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Application of the Frontal Advance Equation to a linear system during MEOR

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ABSTRACT

Microbe concentration during Microbial enhanced oil recovery (MEOR) is an important factor for consideration during this tertiary recovery technique. The injection of microbes into reservoirs with the intention of exploiting certain recovery mechanisms such as viscosity reduction, IFT reduction, wettability alteration etc, can turn detrimental to the whole recovery process without proper monitoring. The frontal advance equation for a secondary recovery process is modified to account for microbial concentration with respect to time, distance, water cut and fluid saturation in a porous media, assuming no in-situ bacteria in the reservoir to distort the certainty of concentration prediction. Results reveal a decrease in the concentration of microbes with distance and a somewhat inverse relationship between the microbe concentration and the water cut.

Keywords : *Bacteria, concentration, microbes, MEOR, water cut.*

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I. INTRODUCTION

Microbial Enhanced Oil Recovery (MEOR) is a biotechnological approach for recovering residual oil to meet the ever increasing energy demand. These microorganisms are equipped with the machinery to use petroleum as a carbon source, multiply, mobilize heavy crude, reduces interfacial tension etc. Prediction of the concentration profile of these injected microbes around the reservoir has been with a varying level of certainty. Islam and Gianetto [1], Nielson et al [2] and a number of patents derived a mathematical models for describing bacterial transport, nutrient propagation and microbial concentration profiles in porous media, using successive over relaxation techniques to solve the governing partial differential equations. Concentration trends and microbial propagation was difficult to deduce directly because of the absence of numerical value of some constants. Assigning values to these constants, they obtain real reservoir results [3].

The dispersion of E.coli NR 50 bacteria as observed by Larry and ford showed that dispersion and concentration of microbes were determined by direct measurement of turbidity in pores and by constructing breakthrough curves [4]. The influence of water saturation and water cut on distribution of microbes (Pseudomonas Strain) in a two dimensional bed of glass beads was also investigated in a lab scale, showing the decreasing trend of microbial concentration with increasing water cut [5]. The experimental and theoretical changes in the flow properties of water and oil in a two-dimensional saturated porous media due to microbial concentration was also studied, concluding that concentration of the bio-phase at any distance varies [6],[7]. Use of Non-viable bacteria for permeability alteration as a result of increasing microbial concentration was investigated [7],[8] .The demonstration of microbial spores to travel faster with less adsorption to the rock because of their sizes was reported also reported [9]. Crawford suggested that in-situ growth and transport of microbes could rectify some detrimental water flooding problems such as water loss into high permeable zones, microbial concentration and transport are important considerations for this remedy [10],[11]. With the ability of microorganisms to multiply and propagate in-situ, knowledge of microbial concentrations at various times and positions is paramount to achieve a perfect plugging project [9][12],[13]. This work aims at modifying the frontal advance equations for an EOR process, typically waterflooding, for the prediction of bacteria concentration profile during Microbial Enhanced oil recovery project.

II. METHODOLOGY

Consider a differential element in a porous media as shown in figure 1 below, having a differential length *dx*, area *A*, and porosity

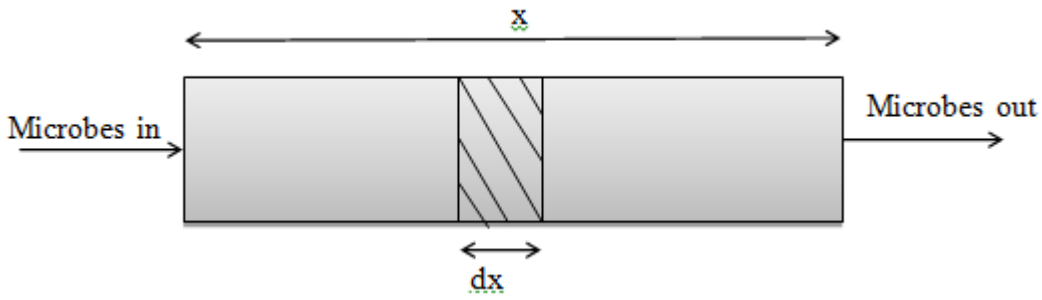

Fig 1. Showing mass entry and mass exit through a porous media of differential length dx.

