Inter-relationship between sulfate reducing bacteria associated with microbiologically influenced corrosion and other bacterial communities in wells

Cullimore and Johnston
Droycon Bioconcepts Inc., Regina, Saskatchewan, Canada S4N 0E7

Abstract

Sulfate reducing bacteria have long been recognized as principal inducers of corrosion within water, oil and gas systems. This study evaluates the potential to utilize the SRB-BART™ tester system to detect SRB in water wells as a possible bioprospecting tool. Here the findings reveal that water wells associated with ground waters overlaying oil and gas deposits may be more prone to very aggressive populations of SRB that generate a BT (blackening at the top of the tester in the oxidative zone). Comparable studies on water wells not known to be associated with oil and gas reserves generally had a lower occurrence of BT reaction when an SRB was detected and these bacteria were less aggressive requiring extended time lags to go positive. It was postulated that the reason for the very aggressive SRB generating BT reaction was that the SRB were growing within reductive niches inside biomass dominated by heterotrophic bacteria that were utilizing the soluble and volatile hydrocarbons emerging at the redox front from the underlying reserves. Second findings relate to the use of the SRB tester system to detect SRB within a gas well collection, storage and distribution system. Here, very aggressive SRB were detected generating BB reactions (reductive black sulfides deposits in the base of the tester) in those parts of the field known to have been impacted by pipeline breaks and had been subjected to segregation repairs. These initial studies indicate that the system as described has a high potential in the bioprospecting for oil and gas reserves and also for SRB monitoring of existing gas collection and distribution systems.

Keywords: SRB, MIC, bacterial monitoring, corrosion, water wells, biofouling, biomass

Introduction

Wells can be viewed as conduits passing down though soils into the overburden with some entering the planetary crust to recover or return gases or fluids of economic benefit with the movement of various forms of sulfur being one factor of particular interest (Ivanov, M.V., 1968). These wells can be designed to extract oil, gas or water from suitable reservoirs or to inject fluids or gases for storage, engineering or disposal purposes. All of these engineered options can be frustrated by the natural microbial flora within the environments inside and around the wells initiating corrosion and restricting the designed movement of fluids and/or gases within the area of influence of the well and associated anaerobic microbial activities (Levette, 1984). Sulfate reducing bacteria have been the most common linked to corrosion events (Pfennig, *et. al.* 1981) partly because they commonly generate hydrogen sulfide as a very distinguishable product that is well known to initiate electrolytic corrosion in metals (Cullimore, 1999). Pit corrosion commonly forms at sites where there has been some form of bioconcretious overgrowth leading to the generation of nodules, tubercles, scaling, encrustation or thick slime-like growths. Often the outside of these structures is relatively oxidative with the confined biomass within the structures being more reductive. It is in these more confined reductive conditions that the sulfate reducing bacteria have been found to dominate commonly generating black growths and extensive damage to any metals forming the platform upon which the growth is occurring.

The Study Structure

This study embraced a role for sulfate reducing bacteria (SRB) as leading indicator groups for microbiologically influenced corrosion (MIC) in well biofouling within ground water systems that in some cases interface directly or indirectly with systems used to exploit oil and gas reserves. For the detection of SRB, the SRB-BART™ tester system (Droycon Bioconcepts Inc., Regina, Canada) was employed. This system employs the patented tester which is able to detect the growth of SRB through the generation of an aspect ratio within the culturing fluids within the tester. The system encourages formation of a reduction – oxidation gradient vertically while a diffusion gradient is generated bottom up of a selective medium specific for *Desulfovibrio* bacteria species based upon the formulations developed by Postgate (1984). This tester received environmental technology verification by ETV Canada Inc. in 2002 and is able to detect two distinct groups of SRB (Anonymous, 2002). These are differentiated by the location of the black sulfide deposits within the tester. One group is formed by the covert anaerobic SRB that form a blackening to the base of the tester (BB reaction). Some SRB however tend to grow in community associations with aerobic bacteria and in this case the black sulfide reaction occurs at the oxidative side of the tester around a floating intercedent device. This reaction is referred to as a BT reaction (black at the top). To undertake a BART test, 15 ml of the sample is placed within the tester without shaking (this would disturb the formation of the reduction – oxidation gradient). To determine the level of active SRB bacteria in the sample, the tester can be observed daily or placed in a reader that would allow automatic ongoing monitoring for the occurrence of black sulfides within the tester (around the ball, BT; or in the base, BB). With further incubation, the reaction may extend much of the length of the culturing fluids creating a blackening throughout much if not all of the liquid. This is referred to as a BA reaction (black all throughout the test). The speed with which the reactions occur indicates the SRB's aggressivity through the time lag length to that event and it is then possible to project a possible SRB population in the sample. This study examines the frequency of occurrence of the two major SRB types in various aquifer systems that have various levels of known interconnections with oil and gas reserves.

