RESEARCH ARTICLE OPEN ACCESS

The Effect of Salt Concentration on Microbes during Microbial Enhanced Oil Recovery

Nmegbu, Chukwuma Godwin Jacob*
*(Department of Petroleum Engineering,Rivers State University of Science and Technology, P.M.B 5080, Nigeria)

ABSTRACT
Reservoir fluid salinity, its effectiveness on viscosity as well as temperature dependency is an important parameter for enhanced oil recovery consideration. Previous studies on formation fluid properties focused on NaCl and KCl, the two most common brines in connate water and in water-based drilling mud, failing, however, to relate its performance to bacterial survival. This work has considered four different brine solutions and how it will affect the useability of pseudomonas species and halobacterium H – 356. The bacterial mixture viscosity shows a considerable difference between NaCl, CsCl, KCl and LiCl with NaCl and LiCl being favourable brines. Hence, for flooding agent at varying temperature since it makes the bacteria mixture viscosity more viscous whereas the KCl appeared less viscous compared to liquid mixture standard water. For the bacteria mixture, the viscosity of KCl and CsCl decreases with the concentration of a low temperature range and increases with the concentration at a high range.
Keywords-Bacteria Growth, MEOR, Salinity, Salt Concentration

I. INTRODUCTION

The Microbial enhanced oil recovery (MEOR) is a mechanism that employs the use of microbes to degrade or ferment hydrocarbons and produce by-products such as surfactants, polymers, gases and biofilms that are useful in the recovery of oil [1], [2]. Microbial methods for increasing oil recovery are potentially cost effective even at relatively low crude oil prices. They can be applied in a variety of ways including permeability modification treatments and microbial enhanced water flooding. The flexibility and potential cost effectiveness of the technology makes it attractive, but further understanding of the transport mechanism and the development of a sound engineering methodology for optimizing microbial and injection strategies are needed to realize its potential [3].

Wagner [4] presented a review on MEOR from carbonate reservoirs with complex formation characteristics. Adapted laboratory models showed a 25% decrease in water production and a three-fold increment in oil production. Such laboratory marvels have further propelled research in this field. The industry remains reluctant, as usual, to accept this new technology wholly.

The practical application of microbial culture to subsurface oil reservoirs imposes several restrictions on the microbial culture. The microbes must be able to migrate, transported deep within the reservoir for any in-situ applications to be of practical significance to oil recovery. The microbes must remain biologically active at elevated temperature and pressure [5]. As such, microbes intended to be used in petroleum reservoirs should be tested with reservoir fluids at subsurface conditions of temperature, pressure and salinity [5], [6].

The effectiveness of the microbes varies from one formation to the other, often influenced by a host of physical, biological and chemical constraints [5], [7]. This was reaffirmed by Alireza et al when they investigated the MEOR technique in fractured porous media using etched-glass micro models [8]. They found that the plugging of matrix-fracture interface by an exopolymer is the main reason for the low performance of the exopolymer producing bacterium. The physical constraints include temperature, pressure, pore geometry, whereas the biological constraint is mainly enzymatic functions. Surface charge, pH and salinity, amongst others, make up the chemical constraints [9].

No doubt, different oil bearing formation waters have a wide range of salinity often increasing with depth. Ivanov and Belyaev [10] examined the microbial flora of water injections and found that bacterial oxidation of oil took place in the zone of contact between the injected low-salinity waters and stratal waters of the oilfield. Masahito et al. [11] in their paper on the effects of salt concentration on encystment induction in ciliated protozoan colpoa sp. discovered that encystment was promoted by an increase in the concentration of ions such as Ca^{2+}, Na^{+} and K^{+} contained in the surrounding medium. According to Collins [12], the highest concentrations of minor cations that may interfere with microbial systems are Lithium – 400 g/L, Barium –670 g/L,

Boron –450 g/L, Bromine – 6000 g/L and Iodine – 1400 g/L.

