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Reservoir Souring : Problems, Uncertainties and Modelling

A Visualisation of Bacterial Process in Porous Media

21

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Reservoir Souring : Problems, Uncertainties and Modelling

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Part I : Problems and Uncertainty involved in Prediction.
Part II : Preliminary Investigations of a Computational Model.

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Abstract

The uncertainty involved in modelling of reservoir souring is discussed. IOR processes are speculated to influence a souring process in a positive direction. Most models do not take into account pH in reservoir fluids, and thus do not account for partitioning behaviour of sulfide. Also, sulfide is antagonistic to bacterial metabolism and impedes the sulfate reduction rate, this may be an important factor in modelling. Biofilms are thought to play a crucial role in a reservoir souring process. Biofilm in a reservoir matrix is different from biofilm in open systems. This has major impact on microbial transport and behaviour. Studies on microbial activity in reservoir matrices must be carried out with model cores, in order to mimic a realistic situation. Sufficient data do not exist today. The main conclusion is that a model does not reflect a true situation before the nature of these elements is understood.

The numerical issues arising in the simulation of reservoir soouring are considered and illustrated with a simplified version of the biofilm model developed by Sunde *et al.* [12] The model incorporates all the important physical phenomena studied in the above reference : bacteria growth limited by nutrients and/or energy sources and hydrogen sulfide adsorption. The results obtained are similar but the behaviour of the model is found to be strongly dependent on both the numerical techniques used in the solution of the discretised transport equations and the experimental data necessary to the formulation of the model.

Part I : Problems and Uncertainty involved in Prediction.

Introduction

The widespread occurrence of the souring of reservoirs, especially in oil fields where pressure is maintained through sea water injection, has led to a wealth of studies and research. In the main these studies conclude that activities of sulfate-reducing bacteria lie at the source of the phenomenon. During the 80`s a considerable amount of activity and resources were targeted to explaining the origins of sour gas in originally sweet oil production. Though some researchers attempted to model the souring process in reservoirs, in general the problem of developing adequate prediction tools was frustrated by uncertainty about the nature of SRB`s, their transport through porous media and their survival conditions.

The reservoir souring process has been approached from the point of view of a near injection well bioreactor as well as a phenomenon also taking place in the deep reservoir. This requires that SRB survive temperatures over a range from as low as 5 degrees Celsius up to 100 degrees plus. Some investigators have studied bacteria which display mesophilic, thermophilic and hypothermophilic behaviour. Invariably the studies have all been targeted to the conventional sea water injection process. There has always been uncertainty as to how to predict the rate and extent of the produced levels of hydrogen sulfide which may be expected at any given production well after sea water breakthrough. The main focus has been on the SRB as the major contributor to the souring process. This may not be the fact in all cases, *Shewanella putrefaciens* has been isolated in produced waters of oil fields, and is also a typical species found in North Sea water. These bacteria use other oxy-sulphur-anions in dissimilative

metabolism and may contribute significantly to a souring process [1]. In general the ongoing discourse involves uncertainty both of the survival zones and total sulphide generating biomass which any given reservoir can support. What is certain is that injection well back flow tests confirm high levels of sulfides only short distances from the well. Furthermore, levels of produced hydrogen sulfide appear to correlate with water cut. Increasingly operators are keen to exploit their reservoirs to the economic potential. In the pursuit of this aim, several recovery optimisation strategies (IOR) are being tried. Among these are alternating water/gas drive (WAG), rapid blow-down and microbial improved oil recovery. The methods that are applied in improved oil recovery, may have positive or negative influence on a microbial souring process. The total effect is difficult to predict as the current understanding of bacterial growth and behaviour in reservoirs is poor.

IOR techniques

The implications for bacterial survival in the near well bore area during alternating water/gas drive are crucial to the continued and uninterrupted development of hydrogen sulfide in reservoir areas supported by alternating injectors. A period of sea water injection at 25 degrees Celsius will allow bacteria to flourish limited only by the availability of nutrients transported by the water. Alternating with gas injection will raise the near well bore temperature to typically 70 degrees Celsius, but more crucially, removal of water and its supply of nutrients must restrict the population of bacteria, if not completely destroy it. The result will be a decline in the levels of hydrogen sulphide being generated in the near injection well area. The gas injection phase will also result in a different chemical environment in the reservoir. As hydrogen sulfide may be soluble in water both as the pressure dissolved gas or as the HS-ion, dependent on solution pH, then acidification of the sea water from pH=7.8 to below pH=7.0 may result not only in the form of the sulfide changing, but also its partitioning. As the gas at low pH then it may be soluble in both water and the oil phase. The result could be that reservoirs pressure maintained by alternating water/gas drive may be less susceptible to sulfide production. Indeed water/gas drive could be a principle mechanism to control and reduce souring in some reservoirs.

