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APPLICATION OF STEADY STATE ANALYSIS TO MICROBIAL ENHANCED OIL RECOVERY (MEOR) UNDERGOING LAYERS IN SERIES

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ABSTRACT

Enhanced oil recovery has come to stay over ages and yet more research is made to improve on existing techniques and find better options to them. One of the promising techniques discovered is the Microbial Enhanced Oil recovery, involving the use of microorganisms to alter petrophysical properties of the reservoir and most especially reducing the viscosity of residual oil. A thorough process of petrophysical parameter determination, efficient process execution and analysis is presented in this work. A model is developed incorporating steady state analysis to a reservoir layered in series undergoing MEOR process. The model is validated by adapting it to a reservoir system dosed with two bacteria culture – Bacillus substilis And Pseudomonas sp.

Keywords : MEOR; Steady State;Layered Reservoir;Series bed

1 INTRODUCTION

Conventional technologies have succeeded in recovering only about 30% of oil in place [1]. The considerable quantity of oil that remains unrecoverable so far, increasing difficulty and limitations in finding new oil accumulations have incited researchers to seek the ways and means to increase oil recovery by applying Enhanced Oil recovery (EOR) technologies such as miscible gas, chemical and thermal injections. Basically, the approach is to maintain the reservoir pressure and attempt effecting chemical and physical improvements on the rock and fluid characteristics.

Russell [2] defines enhanced oil recovery (EOR) to be oil recovery by the injection of materials not normally present in the reservoir. EOR technologies are also being used for in-situ extraction of organic pollutants from permeable media. This definition covers all modes of oil recovery processes (drives, push-pull, and well treatments) and most oil recovery agents (i.e., by-products of microorganism metabolism on crude oil). Microbial Enhanced Oil Recovery (MEOR) is a biotechnological EOR technique that involves the enhancement of production via the action of bioproducts generated by injected microbes in the reservoir.

The concept of using microorganisms to promote oil recovery from underground formations can be tracked back to more than sixty (60) years [3]. However, the first practical demonstration that such a concept might be feasible did not occur until the 1940s. Research supported by the American Petroleum Institute Research Project 43A headed by C.E. Zobell at Scripps Oceanographic Institute showed that anaerobic sulfate-reducing bacteria could release bitumen from Athabasca oil sands as well as conventional oil from laboratory test columns. Field success was also reported by Dejun et al [4] stating that the use of microbial EOR is attractive for the Changqing oilfield owing to the technology's low cost, ease of implementation and suitability to Changqing reservoirs [1[, [2[, [3].

Petzel and Williams [5] reveals that microbial cultures are capable of synthesizing a large variety of biochemical products from crude oil constituents when provided with essential nutrients and proper environmental conditions.

Diran [6] defines a model as the ensemble of equations which describe and inter-relate the variables and parameters of a physical system or process. The term modeling in turn refers to the derivation of appropriate equations that are solved for a set of system or process variables and parameters. These solutions are often referred to as simulations, i.e., they simulate or reproduce the behaviour of physical systems and processes. This tool is key for any process analysis mathematically and is extensively applied in this study.

Donaldson et al [7] reports that the range of metabolic products from microbial attack of petroleum is very broad, depending on environmental conditions (pressure, temperature, salinity, pH and the presence or absence of Oxygen), supporting nutrients available for cell metabolism (Nitrogen, Phosphorus, etc.), and the specific bacteria interacting with the petroleum. In very general terms, the metabolic products may be gases (Methane, Hydrogen, Carbondioxide, Hydrogen Sulphide), Carboxylic acids (formic, acetic, valeric), solvents (alcohols, aldehydes, ketones), polymers (proteins, polysaccharides), surface-active compounds (poly-anionic lipids) and many other compounds ranging from simple to very complex macromolecules.

The principle of steady state analysis has been applied to several processes like mass balancing, force, molecules and heat transfer, cell growth kinetics and lots more. Diran [6] applied this same principle to biomass formation. First was to perform growth kinetics and then followed up by a steady state analysis of both cell growth and production in a continuous flow stirred bioreactor. Similar causes were also cited on how

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steady state analysis for diffusional transport, conduction between two isothermal surfaces and resultant steady state temperature distribution in the interior of the cylinder, yielded models in Laplace equation form [8].

