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Reservoir structural strategies on the integrity of gas mobility ratio.

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Reservoir Structural Strategies on the Integrity of Gas Mobility Ratio

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ABSTRACT

In this study, four commonly injected EOR gases, CH_4, N_2, Air, and CO_2, have been simultaneously investigated through an experimental method to determine the effect and correlational relevance of 28 structural and 22 fluid quantities to mobility ratio integrity. An experimental method involving five analogous structural strategies has been conducted. A total of 1,920 experimental runs were executed, and 15,360 data points were generated. The results revealed that the mobility ratio is significantly affected by the structural and fluid realities of the EOR process. The mobility integrity for the four gases was correlated to Reservoir Quality and Transmissibility variations the most. Overall the mobilities of the four gases experienced correlational variations for 12 structural parameters. Fourteen of the fluid properties have correlational relevance to CH_4 mobility. N_2 and CO_2 have 11, and Air has 10. The findings from this study can be directly applied in selecting suitable injection gas and screening reservoirs so that the correlational dynamics are favourable to mobility objective and integrity, thereby optimising oil recovery in heterogeneous reservoirs.

Keywords—Mobility, Pareto, structural parameter, gas experiment, Permeability, Porosity.

1 INTRODUCTION

Mobility is an important engineering quantity in fluid mechanics. It is a determining factor in several fluid dynamic processes in the agriculture, manufacturing and petroleum industries. Mobility significantly determines trapped oil's micro and macroscopic recovery efficiencies [1], [2]. In planning an Enhanced Oil Recovery (EOR) process, reservoir engineers are faced with the decision to identify the mobility regimes that would maintain or improve integrity given the quality and property type of the oil, displacing fluid and porous rock matrix while simultaneously optimising oil recovery efficiency.

One of the phases in the decision process includes EOR reservoir screening. EOR screening criteria are a set of benchmarks and ranges of petrophysical quantities used to decide what EOR technology and process to apply to reservoir of interest. Permeability and viscosity are some of the criteria screened for in reservoirs, as reported in [3]. Although mobility is not a criterion included in existing screening models, it, nevertheless, features itself in several equations and principles used to characterise reservoirs and oil recovery, such as the Darcy law, Transmissibility, and Buckley-Leverett theory. Thus, it is recommended that mobility, which is a rationalised ratio, should be included in the screening criteria as it combines the effect of permeability (K in cm^2) and viscosity (μ in $g.cm^{-1}.s^{-1}$) into one quantity, intrinsic mobility (λ in $cm^3.s.g^{-1}$) and thereby effectively reducing the degree of freedom in the screening process.

$$Q_{std} = 0.00085 \frac{K}{\mu}\frac{h}{T}\frac{(P_1{}^2 - P_2{}^2)}{\ln\frac{r_1}{r_2}} \qquad 1$$

$$\lambda = \frac{K}{\mu} = \frac{Q_{std}T}{0.00085h}\frac{ln\frac{r_1}{r_2}}{(P_1{}^2 - P_2{}^2)} \qquad 2$$

Where Q_{std} is flowrate in cm^3, T is the temperature in K, P_1 and P_2 are the injection and outlet absolutes pressures in $g.cm^{-1}\cdot s^{-2}$, r_1 and r_2 are the external and internal radii of a radial porous media respectively in cm, h is the height of the radial porous media in cm. 0.00085 is the radial standard conditions constant with units of $cm.s^2.K.g^{-1}$.

Common EOR technologies such as chemical, gas and thermal technologies inject fluid into the reservoir through an injection well to regenerate mobilisation energies in the reservoir required to displace or push trapped oil droplets toward a production well in an immiscible (pistonlike) or miscible fashion [4]. These fluids include polymers, surfactants, alkaline, gas, hot water, and steam. The mobility profile of these fluids in the reservoir pores is a matter of concern to reservoir engineers. The relative mobility of the fluid to that of the *in-situ* fluid regulates the expected displacement of oil by fluid. If the mobility of the displacing fluid is relatively higher than the displaced fluid (oil), then the displacement fluid is likely to overtake or bypass the oil to arrive at the production well in a process called viscous fingering [5]. Viscous fingering can lead to an early injected fluid breakthrough. This is an undesired scenario as the main purpose of injecting the displacing fluid is to cause the fluid to use its energy to escort the oil droplets to the production well. Viscous fingering forfeits this aim and often leads to economic and technical difficulties. Therefore, engineers need to pair the right displacing fluid to the right reservoir parameters (structural), reservoir conditions (temperature and pressure) and *in-situ* oil (heavy, intermediate, and light).