The rapid blow-down of previously sea water flooded reservoirs requires that large amounts of sea water must be removed in order to permit a phase change of the residual hydrocarbons. Such rapid pressure declines will also influence the partitioning of hydrogen sulfide. The consequence of reducing the pressure on water into which hydrogen sulfide has been dissolved through bacterial generation may be to partition the gas into the produced, vaporised hydrocarbons.

Secondary oil recovery, using water to displace oil and maintain pressure, has limited efficiency. Residual oil, trapped by capillary forces will remain in the matrix and may serve as a plentiful carbon source for bacteria. Mobilisation of residual hydrocarbon has been demonstrated in the presence of bacteria, both in cores and in micro models. Some investigators have suggested that, either bacteria reduce surface tension between oil and water, and so mobilise the oil, or they reduce the droplet size by increasing surface area in order to gain more living space or by consuming some of the oil components. The importance of this carbon source is difficult to estimate, but it is reasonable to expect that it plays a vital role in a souring process.

Bacteria are also employed as blocking agents in water diversion schemes, with the goal of improving sweep efficiency by forcing the injected sea water to enter unswept zones in the reservoir, and thus dislodging more oil or reducing water cut. A variety of microbial methods are offered the oil industry, as inexpensive means to recover more oil. In general operators tend to be sceptical to these methods as the mechanisms involved are poorly understood. The fear of boosting a souring process makes oil companies reluctant to engage in field tests with these techniques. Field trials have demonstrated that biogenic sulfide production is mititgated by adding nitrate to the injection water. Nitrate reducing bacteria outcompete the SRB, and less harmful metabolic products are excreted.

Bacteria size, penetration and behaviour in a reservoir matrix.

Bacteria are introduced to the reservoir in the planktonic mode of life, often embedded in particulate matter. Once they have entered the new environment (the reservoir matrix), the sessile mode of life is predominant. The bacteria adapt to this mode of life for several reasons, none of which we are going to discuss now. The important issue about biofilm and souring of oil reservoirs, is to understand where biofilms develop, and what the implications of dealing with biofilms in a reservoir are. In order to answer these questions we need to understand the structure and function of biofilms. A close inspection of bacteria reveal that they are hairy cells with glycocalyx and protein (pili and flagella) appendages. Bacteria "sense" surfaces, and respond by phenotypic change and specific behaviour [2]. Following adhesion, cells immediately do lateral movements involving specific patterns of exopolysaccharide secretion and which are species specific and related to their new environment. A biofilm matrix is typically 99% water [3] More of the volume of a biofilm is occupied by matrix (± 75% to 95%), than by bacterial cells (± 5 to 25%). The cells may be concentrated either in the lower or the upper region of a biofilm.

Oligotrophic (nutrient-poor) aquatic systems are usually heavily populated with ultra micro bacteria (UMB). These are smaller than average bacteria, and due to the size they may penetrate deep into a reservoir [4,5]. The cells are dormant due to nutrient limitations. When nutrients are provided a sequence of events is initiated. Adherence to the reservoir matrix is promoted by favourable changes in the micro environment, and the rapid production of daughter cells by binary fission lead to establishment of consortia of different species. These consortia are based on physiological mutual benefit [6]. An internal infrastructure of the biofilm matrix allows transport and disposal of nutrients and metabolic by-products. The cells have a phenotypic plasticity, which means that they may change their shape and properties of the cell envelope as a response to environmental conditions [7]. These properties; binary fission and phenotypic plasticity make sessile bacteria life profoundly different from their planktonic counter part. Recognising these properties implies that we have to question the usefulness of continuing conventional microbiological studies of planktonic bacteria in monodisperse cultures in rich media.