Incubation of the SRB testers when performed using daily observation to determine aggressivity and community types is at room temperature (22^{o}C) with interpretation of the data using a standard interpretation chart or interpretation program (Cullimore, 2000). When incubation is performed using the reader, the incubation temperature is adjustable but the recommended standard is 28±1^{o}C. Here the time lags shorten as the SRB become more active than at room temperatures.

Two major investigations were incorporated into this study. First was an investigation of the potential to use the aggressivity and community type of SRB on local water well to bio-prospect for oil and gas reserves. To do this two regions were selected for intensive study where one was known to be directly associated with oil and gas reserves in Alberta while the other region was at least 150 kilometers from the nearest known reserves. This study would therefore determine whether SRB could be a suitable marker organism for locating reserves. Second was to determine the potential of the aggressivity of SRB determined by this system to detect sites of greater corrosion potentials in gas collection pipelines and storage tanks.

Potential Application of SRB in Bioprospecting for Oil and Gas

The Three Hills district in Alberta located above a major part of the Viking oil and gas formation was surveyed with 135 water wells being examined for the levels of SRB activity. As a control district Mount Hope in Saskatchewan was selected since was at least 100 km away from any known oil and gas reserves. 55 water wells were sampled from this district and SRB tests performed. Table one displays a comparison of the average time lags for the SRB positive tests at both sites along with the nature of the reactions observed.

From this data set comparing Three Hills with Mount Hope, there were several very significant events relating to the intrinsic SRB populations recovered from the water wells that could be linked to possible interconnections with underlying strata of oil and gas reserves. These events may be categorized as including:

i. SRB were universally detected in the water wells associated with possible oil and gas reserves but were found in only one third of the wells from the district not known to be associated with hydrocarbon reserves.
ii. Aggressivity of the detected SRB was significantly greater with wells associated with hydrocarbon reserves than wells not known to be impacted

causing the time lags to shorten by greater than two days and the SRB populations to be greater by at least one order of magnitude.

iii. BT and BA reactions dominated the wells possibly impacted by reserves of hydrocarbons but the BA reaction was rare in the wells not known to be impacted by such reserves.

This study therefore indicates that there is a potential to bio-prospect for oil and gas reserves using the SRB composition of water samples taken from the water wells throughout the region being surveyed by using SRB aggressivity (time lag) and the reaction patterns (BT and BA would both be positive indicators and BB negative).

Table One, Comparative occurrences of SRB in water wells at Three Hills, Alberta and Mount Hope, Saskatchewan

Parameter	Three Hills	Mount Hope
Location of oil and gas reserves	Over the Viking formation	At least 100 km from any known reserves
Number sampled wells	129	55
Number wells SRB +	129 (100%)	17 (31%)
Time lag mean (days)	3.5±2.2	6.7±2.1
Mean predicted population (SRB/ml)	5,000	150
Number displaying BT reaction	58 (45%)	22 (40%)
Number displaying BB reaction	9 (7%)	13 (24%)
Number displaying BA reaction*	62 (48%)	2 (4%)
Number displaying no reaction	0 (0%)	18 (32%)

Note (*) that most of the BA reactions were extensions of the BT reaction as the SRB activity extended downwards into the body of the culturing fluids.

While no broad SRB survey using these testers has been performed in a documented manner in the U.S.A., a study of rehabilitation techniques for fouled wells was undertaken including 15 wells that were intensively monitored both before and after the selected rehabilitation technique. Wells included in the investigation came from Connecticut (8), New York state (1), Texas (1), Wisconsin (1), Florida (1), New Jersey (1), Iowa (1) with one well from Saskatchewan, Canada. Of these wells, SRB were detected in 9 (60%) of the wells with BT occurring in seven of the wells and BB in the other two. Highly aggressive BT reactions were observed in two of these wells and three out of the four medium aggressive SRB wells also had a BT reaction while the other was a BB. This limited survey would indicate that there a two-thirds possibility that SRB may be recovered from water wells using the SRB tester and that there is a greater probability of a BT reaction being detected in medium to highly aggressive SRB conditions.