Dake [9] also made use of "no accumulation" for steady state analysis. He reported that for steady state analysis, there must be a balance and an influx that will cause pressure maintenance. Consequently, the steady state analysis is often recommended for aquifer supported reservoirs.

Reservoirs can be in parallel or series. These strata configurations pose permeability variations and thus pressure drop across each layer with total pressure being equal to the summation of pressure across each layer. Tarek [8] revealed that for a steady-state flow in lateral layers of a reservoir, the flow rate is constant and total pressure drop equals the sum of the pressure drops across each bed, and proposed an average permeability for the reservoir expressed as follows:

$$K_{avg} = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} \left(\frac{L}{K}\right)_i} \quad (1)$$

where

L_i = length of each layer

K_i = Absolute permeability of each layer

The quest for a better understanding and analysis of recovery processes is the bedrock of this study.

2 MATHEMATICAL MODELING

In order to effectively formulate a MEOR model equation for steady state analysis, it is important to consider a finite element, i.e., an elementary section of the sand pack. Consider the elementary control volume represented below:

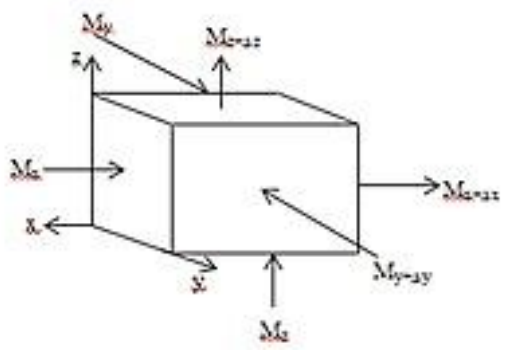

Fig. 1 Schematic of Model Control Volume

Applying the law of conservation of mass to the above elementary system:

Mass In – Mass Out = Mass Accumulation (1)

The MEOR balance equation is given as:

Crude Oil (heavy) + Microbes + Nutrient + Water ⟶

Crude Oil (light) + Bioproducts + Energy

But,

Bioproducts = Biopolymer + Biosurfactant + Biogas + Bioacid + Biomass

Assume that three phases to be present during the MEOR process, i.e., liquid, gaseous and slimy phases. Assuming the liquid phase to consist of oil, bioacid, biosurfactant and water and possesses a combined effect on reservoir rock and fluid properties. This phase can be designated as L. Also, the slimy phase consists of both the biopolymer and biomass and is assigned the symbol, S. The gas phase is a function of biogas and is assigned G. Thus, the components of (1) can be rewritten as follows:

$$\text{Mass In} = M_o + M_a + M_g + M_s \quad (2)$$

where,

M_o = Mass of oil

M_a = Mass of biosurfactant, bioacids and water

M_g = Mass of gas

M_s = Mass of biopolymer and biomass (slimy)

$$\text{Mass In} = \rho_o q_o + \rho_a q_a + \rho_g q_g + \rho_s q_s \quad (3)$$

where

ρ_o = Density of oil

ρ_a = Density of bioacid

ρ_g = Density of gas

ρ_s = Density of slimy phase

q_a = Flow rate of bioacid

q_g = Flow rate of gas

q_s = Flow rate of slimy phase

q_o = Flow rate of oil

Evaluating Mass out,

$$\text{Mass Out} = [\rho_o q_o + \Delta(\rho_o q_o)] + [\rho_a q_a + \Delta(\rho_a q_a)] + [\rho_g q_g + \Delta(\rho_g q_g)] + [\rho_s q_s + \Delta(\rho_s q_s)] \quad (4)$$

$$\text{Rate of Mass accumulation} = \frac{\{[\rho\varphi]_{t+\Delta t} - [\rho\varphi]_t\}\Delta x \Delta y \Delta z}{\Delta t} \quad (5)$$

Importing (2), (3) and (4) into (1) with adequate considerations to the Cartesian system and resolving gives the MEOR continuity equation as:

$$\frac{\partial W_x}{\partial x} + \frac{\partial W_y}{\partial y} + \frac{\partial W_z}{\partial z} = -\frac{\partial(\rho\varphi)}{\partial t} \quad (6)$$

Where

$$W = \Delta(\rho_o U_o) + \Delta(\rho_a U_a) + \Delta(\rho_g U_g) + \Delta(\rho_s U_s) \quad (7)$$

and U is the fluid velocity = Flow rate (q) × Area (A)