The chemical nature of the biofilm matrix is dominated by carbohydrates, many highly anionic-, uronic-, acid-containing polymers. Molecules and ions, approaching or extruded, must satisfy spatial and chemical requirements of the matrix. Some molecules and ions may be retained as a "halo" around the cells by virtue of their size or charge density. The biofilm matrix excludes both antibodies and phagocytic cells (predators). This explains why biocides often are inefficient in killing bacteria embedded in biofilms. The physical nature of the biofilm matrix may change from a sol to a gel when the concentration of Ca^{2+} in the interstitial water is raised.

Metabolic rate determinations are difficult to carry out in porous matrices, due to both the complexity of biofilms and the demanding problems involved in conducting such experiments. Very few data exist about SRB growth rates in a porous medium [8], and hardly any data for mixed sulfidogenic populations in porous matrices.

At RF-Rogaland Research we have been concerned about the transport of bacteria in reservoirs for a long time, and recently a 4 year IOR-research program [9] was terminated, where microbial growth in reservoir matrices was studied in detail. Much of the microbiological work focused on cell size, deposition in the matrix and development of biofilm [10]. Studies of bacterial growth in porous media have shown that in core models of different permeability, the permeability is reduced at a higher rate in highly permeable cores. These data have led to the conclusion that bacteria selectively plug highly permeable zones before low permeability zones (Fig. 1). It was also demonstrated that biofilm development was influenced by flow patterns and pore geometry [11]. The interesting part is that the establishment of a biofilm is governed by 1) the size of the cell(s), 2) concentration of cells, 3) velocity of the cells, 4) pore throat size, 5) physiological state/starved or fed cells.

In several experiments, where both micro and core models were used, the biofilm that developed led

to plugging of cores in the near zone of the injection port. Data indicated that a biofilm in a porous matrix develop a web of mucous material that dramatically impedes the entrainment and deposition of injected cells or particulate matter. From these observations we conclude that once established, a biofilm will efficiently trap invading cells and nutrients. This biofilm will develop in areas that have pore sizes that do not exclude cell invasion, or are too large for a bioweb to evolve. Table 1 summarises some coreflood data. These data suggest that pore sizes 2.3 μm < R < 13,3 μm favour development of this type of biofilm. For the purpose of modelling reservoir souring, this is important. The pore size and geometry are factors that govern where biological activity may take place. Pore channels with a radius ≥ 13.3 μm will not constrain the transport of single cells, and do not lead to reduced permeability.

Microbial metabolism entails changes in the chemical environment. Carbon sources are oxidised, and inorganic electron acceptors are reduced. A variety of possible metabolic patterns produce by-products that have impact on the pH. pH is important for solubility of sulfide, and high sulfide concentrations may again inhibit growth and metabolic rates. This is a balance that is not accounted for in most of the current souring models.

Conclusions

Uncertainty about transport, entrainment and deposition of bacteria in a reservoir matrix makes it difficult to picture where the main activity of bacteria is taking place.

IOR schemes may have a secondary, positive effect on a microbial souring process (i.e. WAG). The pH in a reservoir is important for the sulfide partition behaviour.

Residual oil may be an important element in the understanding of a souring process.

Bacteria are mainly active in biofilms. Thus it is important to understand where a biofilm may develop.

Experiments using corefloods must be carried out in order to assess the rate of sulfate reduction, before numbers are put into prediction models.

Before the correlation between a matrix pore geometry, pore water pH, flow pattern, residual oil and the *in situ* sulfate reduction rate is better understood, it is unlikely that a valid reservoir souring model may be formulated.

