SCA2003-64: DETERMINATION OF ACCESSIBLE PORE VOLUMES OF A POROUS MEDIA DURING MISCIBLE DISPLACEMENT USING TRACER ANALYSIS TECHNIQUES

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ABSTRACT

There are several correlations used to simulate the miscible displacement process contains multiple parameters; i.e. dispersion, diffusion coefficients and accessible pore volume. Determination of these parameters is of critical importance. There are different methods for determination of accessible pore volumes that is the portion of pore volumes that are contributed in miscible process. The X-Ray and thin section analysis, network modeling, pore size distribution determination and some statistical methods are commonly used to determine the accessible pore volumes.

In this study the tracer analysis method is developed to determine the accessible pore volume. For this purpose a series of tracer analysis tests were performed to determine the effluent concentration profile. Using the slope of the concentration profile and the solution of convection-dispersion equation, the accessible pore volume of the porous media can be calculated. To check the results, a series of miscible displacement tests were also conducted. Results show a good agreement between experimental values and analytical solution of the miscible displacement.

INTRODUCTION

The extended of dispersion or mixing of the two fluids during a displacement has been described [1] as dependent upon several factors such as; Dispersion, Diffusion coefficients, Gravity segregation, velocity enhancement, viscous fingering and stagnant fraction of pore volumes. There are several models proposed by researchers for modeling the miscible displacement and effect of these parameters on displacement efficiencies. The proposed models are Advection-Dispersion by Lapidus et al. [2] Advection-Channeling by Neretnicks [3], Advection-Dispersion-Matrix by Tong et al. [4], and Advection-Channeling-Matrix by Neretnicks [5]. All models contain the effects of heterogeneity and accessible pore volumes. The cumulative effects of different parameters can be also examined in the content of the Dispersion-Capacitance model proposed by Coats and Smith [6]. This model permits to existence of both a portion of the pore volume that is stagnant and one that is flowing, uses zero velocity and average velocity within two respective pore spaces. With some simplifications such as single axial flow velocity and the fact that mass transfer is assumed to occur between the stagnant and flowing fluids, the mass balance for this system represented by equation (1) and (2)

$$K_D \frac{\partial^2 C}{\partial x^2} - x \frac{\partial C}{\partial x} = f \frac{\partial C}{\partial t} + (1-f) \frac{\partial C^*}{\partial t} \qquad (1)$$

and

$$(1-f) \frac{\partial C^*}{\partial t} = K_M (C - C^*) \qquad (2)$$

Where C and C* are the concentration of the flowing and stagnant fluids respectively. K_D is dispersion coefficient, K_M the mass transfer coefficient and (1-f) is the stagnant fraction of pore volume. The other multiparameter convection-dispersion models that consider reservoir heterogeneity are transverse-matrix-diffusion [7] and porous-sphere model [8].

Results show that dispersion coefficient measured from field data is often larger than those measured in lab. Cores. Dai and Ore [9] used simulation of the effect of phase behavior on consisting of flowing stagnant fraction to show that the presence of the stagnant fraction reduces the efficiency of miscible displacement. Spencer and Watkins found that cores with a wide pore size distribution showed a higher residual saturation after CO2 flood [10]. Many researcher also used thin section study and pore size distribution to find flowing fraction of the rock samples [11]. Heller [12] proposed a statistical method to define random permeability for a field in miscible process.

PROCEDURE

Four different type samples were selected for tracer and miscible displacement tests, two sandstone and two dolomite samples. Each sample was cleaned and extracted using toluene and then dried in oven. Then the porosity and air permeability of the samples were determined. The petrophysical properties and rock type of the samples are listed in Table1. The samples were saturated with water and the pore volumes of samples were calculated.

Tracer Analysis Experiments

The saturated samples were mounted in core holder and applying confining stress to prevent any breakthrough from the sides of the core. Then the injection water was traced by adding a very low amount of Sodium Chloride-brine, and at a constant rate was injected to the sample. The volume of outflow fluid and time were measured. The produced fluid then analyzed and amount of tracer and then concentration of tracer was determined using analytical process. Knowing the outflow concentration of tracer, the concentration profile is determined.