Expressing the velocity term using Darcy's law,

$$U_x = \frac{K_x}{\mu}\frac{\partial P}{\partial x} \quad (8)$$

$$U_y = \frac{K_y}{\mu}\frac{\partial P}{\partial y} \quad (9)$$

$$U_z = \frac{K_z}{\mu}\left[\frac{\partial P}{\partial z} + \rho g\right] \quad (10)$$

Substituting (8), (9) and (10) into (7) and (6) and assuming that $K_x \cong K_y \cong K_z \cong K$ with negligible gravity effects,

$$\left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right)\frac{\partial^2 P}{\partial x^2} + \left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right)\frac{\partial^2 P}{\partial y^2} + \left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right)\frac{\partial^2 P}{\partial z^2} = \frac{\varphi}{k}\frac{\partial \rho}{\partial t} \quad (11)$$

Set $\left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right) = J$

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Therefore, (11) becomes:

$$J\frac{\partial^2 P}{\partial x^2} + J\frac{\partial^2 P}{\partial y^2} + J\frac{\partial^2 P}{\partial z^2} = \frac{\varphi}{k}\frac{\partial \rho}{\partial t} \quad (12)$$

For a steady state condition, $\frac{\partial \rho}{\partial t} = 0$,

$$k\left[J\frac{\partial^2 P}{\partial x^2} + J\frac{\partial^2 P}{\partial y^2} + J\frac{\partial^2 P}{\partial z^2}\right] = 0 \quad (13)$$

For a reservoir layered in series:

$$k = \frac{\sum_{c=1}^{n} L_i}{\sum_{c=1}^{n}\left(L/k\right)_i} \quad (14)$$

Substituting (14) into (13) gives:

$$\frac{\sum_{c=1}^{n} L_i}{\sum_{c=1}^{n}\left(L/k\right)_i}\left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right)\left[\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2}\right] = 0 \quad (15)$$

Supposing there's a production or an injection well as oil degradation progresses, the final model becomes:

$$\frac{\sum_{c=1}^{n} L_i}{\sum_{c=1}^{n}\left(L/k\right)_i}\left(\frac{\rho_o}{\mu_o} + \frac{\rho_a}{\mu_a} + \frac{\rho_g}{\mu_g} + \frac{\rho_s}{\mu_s}\right)\left[\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2}\right] + q_{sc} = 0 \quad (16)$$

The model equation depicts that a reduction in viscosity will lead to improved recovery. A Similar effect is felt by the density term after microbial activity. The term J can thus be seen as a reduction factor necessary to reduce any factor that will hinder oil production. This term prevails in x, y, z coordinates and thus its effect is expected to be the same in these directions if a steady state condition is applicable.

The assumptions made in arriving at this equation are:

a. Flow rate in equals flow rate out
b. Isotropic permeability condition exist in each layer
c. Temperature is constant, so energy term is absent
d. Permeability for each layer can be expressed as average permeability
e. All bioproducts are capable of deformation under shear stress
f. Gravitational effect is negligible
g. Same bioproduct is formed in each layer and in all Cartesian coordinates
h. Biosurfactant and bioacid are soluble in water
i. Biopolymer and biomass forms the sliming substance capable of deformation under shear stress (i.e., a fluid)
j. Porosity of the system is constant

3 METHODOLOGY

3.1 Culturation of Bacteria from Soil

The culturation of bacteria from soil involves tenfold serial dilution described by Ofunne [10],[11]. In this method, 1.0 gram soil was introduced into 9ml of normal saline (diluent) in a test tube to give 10-1 dilution. Further serial dilution was made by transferring 1ml of the 10-1 dilution to another test tube to obtain 10-3 dilution, 0.1 ml aliquots was introduced onto the surface of sterile solid nutrient agar medium in petridishes. The inoculum were spread plated using a sterile bent glass rod. The inoculated plates were incubated at 37oC for 24 hours and colonies that developed were examined and based on their cultural characteristics, discrete colonies of Bacillus and Pseudomonas organisms were presumptively isolated and purified by subcuttining onto fresh sterile solid nutrient agar and incubated at 37oC for 24hours. Identification of the bacterial isolates (Bacillus substilis and Pseudomonas species) was done based on the procedure established by Bachanan and Gibbons [12],[13].