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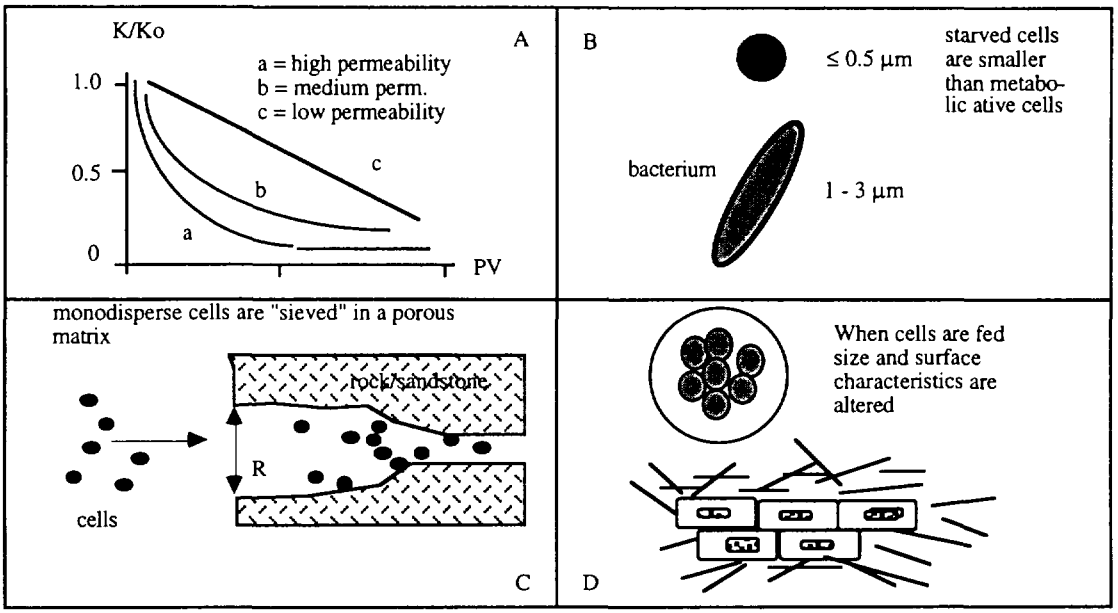

Figure 1. A) Permeability reduction in cores caused by biomass generation (K = Darcy permeability, K_0 = initial permeability). B) Starved cells change size and surface characteristics. C) cells that invade a porous matrix are retained and lead to blocking in a fashion similar to deep-bed filtration. D) Bacteria respond to nutrients by alterating surface characteristics, production of extracellular material and enveloping of daughter cells in larger aggregates.

Table 1. Core floods, cores with different permeability, length, and mean poresize. L = length, PV= pore volume, K = Darcy permeability, R = pore radius, Q = flow rate. A skin plug is a significant reduction of permeability in the near injector area, caused by biomass.

	L (cm)	PV (mL)	K (mD)	R (µm)	porosity (%)	Q (cm/day)	skin plug
core model 1	4.38	15.5	280	2.12	50	45	yes
core model 2	4.74	17.7	280	2.05	53	45	yes
core model 3	4.74	18.7	230	1.83	55	45	yes
core model 4	30	39.5	236	2.13	41.56	45	yes
core model 5	180	225.9	10 000	13.29	45.3	45	no

Part II: Preliminary Investigations of a Computational Model

Introduction

Reservoir souring is an important phenomenon in several North Sea oil fields and it has been studied both mathematically and experimentally e.g. [12][13]. It is clear that the problem involves the complex interaction of chemistry, biology and geophysics and that significant gaps remain before the most effective remediation strategies will be known.

Our long term goals are to understand the detailed process involved in H_2S production and to develop computational models in one, two and three dimensions, making use of numerical expertise gained in other parts of CFD.

The 3-D models will be implemented in full reservoir simulators for complete calculations. It is also intended to produce simplified 2-D models which will be available on PC platforms, as a decision making tool. Furthermore, 1-D models will be used to investigate in details the physical phenomena relevant in souring processes.

This note reports on some preliminary numerical and mathematical work which considers a simplified model of the souring process. The present goal is to investigate the computational issues.

Formulation of the Model

A simplified version of the model given in [12] has been implemented. The model consists of four partial differential equations for the transport in the water phase of the different species within a single pore of the reservoir. The species considered are:

- The sulfate reducing bacteria (SRB) population along the pore.
- The concentration of nutrient (phosphorus — P)
- The concentration of energy source (sulfate — SO_4)
- The concentration of hydrogen sulfide (H_2S) resulting from the reduction of the sulfate.

The transport equations take into account convection and diffusion effects as well as the adsorption of H_2S into the rock. For each species, we have

$$\frac{\partial C_i}{\partial t} + v_i \frac{\partial C_i}{\partial x} = \epsilon \frac{\partial^2 C_i}{\partial x^2} + q_i + r_i, \qquad (1)$$

with $i = SRB, P, H_2S, SO_4$. The q_i are the source terms while the r_i terms model the adsorption effects. These are the crucial elements of the model.

In equation 1, both t and x are normalised variables so that the spatial unit is the pore length L and the time is expressed in terms of pore volume L/v where v is the D'Arcy velocity. Due to this normalisation, $v_i = 1$ for all species which are transported by convection.