Salinity is an ecological factor of considerable importance, influencing the types of organisms that live in a body of water [11], [12]. This work basically seeks to study the effects of salinity on the performance of microbes in oil reservoirs during MEOR.

II. METHODOLOGY

Synthetic porous media with dimensions of length 29.6cm and diameter 7.0cm was used as a reservoir model. The sand used was obtained from a depth of 900ft below sea level and a sieve analysis was done on the sand to obtain different grain sizes of 2.0mm, 3.75mm and 4.35mm. The flooding agent used was distilled water, autoclaved at a temperature of 121˚C. Lab M nutrients broth "E" solution was used as nutrient. It was prepared by dispersing 13g of broth E powder in one liter of deionized water. The mixture was heated to dissolve the powder properly and then sterilized by autoclaving at 121˚C for 15minutes. The pH of the nutrient solution was 7.4±0.2.

Table 1: Oil Physical Property

Parameter	Value
Reservoir pressure, P_R (psi)	3448
Bubble Point pressure, P_b (psi)	1048
Oil Viscosity, μ_o (cp)	0.41
API gravity	35.7
Oil formation volume factor, B_o (bbl/stb)	1.559
Gas gravity	0.647
Reservoir Temperature, T_R (˚F)	117
Gas Solubility, R_s (scf/STB)	979

psi = pounds per square inch; cp = centipoise; bbl = barrels; stb = stock tank barrel; scf = standard cubic feet

The table below shows the nutrient composition and corresponding concentrations used.

Table 2: Nutrient Composition

Composition	Concentration (g/cm^3)
Beef Extract	3.0
Yeast Extract	4.0
Peptone	10.0
Sodium Chloride	10.0

2.1 Growth and Nutrient Condition

The choice of microbes were made for this work – *bacillus subtilis* and *pseudomonas aerogenosa*. Broth bacteria were collected using the Persian Type Culture (PTCC).

A broth culture (liquid growth medium) of *P. Aerogenosa* and *B. subtilis* was done differently in mediums A and B respectively. The composition of each growth medium is presented in Table 3. The bacterial culture was centrifuged at 200rpm for 30 minutes and collected at the stationary state. It was then suspended in autoclaved distilled water. The bacterial suspension was placed on a magnetic stirrer and allowed to mix at room temperature for 8mins. The solution was centrifuged and washed again with water. The cell density of the bacterial solution was adjusted to about $0.8 * 10^7$ cells/cm^3.

Table 3: The composition of liquid growth media A and B

Constituent	A	B
Ammonium Chloride	2.0	2.0
Glucose	5.0	3.0
Peptone	1.0	1.0
Meat Infusion	5.0	5.0
Sodium Hydroxide	2.0	2.0
Sodium Chloride	0.3	0.25

2.2 Experimental Procedure

A three-dimensional glass model was used as a bioreactor. The bioreactor was made a digestor as it was air-tight. The bioreactor was connected between two points: the inflow line and the outlet. The inflow had two valve channels through which the liquid mixture was poured. All system tubing was 1/10 OD PTFE Teflon. The choice of a small diameter flowline was to enable approximate flowline to pore volume ratio.

The following procedure was followed in conducting the experiment:

1. The glass model (bioreactor) was sterilized with Xylene.
2. The glass model was filled with grain of a particular size.
3. The porous media was saturated with a brine of 50g/100ml until the point of connate water was reached.
4. The outlet valve was opened to allow the water to drain out.
5. It was then saturated with crude oil to the point of initial oil saturation
6. Air was then projected at a pressure of 5psi and the flow rate was measured until no more liquid was produced.
7. 100 ml of the mixture of bacterial broth culture was poured through the inlets, through the flowline to the porous media.
8. The system was incubated aerobically for a period of 24hrs [shut-in period] at a steady ambient temperature of 23˚C
9. Following the shut-in period, after 24 hours, air was pumped through the valve to produce oil until no more oil was produced
10. The procedure was repeated for different shut-in periods of 12 and 48 hours for distinct grain sizes

11. The procedure was repeated using different concentrations of the brine solution.

III. RESULTS

Table 4 shows the growth rate of the bacteria at different brine concentrations.