Assume that at t=0 a miscible traced fluid injected to the saturated sample and displaces the saturated fluid. The concentration profile of the output fluid is as S-shape curve mirror image around 1 PV injection. Note that both fluids have the same density, viscosity and interfacial tension. If there is no mixing during process, then the output concentration will be a step-function at 1 PV injection. Diffusion and dispersion causes some mixing and advancing breakthrough of the tracer and it causes the concentration profile became S-shape. The change in diffusion, dispersion and accessible pore volume affect the concentration profile. The solution of convection-dispersion equation using correct initial and boundary conditions is as follows;

$$C/_{Co} = \frac{1}{2}\left\{erfc\frac{x - v_x t}{2\sqrt{D_e t}} + \exp(\frac{v_x t}{D_e})\right\}erfc\frac{x + v_x t}{2\sqrt{D_e t}} \qquad (3)$$

in which D_e=fD and erfc(z)=1-erf(z). The dispersion coefficient for each specific rock sample can be calculated by determining the slope of the concentration profile of tracer test result at 1 pore volume injection by the following equation[13];

$$D = \frac{1}{4p}\frac{LV}{(\frac{\partial C}{Co}\Big/\frac{\partial V}{Vo})^2_{V/_{Vo}=1}} \qquad (4)$$

Using this definition for dispersion coefficient and substitution and solving the equation using error function table, the value of 'f' can be determined. To develop the tracer analysis results, the Do/u ratio for the tracer analysis and miscible displacement process should be setting constant [14].

Miscible Displacement Experiments

The miscible displacement tests were conducted on the core using n-C7 as displacing fluid and n-C10 as displaced fluid. The physical properties of the fluids are listed in Table 2. As the miscible displacement process is rate sensitive, the selected rate of the injection was selected lower than critical velocity, i.e. Vc=(Δρ/Δμ)gk.

GC analyzed the outflow fluid and the concentration of each component was determined, so the concentration profile of injected fluid can be determined. To compare the experimental results and those calculated from model, the Coats-Smith model was run to determine the simulated process.

RESULTS

The output fluid concentration profile of tracer analysis tests were drawn and the slope of the curves and dispersion coefficients (K_D) were determined. As the diffusion coefficient is related to the molecular mixing at no movement, so the extrapolation of the dispersion coefficient to zero velocity in typical charts can show the diffusion coefficient. The values of dispersion, diffusion and accessible pore volumes from tracer analysis and solution of convection-dispersion equation are shown in Table 4. The tracer analysis results were drawn and shown in Figure 1.

The miscible displacement and tracer analysis tests were performed at specific velocities to reach the situation that can develop the tracer results to the miscible displacement process. Table 5 shows the setting velocity and ratio of Km/u values. The concentration profile of miscible displacement tests and results of solution of Coats-Smith model using values of diffusion, dispersion coefficients and accessible pore volumes were compared in Figure 2.

DISCUSSION

The Tracer analysis test was conducted for four different rock types of Iranian reservoir rocks. The concentration profiles of output fluids were analyzed and data were drawn in related curves. The results show that the behavior of the profiles affected by the mixing process and accessible pore volumes. For a homogenous porous media, the concentration profile should be a complete S-shape like with a complete mirror image around 1-PV injection. Any change in the shape would be the effect of non-homogeneity of the porous media. On the other hand, heterogeneity affects the diffusion and dispersion coefficients. A porous media with a complicated fluid pass, two miscible fluids have large interfaces and enough time to molecular diffusion. So the diffusion coefficients will change in different porous media. This change will be negligible compared to the dispersion coefficient. In the sample 1 and 2, the porous media are relatively homogeneous and fluid passes through relatively large channels. This causes little change in dispersion coefficient, which is directly related to the fluid velocity and movement and also the way it passes. In the samples 3 and 4, the rock type is dolomitic and non-homogeneous. The pore-throat sizes are smaller than in samples 1 and 2. For a specific rate, the velocity through narrow channels is higher than for wider channels, so the mixing due to dispersion will be larger. The shape of the concentration curve is affected by these three parameters. Batycky et al. [15] have a complete study on the effects of these parameters on the effluent concentration profiles. Referring to their results, for a porous media with constant dispersion coefficient, the shape of the concentration curve will change to tailing type at the end points of the injection. For a porous media with constant diffusion coefficient, the increase in dispersion coefficient causes early breakthrough of injected fluid and the S-shape will get wider and flatter. For a porous media with constant diffusion and dispersion coefficients, the increase in flowing fraction (f) causes an early breakthrough but with the same profile. It means that the profile moves to the left hand side of the curve.

According to these phenomena, the shape of the effluent concentration profile is affected by these three parameters separately. Referring to the Fig. 1, in sample 1, the curve has a nearly S-shape and mirror image around less than 1 PV injection. As the flowing fraction decreases, the profile moves to the left and an early breakthrough happens. But simultaneously the increase in dispersion coefficient and decrease in diffusion coefficient have different effects and the global effect is shown in Fig. 1

To check the results the miscible displacement tests were conducted on samples 1 and 3. It can be seen that there are good match between the experimental results and those calculated by Coats-Smith model considering the parameters derived from tracer analysis tests(Fig. 2,3).