Adsorption

A simple (one level) adsorption model has been implemented, following [12]. Further details are given in [14].

Source Terms

The source terms model the variations of the different species due to the activity of the SRB. Two effects are taken into account:

1. Bio-mass growth: this implies the consumption of both nutrient and energy.
2. Remineralisation: overall, this implies only the consumption of energy since the balance of mineral nutrient adsorbed and rejected is zero.

Here, the model of Sunde *et al.* has been modified more extensively. It has been assumed that:

1. The bacteria enters in a quiescent state if it faces starvation.
2. The bacteria will only reproduce if sufficient energy is available for remineralisation

Biomass Growth

If sufficient amounts of nutrients and energy producing elements are available, the growth of the bacteria is not hindered:

$$q_{SRB} = \mu C_{SRB}.$$

where μ is the rate constant for bacteria growth.

If the only nutrient considered is phosphorus, an increase of q_{SRB} in the bacteria population necessitates the consumption of an amount

$$q_P = -\alpha q_{SRB}$$

of nutrient where α is the percentage of P in the weight of the bacteria.

If the amount of available nutrient is less than

$$\mu q_{SRB} = \alpha \mu C_{SRB},$$

the growth of the bacteria is limited. Unconstrained bacteria growth occurs if

$$C_{SRB} < \frac{1}{\mu\alpha}\gamma_N \frac{\partial C_p}{\partial \tau}. \qquad (2)$$

where

$$\frac{\partial C_p}{\partial \tau}$$

is the flux of nutrient at a given point and γ_N models the fact that the bacteria has to compete with other species for nutrients.

If C_{SRB} is greater than this critical value, the bacteria growth is limited and given by:

$$q_{SRB} = -\frac{1}{\alpha} q_P.$$

$$q_P = -\gamma_N \frac{\partial C_p}{\partial \tau}.$$

This is consistent with the critical value given by equation (2), and can be interpreted as meaning that the bacteria consumes all the nutrients available.

A similar discussion can be conducted when the growth of the bacteria is limited by scarce energy resources. Let β be the reproducing metabolism needed for the production of one weight unit of bacteria. The requirement in SO_4 for an unconstrained growth rate is

$$|q_{SO_4}| = \beta q_{SRB} = \beta \mu C_{SRB}.$$

Also, the energy requirement for remineralisation is

$$\sigma C_{SRB}.$$

where σ is the remineralisation rate constant. If the growth of the bacteria is limited by energy, then

$$q_{SRB} = \max\left(\frac{1}{\beta}(-q_{SO_4} - \sigma C_{SRB}), 0\right).$$

Analogous to the nutrient consumption, if the energy is the limiting factor, we can take

$$q_{SO_4} = -\gamma_E \frac{\partial C_{SO_4}}{\partial \tau}$$

where γ_E is the fraction of energy producing elements which are available to the bacteria.

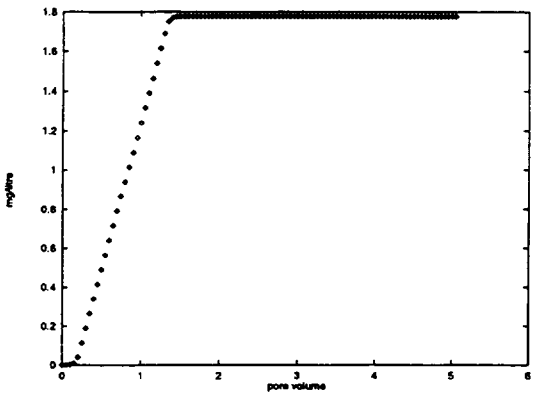

Figure 2: SRB population at injection well as a function of non-dimensional time when the growth is limited by both phosphorus and sulfate

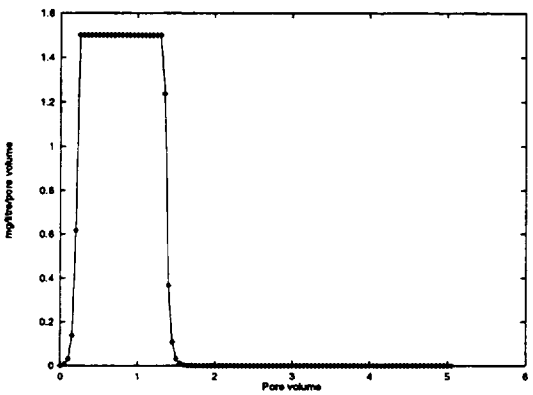

Figure 3: SRB growth rate at injection well as a function of non-dimensional time when the growth is limited by both phosphorus and sulfate

