PRJ, Vol. 5 (January 1993); P16–21, 5 FIGS, 2 TABLES.

CORROSION CONTROL IN DEFA WATERFLOOD SYSTEM

M.A. Elarabi*

التحكم في التآكل بمنظومة حقن المياه بحقل الدفا

ميلود عبد السلام العربي

تقدم الدراسة أمثلة عملية لإختيار أنسب المثبطات الكيميائية لمعالجة التآكل في منظومة حقن المياة بحقل الدفا باستخدام أجهزة قياس ربطت على وصلة جانبية قريبة من رأس أحد الآبار المنتجة للمياه لكي تطابق متغيرات ظروف التشغيل المختلفة.

ABSTRACT

Practical methods are presented to select different biocides and corrosion inhibitors for the DEFA waterflood system. It involves the use of side stream bacteria detection on mounted probes and potentiodyne technique on the well head of a source water well. These methods are well suited for application in systems where high frequency fluctuations in process variables are encountered. Field examples of corrosion problems and solutions are cited.

INTRODUCTION

The efficient and continuous operation of waterflood system requires complete control of corrosion mechanism which could lead to failure in its components from source water wells to injection wells. The corrosion in DEFA waterflood system is severe because hydrogen sulfide, carbon dioxide, sulfate reducing bacteris (SRB) and changing velocity are involved.

Before adopting a solution to corrosion problems, a complete understanding of each corrosion mechanism and the possibilities of combined mechanisms are necessary.

Field study is conducted to investigate the corrosivity of Zelten formation water utilized in pressure maintenance plan in DEFA oil field. These tests include evaluation of different biocides to mitigate the growth of SRB within the waterflood system and corrosion inhibitors to reduce the corrosion rate. SRB growth can cause a highly localized pitting corrosion in the distribution network and the corrosion product (iron sulfide) contributes to formation plugging, injectivity decrease, corrosion cell formation (different aeration) and survival of anaerobic SRB. Therefore bacterial growth should not be tolerated in the water injection system.

SYSTEM DESCRIPTION

The DEFA waterflood system (Fig. 1) was originally designed in the early 1970's with a capacity of 250,000 barrels of water per day. In the late 1970's, the system was expanded to an ultimate capacity of 500,000 bbls/day. In 1982, the booster station was expanded to provide the additional pressure required for water injection. However, with every attempt to increase the system pressure, numerous leaks occured on the trunk lines and distribution lines, particularly at the extremities where the velocity is less than 1 ft/sec (0.3048 m/sec). Most failures occur in the lower quadrant of the pipe with severe pitting corrosion under heavy iron sulfide scale build up. Waterflood production is divided on severe source wells (WSW) alternatively in operation. Water from source wells flows to pump station and via 24″ mainline and 16″ lateral to the injection wells. Filters are located at the wellhead and facilities for pigging the line are available. Because of present low production levels, only five water source wells are in operation producing a total of 225,000 bbls/day.

* El Fateh University, Chemical Engineering Department, G.S.P.L.A.J.