The mass balance equation for the process above is given as;

$$\begin{bmatrix}\text{Concentration of microbes}\\ \text{injected in the porous media}\end{bmatrix} - \begin{bmatrix}\text{concentration of microbes}\\ \text{produced with oil}\end{bmatrix} = \begin{bmatrix}\text{concentration of microbes}\\ \text{accumulated}\end{bmatrix} \quad (1)$$

Concentration of microbes injected = $C_b f_w dt$ (2)

Microbial concentration produced with degraded oil = $C_b(f_w - df_w)dt$ (3)

Subtracting the above expressions gives the concentration of microbes accumulated within the element in terms of differential changes in df_w.

$C_b f_w dt - C_b(f_w - df_w)dt = A$ (4)

Rearranging the above, we have;

$C_b\, df_w\, dt = A$ (5)

Recalling that,

$$\frac{dx}{dt} = V_x$$

$$C_b = \left(\frac{V_x(A\emptyset)}{5.615}\right)\left[\frac{df_w}{dS_w}\right]_{S_w}^{-1} \quad (6)$$

Where

A is cross sectional area (ft^2)

C_b is the microbial concentration ($cells/ft^3$)

$\emptyset$ is the porosity of the media

$\left[\frac{df_w}{dS_w}\right]_{S_w}$ Slope of f_w vs S_w curve at S_w

Assumptions

- No indigenous bacteria present.
- Flow is laminar
- Gravitational effects considered negligible.
- Isothermal system as reservoir fluctuations in temperature is regarded minimal
- Fluid flow is in one-dimension and takes place in a uniform porous medium.
- No break in injection rates of nutrient and bacteria
- Microbial decay not considered.
- No flow boundary condition.
- Chemotaxis not considered.
- No substrate and metabolite adsorption on the pore walls.

III. RESULTS AND DISCUSSION

3.1 Results

Parameters of the model reservoir and fluid used for the model validation are:
Cross sectional area of the porous media = 26400ft^2
Water viscosity, μ_w = 1.0cp
Oil viscosity, μ_o = 2.0cp
Porosity, Ø = 25% = 0.25

TABLE 1 Parameters for model validation

S_w	f_w	df_w/dS_w	dx (ft)	dt(day)
0.25	0.062	0.670	25	20
0.30	0.105	1.084	50	30
0.40	0.173	1.647	95	40
0.45	0.271	2.275	100	50
0.50	0.398	2.759	125	60

At dx=25ft,
Recalling Eqn 6,

$$C_b = \left(\frac{V_x(A\emptyset)}{5.615}\right)\left[\frac{dfw}{dS_w}\right]_{sw}^{-1} \qquad V_x = \frac{dx}{dt} = \frac{25}{20} = 1.25\text{ft/day} \quad ,$$

$$C_b = \left(\frac{1.25\times26400\times0.25}{5.615}\right)\frac{1}{0.670} = 2192.92\text{cells/ft}^3$$

At 50ft,

$$V_x = \frac{dx}{dt} = \frac{50}{30} = 1.67\text{ft/day}\ , \qquad C_b = \left(\frac{1.67\times26400\times0.25}{5.615}\right)\frac{1}{1.084} = 1811.81\text{cells/ft}^3$$

At 95ft,

$$V_x = \frac{dx}{dt} = \frac{95}{40} = 1.88\text{ft/day}\ , \qquad C_b = \left(\frac{1.88\times26400\times0.25}{5.615}\right)\frac{1}{1.647} = 1191.52.92\text{cells/ft}^3$$