Results

Population Growth, Limiting Factors and Transport

The behaviour of the model will be illustrated in the simple case where i) transport is dominated by convection, and ii) the bacteria are not convected away from the injection well. Hence, this is a bio-film model: the SRB population is confined to the immediate neighbouring of the injection well. H_2S is therefore only produced at this inlet and is transported away to the production well by convection only. At the injection well, the concentration of phosphorus and sulfate are equal to those of the sea-water. These determine the evolution of the bacteria population as shown in figures 2 and 3. Because sulfate is generally plentiful in the injection water, we restrict ourselves to the case where the bacteria growth is only limited by nutrients. In this case, after an initial exponential growth, the bacteria population grows at a constant rate proportianal to the concentration of nutrient in the injected sea water.

If adsorption effects are neglected, the produced H_2S is simply convected away to the production well (figure 4). The graph shows that the time delay between H_2S generation at the injection well and its detection at the production well is one pore volume as should be expected. As well as that, the time evolution of C_{H_2S}, when the growth is limited by nutrients, appears to be linear. The model predicts an exponential component due to remineralisation but this seems to be dominated, for the set of parameters chosen here at least, by the bio-mass growth.

If adsorption effects are taken into account, the time history of C_{H_2S} at the production well is slightly reduced at first (figure 5). However, it can be seen that the time delay between generation and detection is not significantly altered (figure 6): this may be explained by the fact that even when the surrounding rock is free from H_2S, not all the H_2S generated is absorbed.

Gas Injection

A possible remedy against reservoir souring is gas injection. This was modelled by alternat-

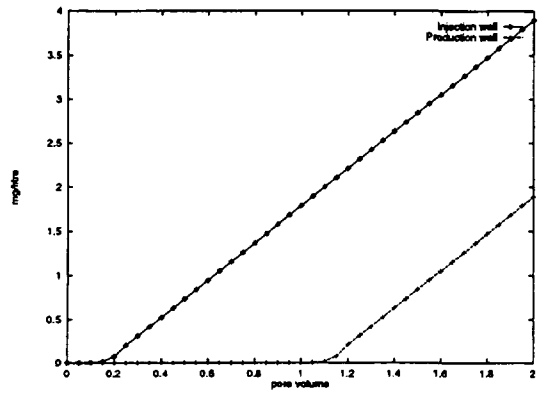

Figure 4: Concentration of H_2S as a function of non-dimensional time at injection and production wells

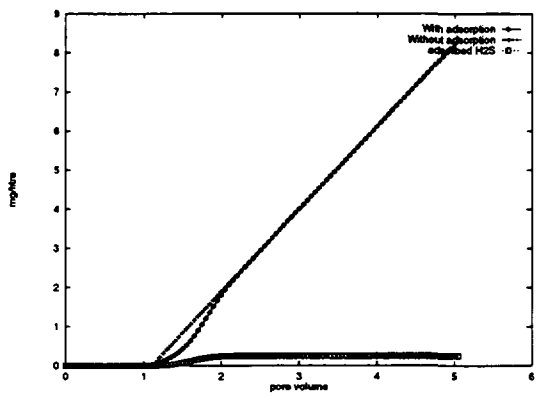

Figure 5: Concentration of H_2S as a function of non-dimensional time at production well with and without adsorption