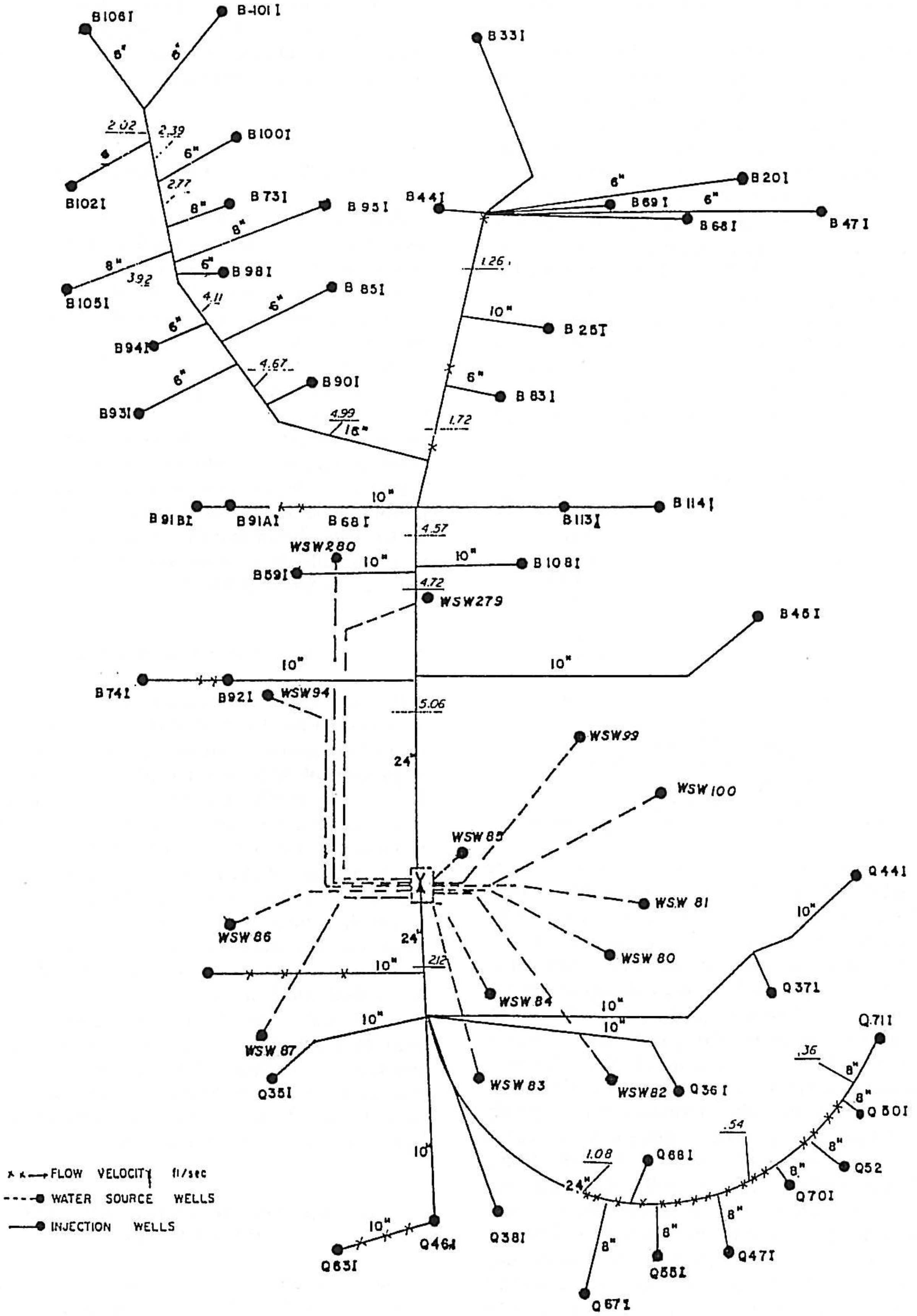

FIG. 1. DEFA water flood system.