Table 4: Growth rate at different brine concentrations

Days	Brine Concentrations			
	10%	15%	25%	35%
0	0.00	0.00	0.00	0.00
2	0.20	0.35	0.30	0.10
4	0.30	0.50	0.52	0.24
8	0.35	0.72	0.78	0.99
10	0.38	0.80	0.85	0.55
14	0.35	0.85	0.92	0.57

The development of the bacteria at different salinities is presented with 25% concentration giving the best growths. This is better revealed in the Fig. 1.

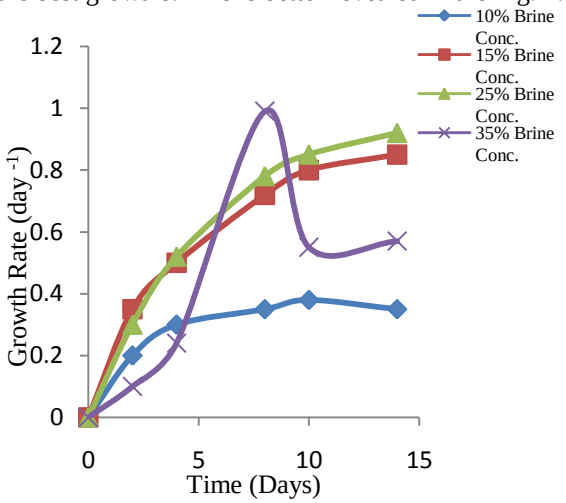

Fig. 1 Growth rate of bacteria for varying brine concentrations

There is a great deal of variation in the growth rate trend at 35% salt concentration. This implies that there would be a lot of morphological changes at this salinity. A similar variation though not as severe, is observed at 10% salinity. Seemingly optimal growth trends are observed at 15% and 25% salt concentrations with the latter showing better growth characteristics than the former.

Table 5 below shows the impact of the salt concentrations on the viscosity of the crude oil samples. The viscosity increased steadily for NaCl and LiCl to a value of 1.58cp and 2.25cp respectively. However, the opposite behaviour is observed for the other salts, i.e. KCl and CsCl.

Table 5: The μ/μ_m values with varying salt concentrations

Salts	30kppm	50kppm	250kppm	335kppm
NaCl	1.20	1.32	1.40	1.58
LiCl	1.20	1.48	1.83	2.25
KCl	1.10	0.90	1.00	1.00
CsCl	1.00	0.87	0.70	0.39

μ = viscosity of the brine, μ_m = viscosity of the bacteria mixture with concentration of brine varying from 3 to 305kppm

Fig. 2 below shows the plot of μ/μ_m for the varying salt concentrations.

The viscosity increases steadily for NaCl and LiCl to a value of 1.58 and 2.25 respectively. However, the opposite behaviour is observed for the other salts, i.e. KCl and CsCl. The Figure below shows the plot of μ/μ_m for the varying salt concentrations.

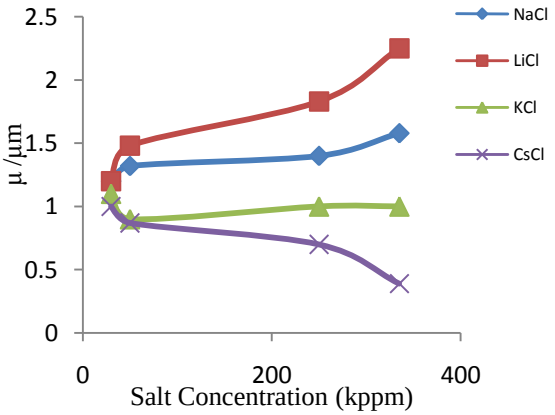

Fig 2: Plot of μ/μ_m for the various salts at varying salt concentrations

The distinctive observation from the figure lies in the strength of the structure in that NaCl and LiCl strengthen the structure of bacteria mixture whereas KCl and CsCl weakens the structure. Thus, the LiCl and NaCl are found to cause the bacteria solution to be more viscous (kosmotrope) and KCl and CsCl makes bacteria ssolution less viscous (chaotrope).