At 100ft,

$$V_x = \frac{dx}{dt} = \frac{100}{50} = 2.00\text{ft/day}\ , \qquad C_b = \left(\frac{2.00\times26400\times0.25}{5.615}\right)\frac{1}{2.275} = 1032.02\text{cells/ft}^3$$

At 125ft,

$$V_x = \frac{dx}{dt} = \frac{125}{60} = 2.00\text{ft/day}\ , \qquad C_b = \left(\frac{2.08\times26400\times0.25}{5.615}\right)\frac{1}{2.758} = 885.05\text{cells/ft}^3$$

TABLE-2 Results of computation of microbial concentration and velocity

V_x (ft/day)	C_b (cells/ft^3)
1.25	2192.92
1.67	1811.81
1.88	1191.52
2.00	1032.03
2.08	885.05

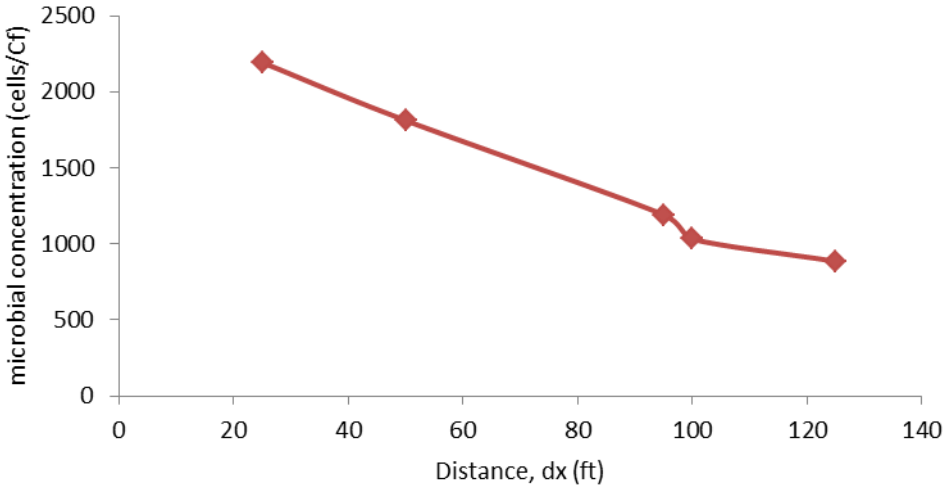

Fig 2 Plot of microbial concentration against distance

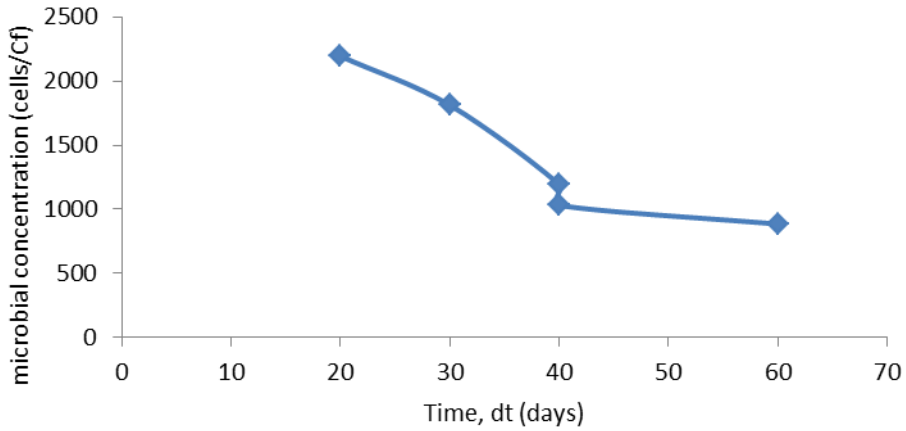

Fig 3 Plot of microbial concentration against time (dt)