WATERFLOOD CORROSION HISTORY

Injection water produced from Zelten formation is highly corrosive due to high temperature, H_2S and CO_2 content, Table 1 shows a typical water analysis for this water. Corrosion failures on the trunk lines started after few years of operation. Section of the pipeline inspected at the failure sites indicated that severe pitting under a heavy layer of iron sulfide scale is taking place. The iron sulfide layer is covered with a heavy layer of organic material, assumed to be inhibitor and crude oil. The crude oil is produced as slug with the produced water. A survey based on serial dilution method, conducted later, confirmed the existence of SRB throughout the system. Also, visual inspection of probes and coupons, used to monitor corrosion, showed black scale (iron sulfide) and highly localized pitting which support the idea that SRB is the main cause of corrosion. It was therefore decided that the possible approach would be to treat both the source water wells and trunk lines with the effective biocide available. This procedure was followed routinely at approximately one month intervals. The source wells have been closely monitored for recurrence of bacteria growth. Only WSW 279 was showing positive SRB growth and complete sterilization has not been achieved. Since this phenomenon doesnot exist in other wells, there is a possibility that the Zelten formation was originally free of SRB. Contamination appears to be caused from an external source near the wellbore during drilling or workover of some wells. Most likely, the WSW 279 is infected in the rathole area (the area between the pump and the bottom hole perforation). As a result of monthly pigging and biocide slug treatment for the 16″ and 24″ trunklines, a marked decline in corrosion rate planktonic (floating) SRB and H_2S levels was noted at the extremities of the system. As a result of continued trunklines leaks, the Company decided to replace the whole injection flowline network with cement mortar lined steel. This, however, will not eliminate further corrosion in source water and injection wells, or formation plugging reduction in water injectivity wells (due to SRB growth).

Table 1. Typical Injection Water Analysis (WSW 85)

Na^+	(mg/l)	4901.0
Ca^{++}	(mg/l)	571.0
Mg^{++}	(mg/l)	170.1
Ba^{++}	(mg/l)	0.13
Cl^-	(mg/l)	2389.0
HCO_3	(mg/l)	427.0
CO_3	(mg/l)	0.0
SO_4	(mg/l)	1379.0
PH	(units)	5.9
Talk	(mg/l)	700.0
H_2S	1–2 ppm (at well head)	
CO_2	4–5 ppm (at end of dist. lines)	
O_2	10–40 ppb	
Iron	300–400 ppm (as $CaCo_3$)	

PLANKTONIC AND SESSILE SRB

Bacterial corrosion is actually caused by sessile anaerobic bacteria living under thick biofilm matrix, debris and sediments in the system, or accumulated corrosion product attached to the metal surface. The visible predominance of iron sulfide in the biofilm, adjacent to the heavily colonized corroded metal surface, is evidence of anaerobics. These anaerobic organisms are believed to play a predominant role in biological corrosion. Planktonic corrosion organisms simply represent a small proportion of the active sessile population of corrosion causing bacteria that happened to detach from the biofilm and enter the flowing phase at a particular point in time. Recent studies have shown that the sessile bacteria population (on cells/cm^2) outnumber the planktonic (as cell/cm^2) by 500 to 50,000 times.

EFFECTS OF BIOCIDES

Present methods of diagnosing bacterial corrosion are based on the detection of planktonic SRB whose intermitted presence indicates a much larger sessile population of SRB that actually live in the lower layers of the biofilm and cause corrosion. Thus the success of certain biocides currently used in the field is illusory in that contaminated systems are detected by the presence of planktonic SRB in injection water used for serial dilution test, and biocides are shown to kill these floating organisms, as indicated by the same test. The quick recurrence of planktonic SRB and continued corrosion, however, indicated that the sessile SRB, which actually caused corrosion, had not been affected by the biocides at the concentration used. Perceiving that a truly successful biocide must penetrate the biofilm and kill the innermost sessile bacteria is entirely misleading and biocide field use must be based on realistic assessment of efficacy against sessile bacterial population.

MECHANISM OF ANAEROBIC STEEL POPULATION

Sulfate reducers, typified by desulfovibrio desulfuricants, use the sulfate ion water as an oxidizing agent for the assimilation of organic matter. They also use high level of iron in their cell structure and are, therefore, prevalent in iron rich environments.

Sulfur reduced from sulfate reacts with available hydrogen and iron to form H_2S and FeS. Apart from the fact that H_2S is highly corrosive, the tying up of iron results in extra dissolution of the metal and thereby increases the corrosion rate.

BIOCIDE EFFICACY AGAINST SRB

Planktonic SRB

Since the early 1980's the API bottle test is used widely in field biocide study. The test procedure is designed with two controlled parameters, concentration and contact time. (Concentration tested are 0, 25, 50, 100, 150 and 200 ppm each at contact timt of 1, 3, 6, 12 and 24 hours). At each concentration and each contact time, serial dilutions of 1:10, 1:100, 1:1000 and 1:10,000 are used.