3.2 Preparation of Bacillus and Pseudomonas species

The bacterial cultures were prepared by inoculating pure culture of the identified bacteria into 500ml of sterile nutrient broth medium. The inoculated medium was incubated at 37°C for 24hours and sieved as culture for treatment of crude oil during the experiment. The composition of the nutrient agar and broth are shown in tables 1 and 2 below.

TABLE 1
MEDIUM COMPOSITION: NUTRIENT AGAR

Constituent/ Parameter	Value
Peptone	10.0g
Meat extract	10.0g
Sodium Chloride	8.0g
Agar	15.0g
Distilled water	1 litre
pH	7.0

TABLE 2
MEDIUM COMPOSITION: NUTRIENT BROTH

Constituent/ Parameter	Value
Peptone	10.0g
Meat extract	10.0g
Sodium Chloride	8.0g
Distilled water	1 litre
pH	7.0

3.3 Porosity determination of Sand Pack Sample

Three Berea core samples were prepared using mesh sizes of 4.75mm, 3.35mm and 2.00mm. These grain sizes represent three well-sorted sand pack samples of hydrocarbon formation. The porosity is estimated on the Archimedes principle.

TABLE 3
POROSITY DETERMINATION

Grain Size (mm)	Mass of core sample (g)	Mass of grain sample (g)	Volume of water displaced (ml)	Grain volume (ml)	Density (g/ml)	Porosity, ϕ
Sample A 4.75	2365	121	36.5	713.4091	3.315	0.56
Sample B 3.35	2510	176	70.5	1005.426	2.497	0.38

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Sample C 2.00	2485	146	57.5	978.6815	2.539	0.40

3.4 Fluid Properties Data

The crude oil sample was obtained from "Z" well Ebocha. The well is named "Z-well" because of confidential reasons best known to the oil company. The fluid properties were given by the company and are obtained at ambient condition.

TABLE 4
PROPERTIES OF THE TEST FLUID AND SYSTEM BEFORE MEOR

System Property	Measured value
Density at ambient conditions, g/cm^3	0.8463
Oil viscosity at ambient conditions, cp	0.41
Oil Formation Volume Factor at ambient conditions, vol/vol ST	1.559
Solution gas at ambient conditions, R_s, scf/stb	955
Gas Oil Ratio (GOR), scf/stb	979
Mean single phase compressibility, psi^{-1}	$14.98 * 10^{-6}$
Gas gravity at ambient condition (Air = 1)	0.883
Outlet pressure	14.7 psi
Inlet pressure	22psi

3.5 MEOR Procedure

The experimental procedure described below was conducted for three core sizes – 2.00mm, 3.35mm and 4.75mm core sizes.

1. Weigh 50grams of Sodium Chloride
2. Pour distilled water into the 1000ml sterilized flat bottom flask (not up to the 1000ml mark)
3. Add the measured Sodium Chloride to the volume of distilled water and stir continuously using the glass rod until the salt is seen to be completely dissolved in the water.
4. Top the water in the flat bottom flask until it gets to the 1000ml mark.
5. Fill the core holder with the sand pack sample A and clamp the MEOR model apparatus at an inclination of 5degress to the horizontal for MEOR process.
6. Close all taps except for inlet B (see fig. 2), then pour the brine solution (1000ml) into the sand pack (porous medium) until the core is completely saturated.
7. Close inlet B and open outlet tap allowing the brine solution to be drained from the sand pack. Collect the drained water by placing a beaker at this outlet.
8. The residual water in the core sample is used for initial saturation calculations.
9. Open inlet A and pour the crude oil into the porous medium using the glass funnel.
10. Close all taps except for the pumping inlet tap.
11. Commence pumping at 5psi and open the outlet tap to begin flow
12. Use breakers to collect flow for 12 seconds interval. Record values.
13. Residual oil is now present in the sand pack.
14. Close all taps except for inlet B and introduce 50 ml each of the microorganism through this inlet.
15. Shut in the MEOR model apparatus to allow for crude oil microbial biodegradation.
16. Open flow after 24 hours and take flow reading using breakers at an interval of 12 seconds.
17. Perform petrophysical analysis to determine fluid properties due to MEOR process effect.
18. Disengage the ground joint of the core holder and change core sample B, and return to step one after inclining the apparatus to 5 degree to the horizontal
19. Perform steps 1 to 17 for sample B with the exception of step 5
20. Perform step 18 for sample C
21. Observe step 5 for 12 hours, 24 hours and 48 hours intervals consecutively while performing step 19 for sample C