1.1 Aim

To characterise the correlational relevance of structural and fluid quantities variations to EOR gases mobilities. A total of 50 quantities were elicited from the literature review. Twenty-eight of the quantities are related to reservoir structure. Twenty-two are fluid and economic quantities usually encountered in EOR field applications.

1.2 Fluid Properties

Gas mobility can be factorised into a linear scale representation through dimensional analysis, as depicted in Figure 1. Here, fluid mobility through a porous media passage with an effective capillary area of radius, r, can be defined as the distance, ɩ travelled by a unit mass of the fluid in unit time, t in the direction of flow. The definition is also dimensionally equivalent to the gas mass rate through a capillary or porous media unit volume. It is seen from Figure 1 that the mobility of the oil droplet and the potential gas interventions (cases 1, 2, and 3) can be estimated by their respective locations on the ɩ scale at a given time. From whence the respective gas-oil mobility ratio of each case can be estimated:

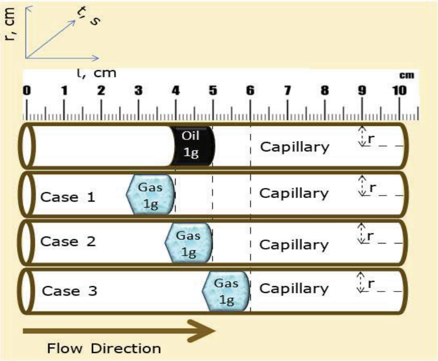

Figure 1 shows the relative mobility of oil and gas in a one-dimensional mobility model.

Give a capillary with a certain structural configuration. The capacity or the drive potential of each case to mobilise the trapped oil droplet through the structure can be described by their one-dimensional relative mobilities:

Case	λ_{gas}	λ_{oil}	Drive Potential	$\lambda_{gas\text{-}oil}$ ratio	Comment
1	3	4	$3 < 4$	$3/4 = 0.70$	desired
2	4	4	$4 = 4$	$4/4 = 1.00$	desired
3	5	4	$5 > 4$	$5/4 = 1.25$	undesired

Cases 1, 2 and 3 are injections of different hypothetical gases, such as X, Y and Z. The X and Y mobilities are less likely to cause viscous fingering due to their low gas-oil ratios. Thus, they are considered comparatively more competitive than the Z gas. However, if the 3 cases are using the same fluid, such as gas X, it follows that the set of operating conditions, structural and fluid properties that engenders Cases 1 and 2 are the most competitive. These conditions and properties could involve pressure, temperature, viscosity, density management, permeability, porosity

1.3 Structural Parameters

Reservoirs are solid structures of grains and passages (conduits) containing fluid (oil, water and gas). The walls of the passage can be tortuous or smooth. The dimension of the passage can be on the nano or micro scale. Blocks of grains and passages with different structural configurations can be stacked in parallel or series (Figure 2). When the blocks are parallel, the passages in each block (A, B, C) function as sovereignties and are independent of the neighbouring blocks' structural realities. Fault can make parallel layers of reservoirs fall into series with each other. When stacked in series, as shown in Figure 2, each block needs to negotiate with its neighbours on how to use the new commonwealth passage. This negotiation would consider as many parameters as relevant to the use of the passage and their weighed contributing effect to its use. Therefore, any fluid permeating through the passages must experience these structural realities and then respond to their individual and resultant effect on its optimal use of the passage to displace *in-situ* trapped oil.

In Figure 2, the blocks A, B and C have three different individual structural realities based on their pore sizes. The interface at AB and BC are circled in red and further isolated to reveal the pore size and conduit characterisation of the respective block interfaces. It is seen that block B has relatively small pores (tinniest passage) than blocks A and C. Therefore, the mobility of an *in-situ* or injected fluid would experience different pressure and velocity profiles as it navigates between the interfaces.

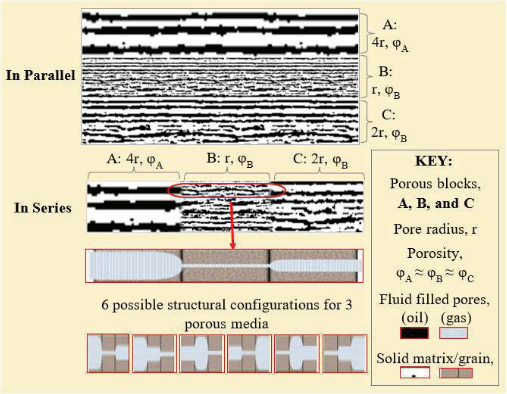

Figure 2 shows the structural mix of reservoir blocks.

There are over 20 structural parameters that can be elicited from the geological and geometrical profiles of reservoir passages. The injected fluid mobility is intuitively expected to respond to each parameter differently. Furthermore, the reservoir-oil system's PVT (Pressure-Volume-Temperature) profile may accommodate the injected fluid differently. Finally, the *in-situ* oils in different reservoirs are characterised by thermochemical and thermophysical properties such as density or API, viscosity and solubility, such that injected fluids' properties may interact with the corresponding oil properties differently.