The problem with this method is the difficulty to find a uniformaly contaminated water sample within the waterflood. This is obvious since the method is based on planktonic bacteria which represent a small fraction of sessile bacteria.

More than five biocides are tested using the API method. Most of them show a complete kill at high concentration. Gluteraldehyde blends give consistently good kill and growth reduction results, while organic diamine acetate appears to be the alternative treating agent. For preliminary chemical screening purposes, this approach is probably adequate. Final biocide selection should include tests against surface associated populations and their effectiveness in penetrating biofilm layers on the metal surface.

Sessile SRB

A number of methods are developed in recent years to sample sessile SRB including; test spools or nipple on the by-pass loop (side stream), corrosion monitoring coupons, flush mounted coupons or probes, and a laboratory test loop. The last two methods are utilized to test the effectiveness of different biocides on sessile bacteria.

In the test loop procedure, a sample of water is used for developing SRB by incubation at 55°C for two days and adding a specific nutrient. Special bottles designed with a plastic probe are filled with the water. After 16 days of incubation time a biofilm is developed on the probes. Different biocides are added at various dosage and bottles are kept under agitation for 4 hours. The biofilm is scrapped from the probes into a sterile plastic bag containing 40 ml of sterile water. Finally 1 ml of water is inoculated for the SRB count. A summary of the result is shown in Table 2.

Table 2. Kill Test Against Planktonic and Sessile SRB

Biocide	Concentration (ppm)	Planktonic*	Sessile
A	100	−	+
	200	−	+
B	100	−	−
	200	−	−
C	100	+	+
	200	+	+
D	100	+	+
	200	+	+
E	100	+	+
	200	+	+
F	100	−	−
	200	−	−
BLANK 1		+	+
BLANK 2		+	+

* + Bottle turned black
− bottle not turned black

The side-stream loop consists of mounted coupons or probes which are exposed to water flowing through the system. A complex microbial biofilm develops and sessile bacteria population can be quantitatively recovered and analysed for total number of surviving bacteria on the metal surface at frequent intervals. This is part of continuing program and no complete data is available.

As shown in Table 2 both biocides B and F show a complete kill for planktonic and sessile bacteria. Biocide B is an aldehyde/ammonium salt derivative and biocide F is diamine active ingredient based derivative. This supports the original finding for biocide evaluation against planktonic SRB.

CORROSION INHIBITOR EVALUATION

To reduce the corrosion rate throughout the waterflood system and reduce the time required in routine chemical trials, the Potentiodyne analyser with conventional process (mild steel) is used.

The electrodes are equilibrated in the injection water under prevailing well head conditions as shown in Fig. 2. The scanning rate is kept at 4V/hr for all the runs on WSW 85. The procedure is typical of utilizing side-stream for inhibitor injection at different concentrations until practical predetermined level of corrosion rate is achieved. Each inhibitor is evaluated at three different concentrations 2, 4 and 6 ppm, and the corrosion rate at each concentration is measured at 0, 1, 3, 6 and 24 hours. However, due to iron sulfide deposition, the data at 24 hrs is not included in the evaluation. To prove it is the iron sulfide and not the filming ability of corrosion inhibitor, the corrosion rate without