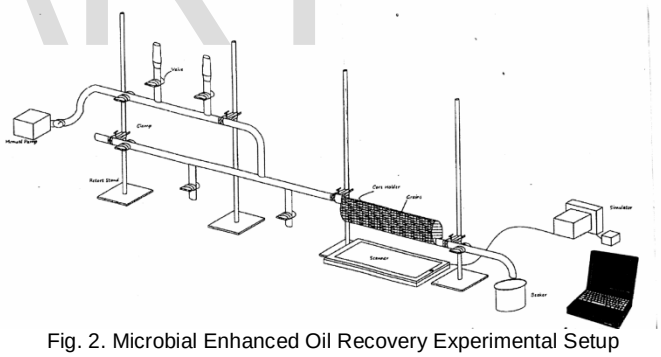

Fig. 2. Microbial Enhanced Oil Recovery Experimental Setup

The core samples in the core holder were scanned before, during and after flow. That is shut in periods and flow periods of normal crude oil in core sample and crude oil plus microorganisms are scanned. Scanned pictures are analyzed on the computer before saving. Physical observation of the process is also done before resuming flow after each shut-in. crucial observations were photographed with a camera and saved for reference and analysis.

4 RESULTS AND DISCUSSION

After the microbe flooding, slimy substances were observed at the bottom of the core indicating the presence of biopolymers. Crystalline substances were also observed along the flowline, likely an indicator of biomass formation. There was no consid-

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erable physical change in the crude oil colour possibly due to the relatively short test time. The table below shows the flow rate for the different test scenarios.

TABLE 5
CONCISE MEOR PROCESS RESEARCH DATA

SAMPLE	Flow ID	Before MEOR (ml/Sec)	After MEOR		
			12 hours	24 hours	48 hours
A	Q_{01}	4.58	4.83	1.83	1.53
	Q_{02}	3.92	4.17	1.58	1.39
	Q_{03}	2.87	3.33	1.5	1.18
	Q_{04}	2.86	2.92	1.48	0.93
	Q_{05}	2.63	2.75	1.33	0.78
	Q_{06}	2.36	2.34	1.55	0.58
B	Q_{01}	3.08	N/P*	4.13	N/P
	Q_{02}	2.42		3.91	
	Q_{03}	2.35		3.62	
	Q_{04}	2.03		3.3	
	Q_{05}	2		3.13	
	Q_{06}	1.92		3.04	
C	Q_{01}	2.23	N/P	2.68	N/P
	Q_{02}	1.42		1.58	
	Q_{03}	1.17		1.54	
	Q_{04}	0.83		1.08	
	Q_{05}	0.67		0.92	
	Q_{06}	0.5		0.76	

*N/P – Not Performed

TABLE 6
ADDITIONAL CONCISE MEOR PROCESS RESEARCH DATA

SAMPLE	Porosity	Permeability, k (D)	Produced water rate (ml/sec)	Initial water saturation
A	0.56	2.0926	Absent	0.02
B	0.38	1.4097	Absent	0.06
C	0.4	1.0206	0.75	0.3
			0.62	
			0.43	
			0.36	
			0.24	
			0.21	

It is observed that recovery flow rate did not consecutively increase when comparing the flow rates of 12 hours, 24 hours and 48 hours respectively. However, the improved flow rate through the cores after microbial treatment is still evident. The decline in the production rate after some time is expected of all naturally flowing system. The comparison of these results is best illustrated in the figures below. Note that produced water rate is absent for samples A and B because of the small quantity of water after initial sand pack saturation.