SRB are commonly associated with the biofouling of water wells and are generally linked to conditions where there are taste and odor problems associated and electrolytic corrosive processes caused by the hydrogen sulfide they generated. Two major focal groups of SRB have been recognized occurring in water wells (Cullimore, 1999). Group one generally grows cloistered deep into the reductive porous media surrounding the bore hole and is not commonly associated with any other forms of bacterial activity. Reaction patterns generated by this group are of the BB type. Group two SRB also grow in reductive conditions but normally associated by various aerobic heterotrophic bacteria that generated an oxidative biomass within which the SRB grow in reductive niches. Hence the SRB grow in the oxidative zone of the tester in amongst the slime growths of aerobic heterotrophic bacteria commonly associated with the patented ball shaped device floating on the culturing medium. This reaction is a BT reaction and indicates that the SRB are growing cloistered with an aerobic community of oxidative heterotrophs. In water wells that are being impacted by mobile products from oil and gas reserves it can be expected that these products would include the gaseous (e.g., methane and propane) and volatile (short chained hydrocarbons) products being emitted from the reserve. These products may not be significantly degraded until the carrying ground water reaches oxidative environments associated with near-surface activities (e.g., soil, spring or water well). As these products cross into the oxidative zone they are prone to degradation primarily by heterotrophic aerobic bacteria (HAB). Where this happens there would be the generation of reductive environments within the growing biomass within which SRB could flourish utilizing primarily the fatty acid products from the growth of the HAB. Such SRB would generate a BT form of reaction because even the BART tester they would retain a dependency on the HAB for the generation of suitable niches for growth (i.e., a BT reaction involving the formation of blackening on the under side of the ball). A BT reaction would therefore form a natural indicator of the presence of heterotrophic bacteria that would have been stimulated by the mobile products arriving at the water well from the hydrocarbon beds beneath.

Investigation of corrosion risk in gas distribution systems

For practical purposes this SRB testing system provides a means of detecting the major two groups of SRB in water whether that ground water from a well or produced water associated with gas wells. While the study described above focused on detecting SRB as biomarkers for oil and gas prospecting, this part addresses the ability to use this system to detect within gas distribution and storage systems. For this evaluation a natural gas collection, distribution and storage system was evaluated in south-eastern Saskatchewan. This system had 148 wells consisting of 233 zones with some wells dual-zone producing. Within the well system there was one pipeline that carried gas principally from 40 wells that was subject to frequent breaks. This focused corrosion along this pipeline indicated that some combination of gas and water from the wells and the environmental conditions within the pipeline itself had the effect of creating an area with many pipeline breaks (5) and segregation repairs (12). Sampling the produced water from individual wells was performed only from those wells having confined well-specific separators. All pipeline breaks and half of the segregation repairs (7 of the 12) occurred in the northern region of the field. A summary of the relationship between the presence and activity of the SRB in the northern and southern parts of field are summarized in Table Two.

Table Two, Relationship of breaks and repairs to SRB presence

Field	Total number	SRB detected number	SRB absent number	Reaction pattern
North pipeline breaks	**5**	**2**	**3**	**BB-BA**
North no breaks	**N/A**	**19**	**N/A**	**BB-BA**
North segregation repairs	**11**	**7**	**4**	**BB-BA**
South pipeline breaks	**0**	**4**	**0**	**BB-BA**
South no breaks	**N/A**	**5**	**N/A**	**BB-BA**
South segregation repairs	**2**	**0**	**2**	**BB-BA**

Note: N/A refers to not applicable data entry; BB-BA refers to a reaction pattern that went from an initial black base to the black all throughout the tester liquid culturing medium.

SRB were detected in the produced water associate with two (40%) of the five pipeline breaks and 7 (54%) of the thirteen places where segregation repairs had been conducted. Of the 46 sample sites tested SRB were detected in 35 (76%) of the samples and routinely displayed a BB-BA reaction that would be typical of a very aggressive strictly anaerobic SRB community. SRB were not detected in the remaining 11 samples. This would indicate that at the sampling time that would have occurred after the various breaks and repairs there was a significant SRB community mostly in the northern half of the field (80% of the total SRB detected). Using the SRB reader version 1.0, the aggressivity for the positive detections was found to be universally high with the time lags having a mean of 57.1±39.8 hours and a projected log population mean of 5.8±1.3 predicted active cells/ ml (pac/ml). There were considerable differences between samples with the minimum time lag being 1 hour and the maximum of 147 hours. These large and highly aggressive populations of SRB recorded in 80% of the samples would indicate that the northern half of the field is most likely to continue to degenerate as the microbially induced corrosion thought to be due primarily generated to SRB continues.

Given that the SRB are likely to be a very significant if not dominant contributor to the various pipeline breaks and segregation repairs then improved management could ensue through the ongoing monitoring of the time lag (aggressivity) of the SRB under the premise that an effective treatment (e.g., biocide) would significantly inhibit the activity of the SRB lead to either extended time lags or failure to detect these bacteria within the produced water. Ultimately this would result in more sustainability for the equipment installed in the field.

