2). On the other hand, Jacket 34 flowline is 14-in (356-mm) ID and 1.507 miles (2.425 km) long, with an estimated exposed surface area of 3,826,765 sq in (2,469 m2). Similarly, average water injection volumes through Jackets 5 and 34 are 84,000 BWPD and 60,000 BWPD, respectively.

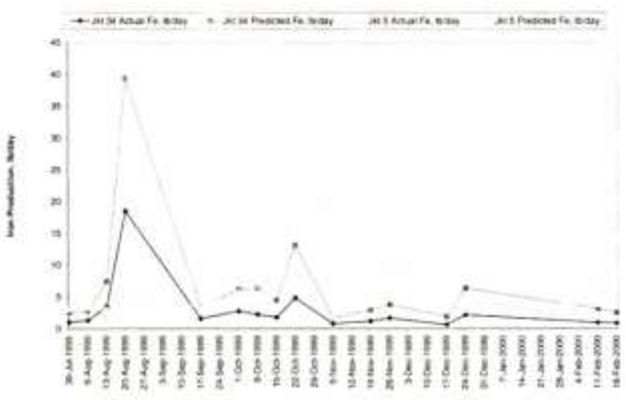

Figure 3: Iron Production Trends for Jackets 5 and 34: Actual and Predicted Compared

In general, the higher the volume the more detrimental is the iron concentration in the water. Also, the larger the surface area, the higher the iron production for a given corrosion rate. The use of iron production numbers therefore offers some averaging effect on the iron counts data, and hence more representative of the system corrosion profile. This observation further justifies the use of iron production in preference to iron counts data for corrosion monitoring1.

However, the observed relationship should be applied on case-by-case basis to predict average corrosion rate for each jacket system. These relationships are given in equations 6 and 7 for Jackets 34 and 5.

For jacket 34:

$$\text{Eqvt. CR}(mpy) = 7.151\ \left\{Fe\left(\frac{mg}{l}\right)\right\}$$

For jacket 5:

$$\text{Eqvt. CR}(mpy) = 6.352\ \left\{Fe\left(\frac{mg}{l}\right)\right\}$$

Based on the water injection volumes through each system, an average (geometric) equivalent general corrosion rate for the water injection system may be given as:

$$\text{Eqvt. CR}(mpy) = 6.818\ \left\{Fe\left(\frac{mg}{l}\right)\right\}$$

Performance of equation 8 in predicting the equivalent corrosion rates in the two well-jacket systems was compared with those of equations 6 and 7 as shown in Figures 4 and 5. As demonstrated in Figures 4 and 5 , the correlation is in agreement with similar trends reported in the literature[7].

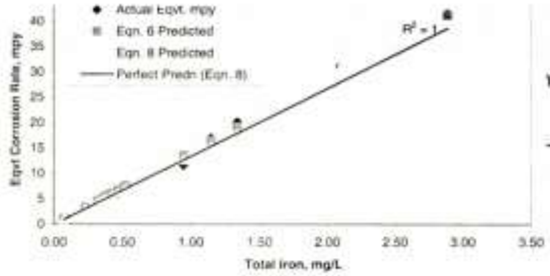

Figure 4: Performance of Prediction Models on Jacket #34 Iron Counts Data

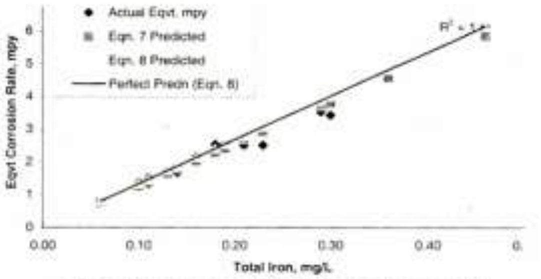

Figure 5: Performance of Prediction Models on Jacket #5 Iron Counts Data

Ideally, caution is recommended in the use of predictive tools for corrosion monitoring. In this case, corrosion prediction is based on iron counts, and this requires reliability of the iron counts data. Iron measurement must therefore account for iron that may precipitate out in the system or added from the source by means other than corrosion. Therefore the baseline iron concentration (i.e., iron exiting the injection plant) must be subtracted from the total iron measured at the well jackets. In those water injection systems with cartridge filters at the wellhead, the impact on corrosion prediction of iron removal by filtration should be accounted for. The predicted equivalent corrosion rates are general average rates under normal system operating conditions. Therefore the effects of pitting, velocity, chemical treatment, and water chemistry have been considered but not accounted for separately.

CONCLUSIONS

1. Approximate instantaneous corrosion rate has been correlated, in the study, to iron counts for two jackets in the Meren field. Corrosion rates based on equivalent iron production can be calculated based on daily production data.
2. It is possible to correlate iron counts data to corrosion rates. However, this should not be based on theoretical models alone. Such correlation should be based on system history and take into account the limitations of corrosion prediction based on iron counts, e.g., the reliability of the iron counts data and the possibility of pitting corrosion.
3. It is recommended for a further study, to simulate with data collected, so as to compare the predicted corrosion rates based on iron counts with those obtained with weight loss coupon measurements.

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