2 EXPERIMENTAL METHODS

The experimental materials and equipment pictorial flow diagrams are presented in Figures 3 and 4. Figure 3 shows some of the structural parameters of the samples used in this study. The experimental procedure involves injecting gases into an analogous core sample held in a steel core holder at set pressures and temperatures. Permeates are measured at a steady state. The experiment was conducted using pressure gradient and temperature ranges of 19-35 atm/cm and 293-673 K. Five analogue cores were sampled. A total of 1,920 experimental runs were executed, and 15,360 data points were generated. Mobility was calculated from the gas flow rate using Eq. 2.

2.1 Evaluation Techniques

Many quantities can describe fluid mechanics, but not all may show correlational relevance to the fluid property of interest. To test the strength of the correlational relevance between varied quantity and gas mobility, regression analysis (R^2) and the Pareto 'Vital Few from Trivial Many' dimension reduction technics [6] were applied to measure correlational relevance. The quantities that fall into the vital few categories for each gas are considered to be of correlational relevance to mobility studies and management. Relatively high R^2 implies greater relevance. There was no mark difference between the linear, power, logarithm and exponential R^2s. Thus, linear regression was adopted for the analysis.

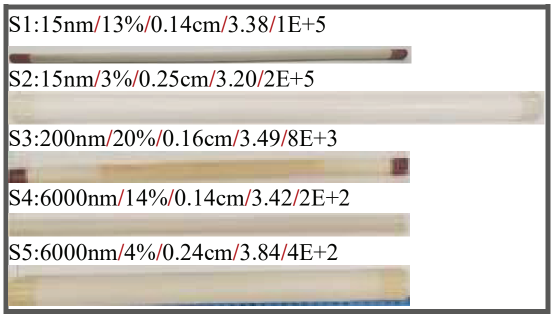

Figure 3 shows some parameters of the analogous core samples (S1-5): pore size / porosity / radial thickness / tortuosity / aspect ratio.

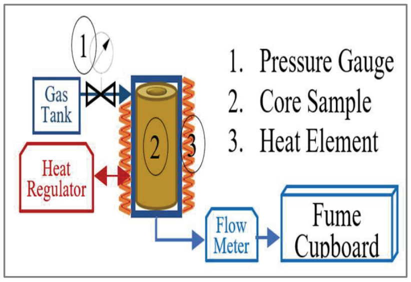

Figure 4 shows the CS experimental pictorial diagram.

3 RESULTS

Figure 5 shows the degree of heterogeneity for some of the structural quantities. Ten of them are highly heterogeneous (>1.00). Some 28 structural parameters were sampled. Twelve of them showed correlational relevance for all the gas mobilities, as shown in Figure 6a.

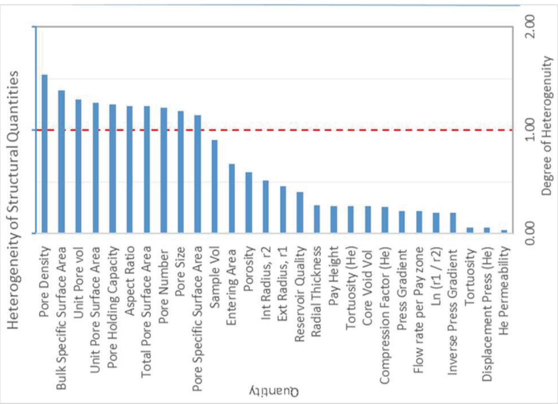

Figure 5 shows the heterogeneity profile of the samples.

Nevertheless, the degree of correlation ranks differently for each gas. For instance, Reservoir Quality ranks as the most correlated structural parameter for Air and CO_2 ($R^2 > 0.97$). However, for CH_4, the most correlated is the media's internal radius ($R^2 > 0.97$), which corresponds to the reservoir producer wellbore. For all gases, payzone height and tortuosity have the least correlational relevance to mobility in the Pareto ranking as they reported the least R^2 (< 0.50).

There was an observed dichotomy in the respective gas response to fluid properties in Figure 6b. Fourteen of the fluid properties show correlational relevance to CH_4 mobility. N_2 and CO_2 have 11, and Air has 10. Transmissibility consistently has the highest correlation for all four gases. Nine of the fluid properties are correlational to all four gases. Some correlational exclusivity exists among the gases. Well-coverage is exclusive to CH_4 and N_2. Well Denseity is exclusive to N_2. Surface tension is exclusive to Air and CO_2 gas mobilities. Interstitial velocity is exclusive to CO_2.