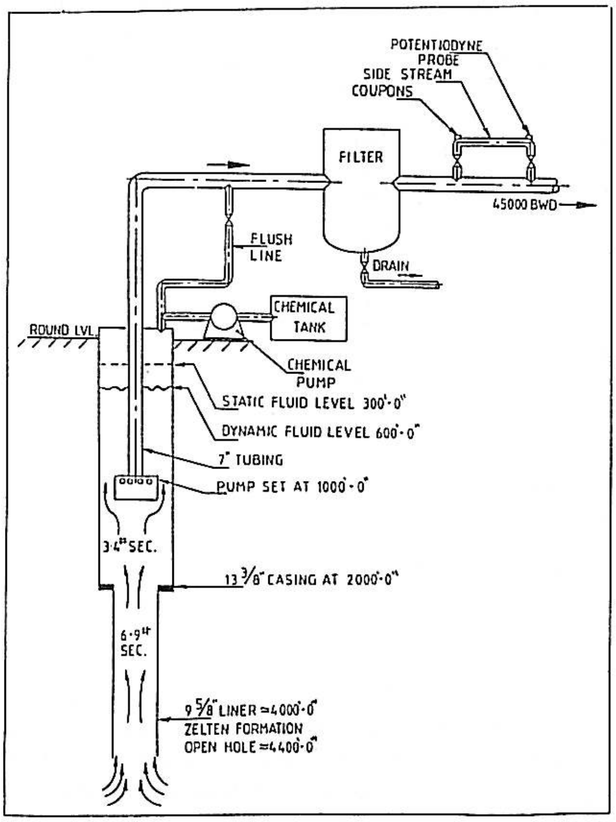

FIG. 2. Typical water source well.

inhibitor is reduced from 18 mpy to 13.6 mpy under the same conditions.

In comparison with the presumed practical and economical corrosion rate of 1 mpy, the result shows that corrosion inhibitors A, B, C and D are all effective at 6 ppm as shown in Fig. 3. However, this concentration is measured at the well head, and as we move farther from the injection point, this concentration diminishes due to filming properties of these inhibitors. Therefore, inhibitor B is not recommended for use at concentration below 4 ppm level as shown in Fig. 4. All chemicals are ineffective at 2 ppm as shown in Fig. 5.

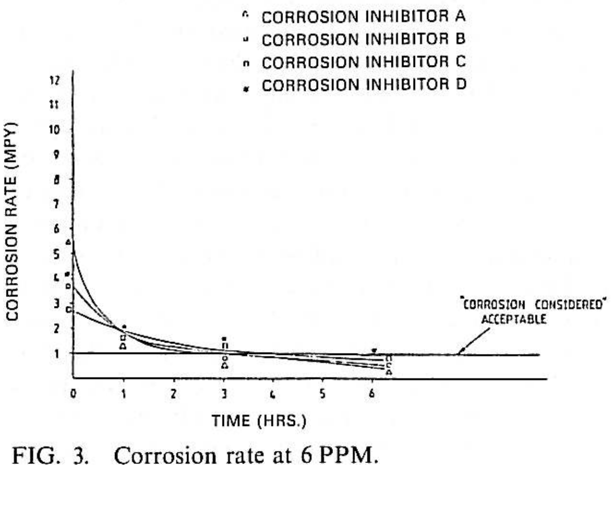

FIG. 3. Corrosion rate at 6 PPM.

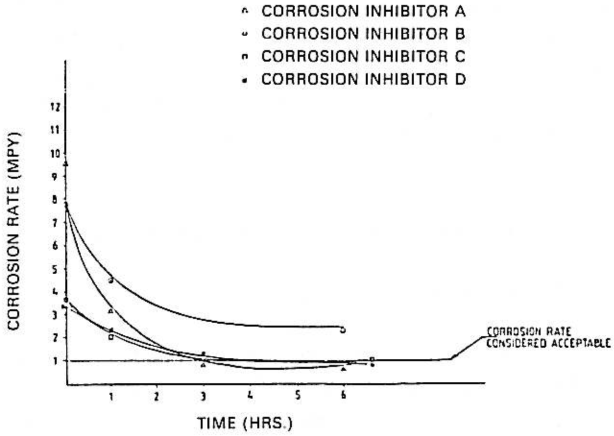

FIG. 4. Corrosion rate at 4 PPM.