Permeability Produced Initial

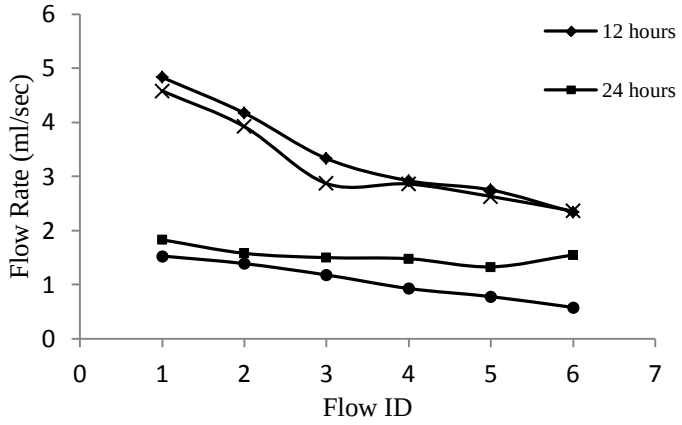

Fig. 3 Sample A Flow Rate before and after MEOR

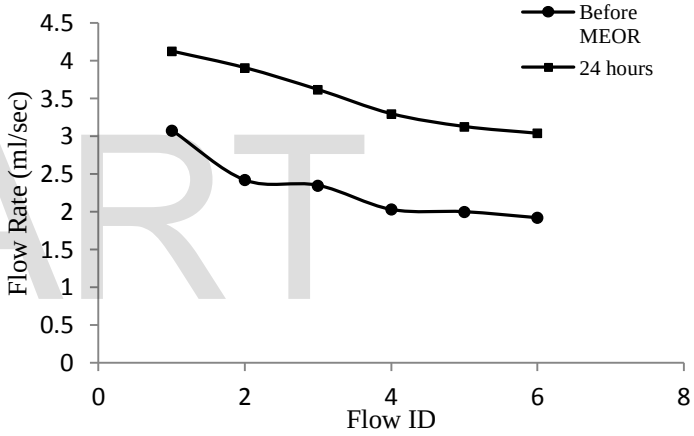

Fig. 4 Sample B Flow Rate before and 24 hours after MEOR

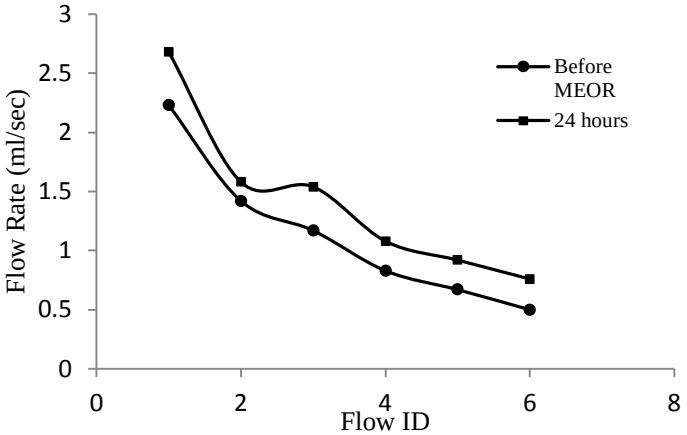

Fig. 5 Sample C Flow Rate before and 24 hours after MEOR

5 CONCLUSION

The results obtained from the research study and the models formulated are great concern for analysis. The following are critical deductions worthy of note:

a. The reduction factor as expressed by the formulated mod-

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el is one whose effect is felt in the x, y and z directions respectively. This factor is supposed to create the necessary petrophysical alteration in these directions.

b. The model equation is a steady state equation and diffusive in nature. This implies that the bioproducts are under diffusion in x, y and z directions. The diffusion state of these parameters does not necessarily imply gaseous state kind of diffusion but a scenario of parameter profile. This means that the molecules are not actually diffusing but these parameters are changing from point to point along the x, y and z directions.
c. The diffusive profile of these parameters results from change of concentration of microbes from the point of injection to that of production.
d. The leading edge of this factor is crucial for initial residual oil biodegradation. This does not imply that there is no bioproduct production along the path already passed or affected by the leading front of the factor. In fact, at any point and instance as will be proposed by an unsteady state, bioproduct effects are observed. But for this steady state analysis, this factor is same across the Cartesian directions and at time causing all necessary microbial EOR consequences. It is also important to point out that the rate of bioproduct movement is same in each section – this actually is the principle of steady state analysis.
e. Apart from the diffusive movement of this factor along the Cartesian coordinates, under steady state analysis the bioproducts formed is same in each elemental section of the reservoir or alternatively put, the bioproduct formed is constant in the elemental control volume considered and this is applicable to the entire reservoir system undergoing MEOR process.
f. Also for the steady state condition to be effective, the rate of bioproduct, lighter hydrocarbon and energy influx into the control volume is same as that leaving the control volume if no accumulation is accounted for. But as stated in the above point, bioproducts are still formed in the control volume regardless of the fact that they are also under diffusive movement. Thus, the bioproduct into the control volume will be equal to that leaving the control volume plus the accumulation of bioproducts in the control volume.
g. Accumulations of bioproducts results in further biodegradation of oil in the control volume.
h. For the entire reservoir, the microbes injected following the inflow, outflow and accumulation balance (mass balance) as analyzed above are also produced at the point of lighter oil production. This for MEOR to be effective, the accumulation of bioproducts in the reservoir must be sufficient to cause all necessary alteration of petrophysical properties.
i. The slimy phase of bioproduct after MEOR effect is responsible for the plugging effect. Thus causes reservoir damage which over time will lead to a reduction in oil production. This must be greatly considered by the reservoir engineer to ensure that flow does not cease due to formation damage.
j. The bioacid and solvent might cause changes to formation damage caused by biomass but this might not be effective enough. A permeability calculation using improved flow rate indicates permeability improvement. In practice, however, this is not always so because of the effect of biomass production with time and also the plugging effect of the biomass. With time this damage can be extensive enough to cause a considerable reduction of oil flow rate. Biogas can also cause this effect.