The correlational relevance and exclusivity of these fluid properties and structural parameters are very important in selecting gases and screening reservoirs, as they suggest gases are responsive to structural nuances. For instance, being exclusive to N_2, the Well density correlation suggests that reservoir engineers need to pay attention to its effect on N_2 mobility performance optimisation. However, the other gases do not require this attention because their mobilities do not respond to well density variation.

Furthermore, CH_4 mobility is correlated to 14 fluid properties, which implies a higher degree of freedom. The impact of 14 potential properties variation needs to be catered for in implementing CH_4 gas. The process can be time and resource-consuming and might increase implementation uncertainties.

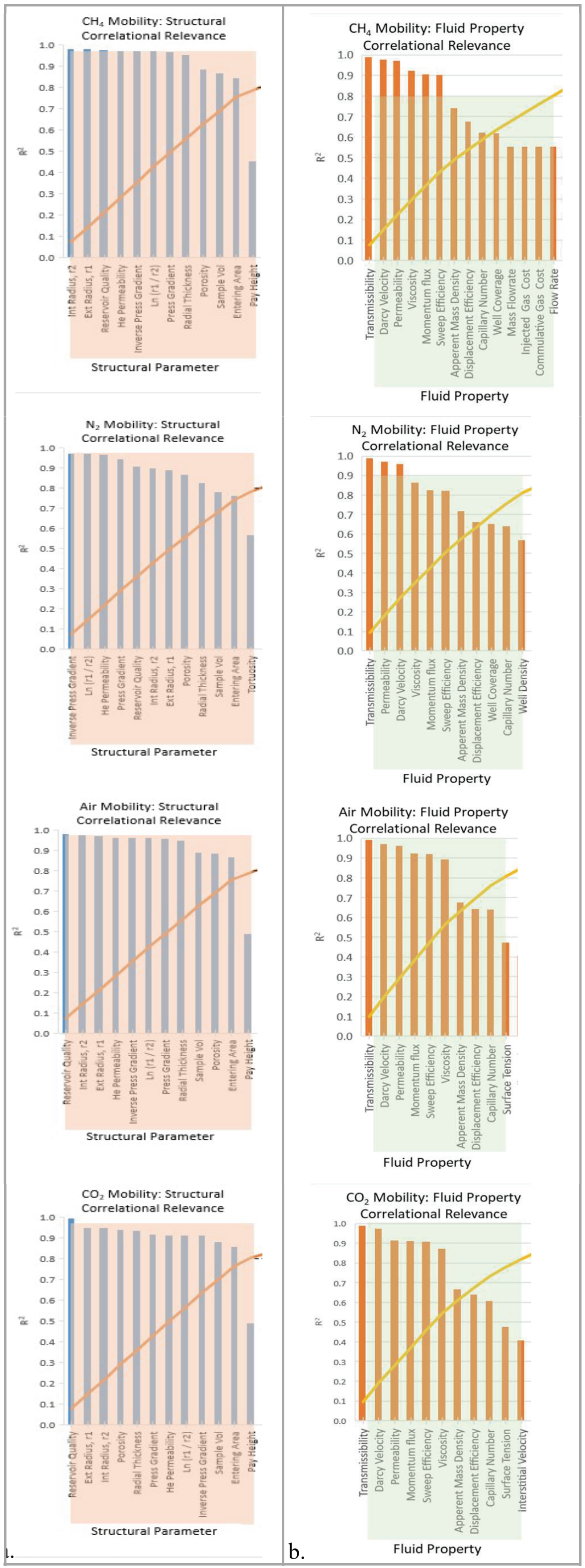

Figure 6 shows correlational relevance (R^2) of (a) structural parameters and (b) fluid properties to EOR gas mobility.

4 CONCLUSION

It has been demonstrated that some structural quantities, such as aspect ratio, pore size, and specific surface area, although considered important in reservoir studies, however, have no linear correlational relevance to the mobility of injected gases. Hence their heterogeneity may not threaten mobility integrity.

Reservoir quality is consistently the most correlated structural parameter for Air and CO_2. The reservoir wellbores have the most correlational relevance for CH_4. The Pareto dimensional reduction analysis indicates that the variation or heterogeneity of 12 structural parameters would affect the mobility profile. This can positively or adversely affect mobility and hence recovery efficiency. Nine of the fluid properties variations were found to affect all four gases. Some gases were found to have peculiar relation with some fluid properties exclusively. CH_4 has the highest degree of freedom based on the number of quantities and variations that would need to be considered before and during implementation.

This study is beneficial to reservoir engineers and other process engineers because understanding correlations relevant to an objective function helps reduce dimensional and technical considerations and improves optimisation.

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