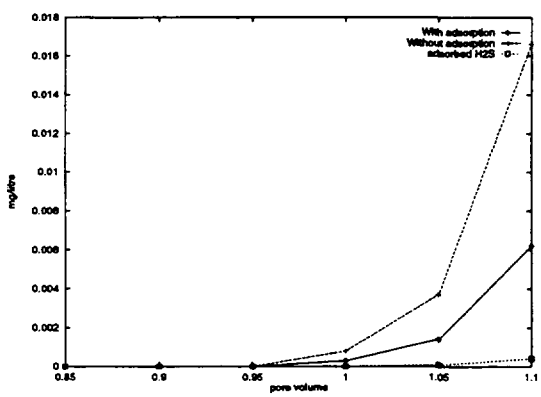

Figure 6: Concentration of H_2S at the production well after one pore volume

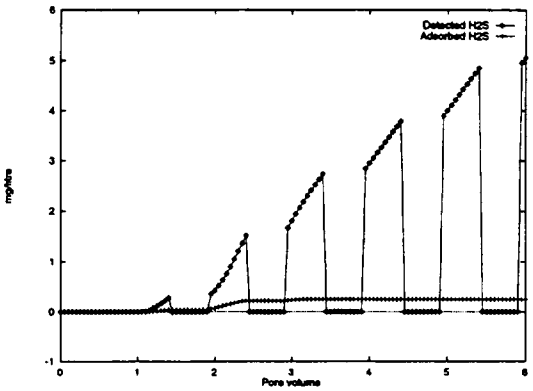

Figure 7: Concentration of H_2S at the production well as a function of dimensionless time with gas injection

ing the phosphorus and sulfate concentration at the injection well between their sea water values and zero when the gas is injected. It was assumed that the convection speed remain unchanged. The results obtained are shown in figure 7.

Biocide Treatment

For this remedial strategy, the biocide is introduced periodically at the injection well at a constant concentration. Its effect is to modify the growth rate of the bacteria. Two cases have been studied:

- The biocide concentration is such that the bacteria population grows only slowly.
- The biocide concentration is such that the bacteria population actually decreases (figure 8)

Numerical Issues

The diffusion through pores is small so the transport of species is dominated by convec-

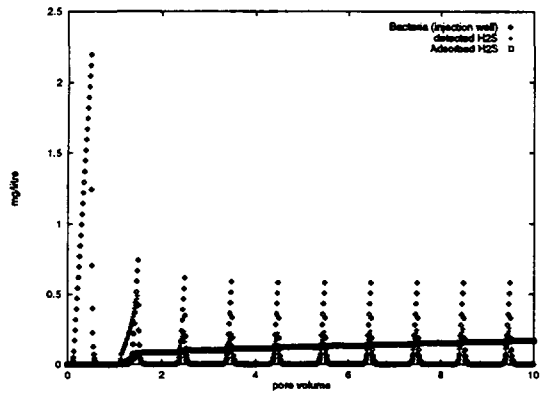

Figure 8: Biocide treatment, $\mu_{biocide} = -0.5\mu_{SRB}$

tion, which renders the transport equation hyperbolic or nearly hyperbolic. It is therefore important to minimise the effect of numerical diffusion associated with the use of upwind differencing [15].

The above results have been obtained with time and space steps such that the Courant number,

$$u\frac{\Delta t}{\Delta x},$$

is equal to one. For this value, numerical diffusion is removed. If this condition is not met, numerical diffusion causes an error in the prediction of the time delay between the generation and the detection of H_2S.

Secondly, reservoir souring involves the interaction of phenomena on different time scales:

- potentially rapid variation of the bacteria population and/or boundary conditions.
- relatively slow convection

The combination of these two factors indicate that the numerical scheme used to discretise equation 1 should be selected with care and secondly, that time and space adaptivity will be useful.

It is therefore clear that advanced numerical techniques [16] will be necessary to obtain reliable, robust and efficient simulation data. These include:

- automatic error control
- automatic gridding
- automatic time stepping
- efficient coupled solvers

These techniques have already been succesfully applied to difficult problems including buoyant flows at high Rayleigh number [17] and multiphase flows [18]. It is envisaged that they will enable comprehensive souring models to be implemented in an efficient and an accurate way.

Modelling and Experimental Issues

The model presented here only takes into account a limited number of physical parameters and the question of when and where in the reservoir is H_2S produced has many open issues.

It also appears that the model is sensitive both in a qualitative and a quantitative way to experimental data. The development of a successful numerical model will therefore rest on accurate experiments.

Conclusions

- A simple souring model has been implemented and preliminary studies conducted.
- The model is very sensitive to the values assigned to many of the different biochemical and geophysical parameters.

- Numerical issues arise in the simulation of reservoir souring and need careful handling.
- Progress can be made by a combination of experimental and computational work together with the exploitation of field data.