Thus far, the possibility of MEOR for improved oil recovery has been proven true, increased flow rate observed as microbes effectively cause biodegradation and the reduction factor simultaneously causing petrophysical alterations in the reservoir. There is still, however, a lot of work to be done owing to the relatively unpredictable nature of the two components of the technology – the reservoir and the microbes.

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REFERENCES

[1] A.A. Sepahy, M.M. Assadi, V. Saggadian and A. Noohi , "Production of biosurfactant from Iranian Oil fields by Isolated Bacilli", *Int. J. of Env. Sci. and Tech.*, vol.1, no.4, pp.287-293, 2005

[2] J. Russel (n.d.) *Fundamentals of Enhanced Oil Recovery*, [online], http://www.scribd.com/doc/146289077/Fundamentals-of-Enhanced-Oil-Recovery-Russel-Jhons-pdf

[3] R.H. Lee, E. Jamshidi, A. Mazahari and H. Bonakdarpour, "Isolation and Production of Biosurfactant from pseudomonas aeruginosa isolated from Iranian Southern oil wells", *Environ Sci Tech*, vol. 2, pp.121-127, 1995

[4] Dejun, D., Chenglong, L., Quanyi, J., Pingcang, W., Dietrich, F.L., Zhou, Z.H., "Systematic Extensive Laboratory Studies of Microbial EOR Mechanisms and Microbial EOR Application Results in Changqing Oilfield", *Proc. 1999 SPE Asia Pacific Oil and Gas Conf. and Exhibition, Jakarta, Indonesia*, 20 – 22 April, 1999.

[5] Petzel, G.A. and Williams, B., "Operations trim basic EOR Research", *Oil and Gas J.*, vol.84, no.6, pp.41-45, Feb. 10, 1986

[6] B. Diran, *The Art of Modeling in Science and Engineering*. New York, USA: Shapman and Hall/CRC, pp.27-39, 1999.

[7] E.C. Donaldson, G.V. Chilingarian and T.F. Yen, *Enhanced Oil Recovery, I: Fundamentals and Analyses*, Developments in Petroleum Science, Elsevier, Feb 1, 1985

[8] A. Tarek and P. McKinney, *Advanced Reservoir Engineering*. USA: Gulf Professional Publishing, 1st Ed., pp.334-352, 2006.

[9] L.P. Dake, *Fundamentals of Reservoir Engineering*: Amsterdam, Netherlands, Developments in Petroleum Science, Elsevier, pp. 188-232, 1998

[10] J.I. Ofume, "Bacteriological Examination of clinical specimens", Achua Publications, Ama J.K. Recreation Park, Owerri, Nigeria, 1991

[11] C.G.J Nmegbu and J. Spiff, "Chemical Flocculation of Microorganisms in the Reservoir during MEOR", *Int. J. Eng. Adv. Tech.*, vol.3, no.5, June, pp.46-49, 2014

[12] R.E. Bachanan and N.E. Gibbons, *Bergeys Manual of Determinative Bacteriology*. Baltimore: 9th Edition, The Williams and Williams company, pp. 39-59, 1994

[13] Premuzic, E.T. and Lin, M.S., "Effects of selected microorganisms on crude oil at elevated temperatures and pressures", *Annual report BNL 42048*, 1988