Discussion

Two aspects relevant to the oil and gas industry are addressed in this paper. First it is shown that the SRB may prove to be an effective biomarker organism for the presence of oil and gas deposits interfacing directly or indirectly with the ground water sources for producing near-surface water wells. Second, the presence of SRB in gas well field in distribution and storage systems may be used to control the occurrence of microbial mitigated failures by identifying where chemical suppressive treatments are needed.

For the use of SRB as a biomarker in the bioprospecting for oil and gas, the premise would be that the SRB form a part of the normal pathway along which mobile soluble or gaseous products from hydrocarbon reserves move up though the reductive ground water to the redox fronts near- or at- surface whereupon there is a focused microbial degradation of these chemical leading to biomass growth within which the SRB (generating a BT reaction) form an integral part of the degrading biota. This biomarker occurs in the production water from the water well since the biomass formed at the redox front containing hydrocarbon marker degraders will slough causing the SRB to enter the downstream water and be detectable. While this observation represents a potential that the water well is under the influence from distant oil and/or gas reserves because of the presence of aggressive SRB displaying BT reactions, these organisms can also be present when other sources of organic pollutants are present in the ground water in sufficient quantity to affect the nature, form and function of the biomass growing at, and around, the redox front. These findings indicate that there is a potential for the SRB (BT reaction) to be used as biomarkers for the discovery of hydrocarbon reserves but further confirmatory studies are required.

In the second part of the study it was found that very aggressive SRB (commonly generating a BB reaction) appear to occur commonly in gas well collection and distribution fields and may be recovered from the produced water in very significant populations. It can therefore be proposed that the SRB reader system could be employed to monitor the natural aggressivity of SRB within a gas well field and furthermore be used to monitor the effectiveness of suppressive techniques such as the use of biocides. Such effective management would be expected to extend the time lag (reduce the aggressivity) of the SRB in the water in direct proportion to the effectiveness of the control strategy. The short time lags observed during the studies on the Saskatchewan well field would suggest that the use of an in-field SRB reader would allow field operators to respond to failures and uncertainties that are a part of the present-time strategies that rely on semi-quantitative field testing or the shipment of samples to laboratories in a manner that causes additional costs and uncertainties.

Conclusions

A. SRB can be examined for activity (by time lag) and reaction type using the SRB reader system.
B. Where ground water is under indirect or direct influence from gas and/or oil reserves, the impact of soluble and volatile products from those reserves can significantly modify the microbial fouling that occurs around water wells receiving these products. A result of this can be that the SRB become more aggressive (generating shorter time lags) with a typical BT (black around the ball at the top of the tester) reaction. Hydrogeologists familiar with formations would be able to predict the location of unknown reserves based upon the location of water wells exhibiting high levels of aggressivity and BT reactions.
C. Where produced water is being generated as a normal part of the operation of a gas well collection, storage and distribution system it appears possible to detect focal sites, where the SRB are concentrating, using the SRB reader system with the sites being recognized by very short time lags (<24 hours) and BB reactions.
D. These conclusions are the result of limited trials and further confirmatory trials are required to improve the precision of these findings.

Acknowledgements

The authors wish to acknowledge firstly Trent Kostick who undertook the field trials on the Saskatchewan gas well field used in the second part of this study. Support is also gratefully recognized from the Petroleum Research Technology Center of the University of Regina for aiding in the funding of the bioprospecting study using SRB and also Canada Agriculture and Agri-Food for the funding of some of the field work relating to the studies at Three Hills, Alberta and Mount Hope, Saskatchewan. The time and provision of testing equipment by the technical staff of Droycon Bioconcepts Inc is also recognized. In addition financial support was obtained from the National Research Council Industrial Research Assistance program for some of the research and experimental development involved in the development of the SRB testing system.

References

Anonymous (2002) SRB-BART™ Technology Fact Sheet for Droycon Bioconcepts Inc., verified by Environmental Technology Verification (ETV) Program, ETV Canada Inc., Government of Canada.

Cullimore, D.R. (1999) Microbiology of Well Biofouling, Lewis Publishers / CRC Press, Boca Raton, FL

Ivanov, M.V. (1968) Microbiological processes in the formation of sulfur deposits, Israel Program for Scientific Translations, Jerusalem

Levette, P. (1984) Anaerobic Bacteria, Open University Press, Bristol, PA

Pfennig, N., Widdel, F. and H.G. Trüper (1981) The Dissimilatory Sulfate Reducing Bacteria, Chapter 74 in “The Prokaryotes” Volume 1, Springer-Verlag, N.Y. pages 926-940

Postgate, J.R. (1984) The Sulfur Reducing Bacteria, Cambridge University Press, Cambridge, U.K.