CONCLUSIONS

1- The developed tracer analysis test in this study can be used to determine the accessible pore volume of core samples with different lithologies. It is also a way to find the dispersion coefficient of a porous media.
2- Each specific core samples has specific and unique values of coefficients find by this method. So for different samples they will vary and new tracer analysis test should be done.

3- Comparison of experimental miscible displacement tests result and those calculated by Coats-Smith model show good agreement, so the Coats-Smith model is a good model to describe the miscible displacement process if the parameters used in this model derived by tracer analysis test.

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Table 1: The Petrophysical Properties and Lithology of Samples

Sample No.	Length (cm)	Diameter (cm)	Porosity (%)	Air Permeability (mD)	Pore Volume (cc)	Rock Type
1	6.71	3.740	19	160	14.05	Sandstone-Consolidated
2	6.80	3.725	17	140	12.15	Sandstone-Homogeneous-Consolidated
3	6.72	3.735	12	85	8.81	Dolomite-Matrix Porosity
4	6.83	3.741	8	14	6.01	Dolomite-Moldic porosity

Table 2: Physical Properties of Fluids Used in Miscible Displacement Tests

Fluid Type	Density (gr/cc)	Viscosity (cp)
n-C7	0.68	0.4
n-C10	0.73	0.868

Table 3: Results from Tracer Analysis Tests

Sample No.	Dispersion Coefficient (K_D) (*10^-4)	Diffusion Coefficient K_m (*10^-6)	Accessible Pore Vol. (%) f
1	7.76	0.89	0.668
2	6.41	0.86	0.72
3	8.38	0.81	0.621
4	9.32	0.79	0.585

Table 4: Velocity and Km/u Ratio

Fluid Type	Diffusion Coefficient	Velocity (cm/sec)	Km/u (*10^-4)
Water-Salt	0.025	0.006	4.13
n-C7 – n-C10	0.062	0.0015	4.13

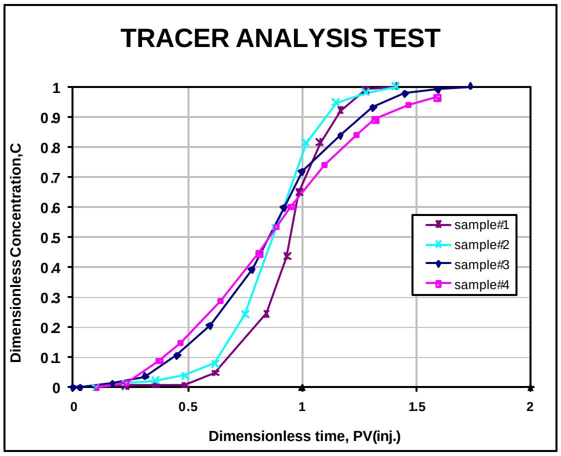

Fig. 1: Tracer Analysis Test for all Samples

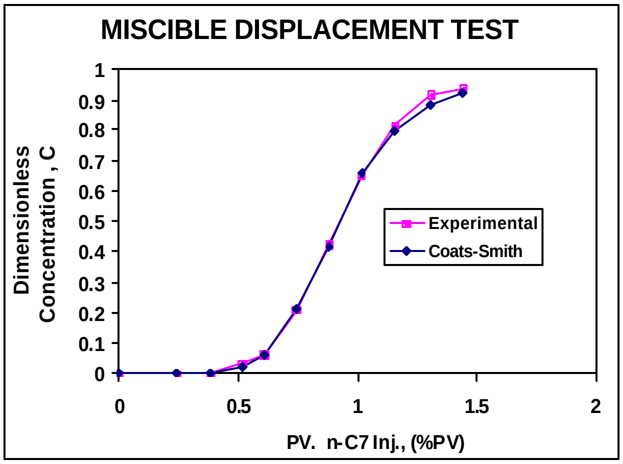

Fig. 2: Concentration Profile of Miscible Displacement Test of Sample no. 1

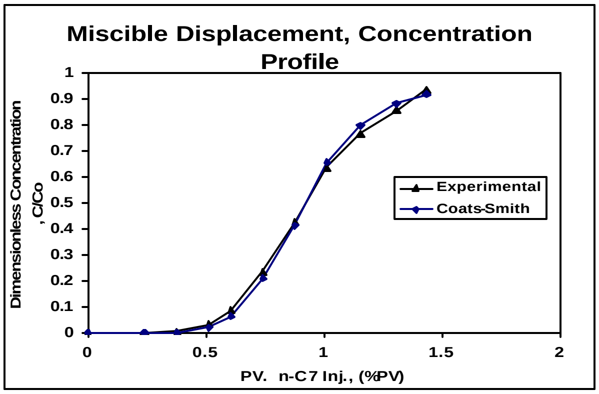

Fig. 3: Concentration Profile of Miscible Displacement Test of Sample No. 3