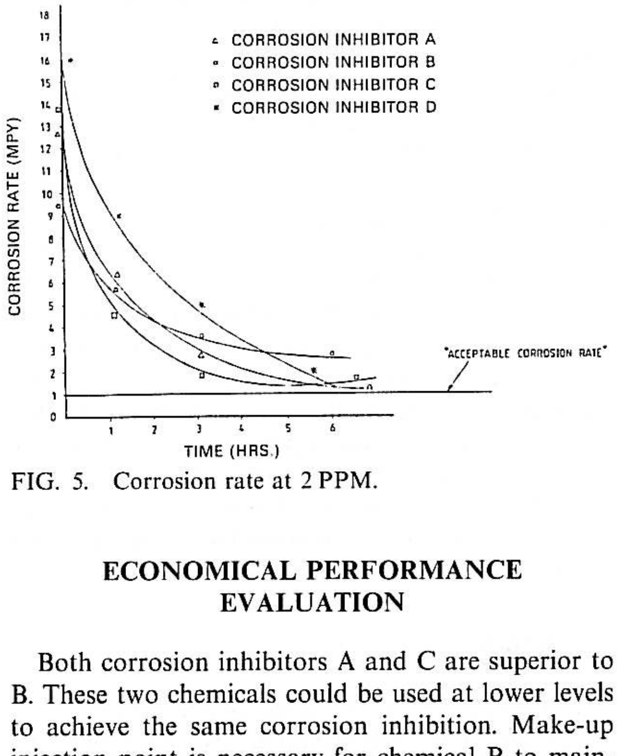

FIG. 5. Corrosion rate at 2 PPM.

ECONOMICAL PERFORMANCE EVALUATION

Both corrosion inhibitors A and C are superior to B. These two chemicals could be used at lower levels to achieve the same corrosion inhibition. Make-up injection point is necessary for chemical B to maintain a residual concentration of more than 4 ppm throughout the waterflood system. Except for corrosion inhibitor D (the highest price), the prices of the other three chemicals vary by only 5%.

CONCLUSIONS

- SRB are still present despite the regular biocide injection. Some source water wells are still giving positive growth and complete sterilization has not been achieved.
- Bacterial growth should not be tolerated in the water injection system as it may cause corrosion or formation damage.
- Bacterial corrosion is actually caused by sessile anaerobic bacteria living under a thick biofilm

matrix attached to the metal surface. Sessile bacteria population outnumber the planktonic 500–50,000 times.

- Biocide efficacy testing that only samples planktonic bacteria is entirely misleading, and biocides field use must be used on their efficacy against sessile bacteria.
- The investigation has shown that the potentiodynamic technique enables the influence of chemicals to be evaluated under field conditions in a short time, whereas, conventional methods would have required extended periods of testing.

ACKNOWLEDGEMENT

I thank Waha Oil Company, Corrosion Section and Technical Laboratory personnel for their assistance and support to complete this work.

REFERENCES

[1] D.P. Moore and Byars H.B., 1990, Field Measurements Involve Various Techniques, Oil and Gas Journal, 90.

[2] D.P. Moore and Byars G.B., 1990, Measurement Records Vital for Effective Program, Oil and Gas Journal, 97.

[3] E.L. Liening, 1979, Practical Applications of Electrochemical Techniques to Localized Corrosion Problems, Corrosion/79, Atlanta, Georgia, 78.

[4] E.Y. Chen and Chen R.B. Chen, 1984, Monitoring Microbial Corrosion in Oil Field Water Systems, JPT, 1171.

[5] I. Ruseska et al, 1982, Biocide Testing against Corrosion Causing Oilfield Bacteria Helps Control Plugging, Oil and Gas Journal, March 8, 253.

[6] J.G. Stoecker, 1984, Guide for the Investigation of Microbiologically Induced Corrosion, Materials Performance, 48.

[7] S.M. Gerchakov, Little B.J. and Wagner P., 1986, Probing Microbiologically Induced Corrosion, Corrosion, Vol. 42, No. 11, 689.

[8] W.P. Iverson, 1984, Mechanism of Anaerobic Corrosion of Steel by SRB, Materials Performance, 28.