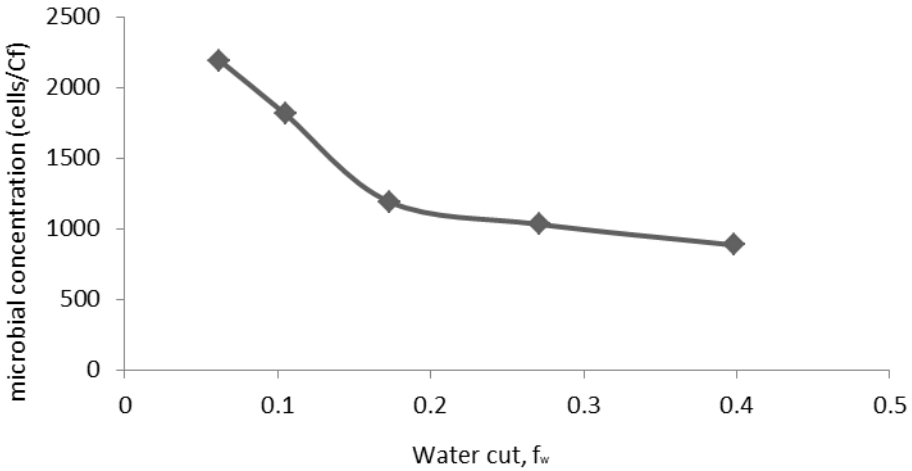

Fig 4 Plot of microbial concentration against water cut

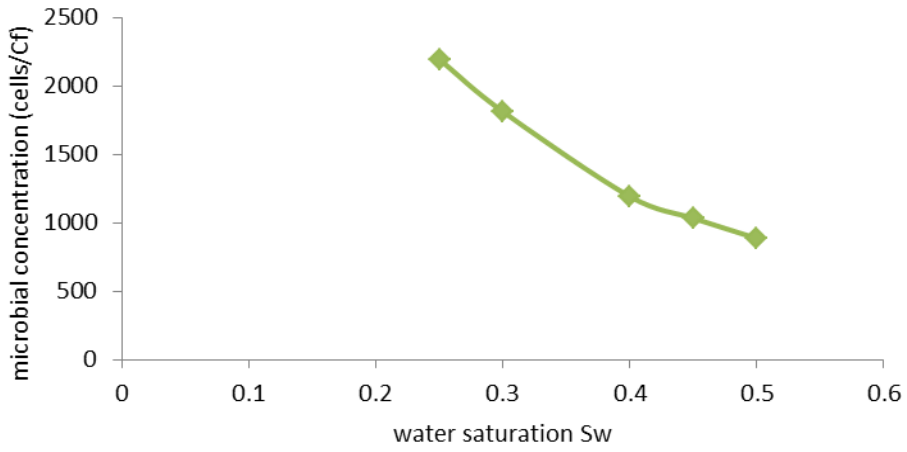

Fig 5 Plot of microbial concentration against water saturation

IV. DISCUSSION

The figures above show the relationship between microbial concentration and other frontal advanced parameters. Fig 2 shows the decreasing trend of microbial concentration with distance, showing a higher concentration of microbes at about 20ft from the point of injection and a lower concentration at a higher distance. The average concentration of microbes in the porous media decreases with time as shown in Fig 3. This is because production of oil is at a higher rate than that of the injection rate of the microbes. The higher the microbial concentration, the lower the water cut or water saturation and vise-versa, an increased water cut of 0.5 has the lowest value of concentration of microbes as seen in Fig 4. Fig 5 shows the decreasing trend of microbial concentration with increasing water saturation

V. CONCLUSION

Results have shown the relevance of the knowledge of microbial concentration during MEOR projects. This knowledge helps ascertain the optimum microbial concentration required to be injected so as to prevent clogging of microbes in the porous media, which impedes fluid flow through the media. The model presents a means of predicting microbial concentration as a function of some parameters such as fluid saturation, water cut, distance and time.

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