IV. CONCLUSION

An experimental investigation of the effects of salinity on microbial regeneration during Microbial enhanced oil recovery is presented. The results show that 25% salt concentration gave the best growth trend, making it a suitable choice for salt concentration. There is a great deal of variation in the growth rate at 35% salt concentration. The results also reveal that Lithium Chloride (LiCl) and Sodium Chloride (NaCl) increase the viscosity of brine solutions. The reverse is observed for Potassium Chloride (KCl) and Caesium Chloride (CsCl). This result show that while 25% salt concentration could be beneficial to microbial growth in reservoirs, a wrong choice in the particular choice made could

undo the effort by making the microbial solution too viscous to migrate within the reservoir.

REFERENCES

[1] S.L. Bryant andT.P. Lockhart, *Reservoir Engineering analysis of microbial enhanced oil recovery*, *SPE Reservoir Evaluation and Engineering*, Oct 2002, 365-374

[2] S.L. Marshall, "*Fundamental Aspects of Microbial Enhanced Oil Recovery: A Literature Survey*", National Research flagship, CSIRO, Western Australia, 2008 [online], http://www.clw.csiro.au/publications/science/2008/WFO-MicrobialOilRecovery.pdf (accessed Feb 13, 2014)

[3] M-M.Chang, R.S.Bryant, H.W. Gao andT.-H. Chung, *Modeling of Microbial Transport Phenomena in Porous Media*, *US DOE Report*, July 1991 [online], http://www.netl.doe.gov/kmd/cds/disk44/I-Microbial/NIPER539.pdf (accessed Feb 13, 2014)

[4] M. Wagner, *Microbial enhancement of oil recovery from carbonate reservoirs with complex formation characteristics*. Microbial enhancement of oil recovery-recent advances. In: Premuzic ET (ed.), Developments in Petroleum Science: *Proc. of the 1992 international conference on microbial enhanced oil recovery*, 31. (New York, USA : Elsevier, 1992), 387-398

[5] B. Bubela,*Combined Effect of Temperature and other Environmental Stresses on Microbiologically Enhanced Oil Recovery*, In: E.C. Donaldson and J.B. Clark (Ed.), *Proc., 1982 International Conference on Microbial Enhancement of Oil Recovery*, NTIS, Springfield, Va,1983, 118-123

[6] B., Bubela, A.J. DaviesandJ. Ferguson,*Biological and Abiological processes in a simulated sedimentary system, J. Geol. Soc. Austr.,32(2),*1975, 135-141

[7] T. Teresa, Introduction to Bacteria, *J. Science in the real world*, 1999, 3-6

[8] A., Soundmand-asli, S.S. Ayatollahi,H. Mohabatkar, M. Zareie, andS.F. Shariatpanahi, *The in situ microbial enhanced oil recovery in fractured porous media, Elsevier Journal of Petroleum Science and Engineering,58,*2007, 161-172

[9] R.S. Bryant, E.C. Donaldson, G.V. Chilingariam andT.F. Yen, *Microbial Enhanced Oil Recovery II, Process and Operation* (Amsterdam, Netherlands: Elsevier, 1989) 432-450

[10] M.V. IvanovandS.S. Belyaev,*Microbial Activity in Water Flooded OilField and its Possible Regulation*, In: E.C. Donaldson and J.B. Clark (Ed.), *Proc. 1982 International Conference on Microbial Enhancement of Oil Recovery*, NTIS, Springfield, Va, 1983, 48-57

[11] A.G. Collins, *Geochemistry of Oilfield waters*, (Amsterdam, Netherlands: Elsevier, 1975) 496 Masahito, Y., Tamako, W. & Tatsuomi, M. (2004) "Effects of salt concentration and bacteria on encystment induction in ciliated protozoan colpoda sp.", *J. ACTA protozool.* **43**, 93-98