Parameter Values

Reservoir data:

- Pore length: $L = 1125m$
- D'Arcy velocity: $v = 1.6m.s^{-1}$

Bacteria population:

- $\mu = 69.31$ (1 population doubling in 1/100 pore volume)
- $\sigma = 27.72$ (the half period of remineralisation is 1/40 pore volume)
- $\alpha = 0.04$
- $\beta = 2$
- $\gamma_e = \gamma_n = 0.05$

Initial Conditions:

- $C_{SO_4} = C_P = C_{H_2S} = 0$ throughtout the pore at $t = 0$
- $C_{SRB} = 0.0001$ at the injection well, C_{SRB}=0 elsewhere.

Boundary Conditions at injection well:

- $C_{SO_4} = 50mg.l^{-1}$ for figures 2 and 3, $C_{SO_4} = 2700mg.l^{-1}$ for other computations
- $C_P = 0.06mg.l^{-1}$

Adsorption (cf. [12]):

- normalised adsorption affinity: $R = 1$
- rock saturation: $C^s_{\max} = 0.25mg.l^{-1}$

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Appendix

$$PI = \frac{Q}{P_{av} - P_{wf}} \qquad \text{for } P_{wf} \geq P_b$$

$$= \frac{Q}{P_d - P_{wf} + \Delta P_{turb}} \qquad \text{for } P_{wf} < P_b$$

$$PI = \frac{Q}{P_d - P_{whf} - \Delta P_{tubing}}$$

$$\Delta P_{tubing} = \Delta P_g - \Delta P_f - \Delta P_a$$

$$PI_{id} = \frac{Q}{P_d - P_{wf} - \Delta P_s}$$

$$S = \frac{2\pi kh}{QB\mu} \times \Delta P_s$$

$$S = S_d + S_{comp} + S_{dev}$$

PI = productivity index ($Sm^3/d/kPa$)
Q = rate (Sm^3/d)
P_{av} = average pressure within drainage area
P_b = saturation pressure (bubble point)
P_{wf} = flowing bottomhole pressure
P_{turb} = pressure drop due to turbulence
P_{whf} = flowing wellhead pressure
ΔP_{tube} = pressure drop in tubing
ΔP_g = pressure drop due to gravity
ΔP_f = pressure drop due to friction
ΔP_a = pressure drop due to acceleration
PI_{id} = ideal productivity index
ΔP_s = pressure drop due to "skin"
S = skin factor (dimensionless)
k = formation permeability (mD)
h = formation thickness (m)
B = reservoir volume factor (Rm^3/Sm^3)
μ = viscosity (cp)
S_d = skin due to formation damage
S_{comp} = skin due to partial completion
S_{dev} = skin due to well deviation

Table: Summary of Well Operations & Production Test Data

Date	Operation	PI ($Sm^3/d/bar$)	S_d	Comments
09.02.93	Initial perforation of LB B3/B2C. Production test & pressure build-up test with downhole pressure gauge.	22.1	2.5	Q_{oil} = 1026 and Q_w = 0 Sm^3/d on 11.02.96.
28.05.93				H_2O = 2.2% (formation water).
17.07.93	Caliper from 1950 m TVD to surface.			No significant reduction in tubing diameter.
20.09.93	Caliper from bottomhole.			Deposits detected in liner and lower tubing joints.
22.09.93	Production test & pressure build-up test with PLT.	5.4 PI_{oil} = 3.9	18.0	
22.10.93	Reperforation of B3/B2C.	(16)		PI estimated from separator test. Increase in Q_{oil} from 356 to 767 Sm^3/d.
05.11.93	Scale squeeze (phosphonate pH 8).			Q_{oil} = 235 Sm^3/d on 16.11.95.
01.04.93	Injection of gas.			No effect, indicating fines migration not a damage mechanism.
02.04.95	Acid stimulation (HCl).			Increase in Q_{oil} from 250 to 386 and in Q_w from 388 to 723 Sm^3/d.
06.04.95	Scale squeeze (phosphonate pH 2).			Q_{oil} = 281 and Q_w = 738 Sm^3/d on 13.04.95.
27.04.95	Perforation of MB B6A & B5A/B.			Q_{oil} = 286 and Q_w = 1144 Sm^3/d on 02.05.95.
25.10.95	Production test with PLT.	B6A = 0.4 B5A/B = 0 B3/B2C = 9.8		Q_{oil} = 413 and Q_w = 910 Sm^3/d on 25.10.95. γ-log indicated B5A/B plugged with sulphate scale.