ABUNUMAH, O., OGUNLUDE, P. and GOBINA, E. 2021. The effect of pressure and porous media structural parameters coupling on gas apparent viscosity. In *2021 TUBA (Turkish Academy of Science) World conference on energy science and technology (TUBA WCEST-2021) book of abstracts*, 8-12 August 2021, [virtual conference]. Ankara: Turkish Academy of Sciences [online], pages 88-89. Available from: https://doi.org/10.53478/TUBA.2021.017

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2021

THE EFFECT OF PRESSURE AND POROUS MEDIA STRUCTURAL PARAMETERS COUPLING ON GAS APPARENT VISCOSITY

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ABSTRACT

Crude oil production is still considered a significant contributor to global energy security. To improve oil production, gases such as CH_4, N_2, Air and CO_2 are injected into oil reservoirs in a process called gas Enhanced Oil Recovery (EOR). Authors have used several engineering, geological and geometrical quantities to characterise oil reservoirs and evaluate immiscible gas EOR processes. Viscosity is one of such critical engineering quantities. However, the relationships between viscosity and structural parameters, such as porosity, pore size, and aspect ratio, have not been directly investigated in the literature. This paper investigated the coupling effect of pressure and structural parameters on the apparent viscosity of EOR gases in reservoir pore matrix through rigorous data mining and experimental approaches. The data mining analyses demonstrated that EOR reservoirs are characterised by viscosity and porosity. The experimental investigation indicated that the viscosity of injected EOR gases increases with pressure and pore size, decreases with porosity, and initially decreases before increasing with aspect ratio. The study concluded that CO_2 is the most influenced by porosity, and CH_4 is the least. Furthermore, N_2 is the most responsive to pore size and aspect ratio, while CH_4 is the least responsive.

Keywords: Viscosity, reservoir characterisation, porosity, pore size, EOR gases

INTRODUCTION

In Enhanced Oil Recovery (EOR), viscosity is considered the single most important fluid property that lends itself to the estimation of other engineering quantities such as pressure drop, displacement velocity, momentum, diffusibility, kinetic energy, interfacial tension, capillary number, flowrate, mobility and viscous ratios, [1]. Furthermore, viscosity is featured as a critical quantity in all EOR screening models found in the literature [2].

The displacement of oil by another fluid involves the interactions between the displacing fluid and oil's viscosities, and the interactions with other reservoir properties such as pressure and structural parameters. Gases such as CO_2, N_2, CH_4 and Air are some of the fluids injected into oil reservoirs pore to displace trapped oil. Unfortunately, oil is about 100 times more viscous than these gases [3], and reservoirs are usually structurally heterogeneous. Therefore a need to understand the interactions.

Previous authors have sparsely studied the effect of pressure and temperature on fluid's viscosity in the context of EOR gases in reservoir pore matrix. Furthermore, the impact of reservoir structural parameters such as porosity, pore size, and aspect ratio on EOR gas viscosity and the consequential effect on gas-oil displacement performance is lacking. Consequently, the study aims to characterise the apparent viscosity of reservoirs and subsequently investigate the coupling effect of pressure and reservoir structural parameters on the competitiveness of EOR gases.

MATERIALS AND METHODS

The methodology applied two rigorous empirical approaches: (1) the data mining of field data from 484 EOR projects and (2) the analyses of data from gas experiments, comprising five reservoir analogue core samples, four gases, and eight isobars. The viscosity, μ, was acquired using gas and radially modified Hagen-Poiseuille equation in Eq. (1). The porosities of the respective cores were acquired using Eq. (2). Pore sizes are as stated by the sample's manufacturer.

$\mu = -\frac{\pi h}{4QP_2}\left(\left({P_1}^2 - {P_2}^2\right)/\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\right)$...................... (1)	$Porosity = 1 - \left(\frac{Specific\ Particle\ Density}{Specific\ Bulk\ Density}\right)$............... (2)

Where Q is the gas flowrate; P_1 and P_2 are the inlet and outlet pressures; and h , r_1 and r_2 are the height, inner and outer radii of the core sample respectively.

CONCLUSIONS

The study has contributed to engineering knowledge and reservoir practices as follows: It has been demonstrated that EOR technologies and Gas processes are markedly characterised by viscosity (Figure 1a) and slightly characterised by porosity (Figure 1b). It is established in Figure 1a that CH_4 and N_2 EOR processes favour relatively low viscosity reservoirs than Air and CO_2 processes. The Coefficient of Variation (CV) indicates that N_2 has the tightest clusters, suggesting that viscosity may be critical to the applicability and performance of N_2 EOR processes in a reservoir.

The study presented a strong relationship between viscosity and porosity for gas EOR technology, as shown by the grey cluster in Figure 1c. This relationship reveals that gas EOR is commonly applied to tight reservoirs. Furthermore, the findings from the data mining phase (Figure 1a, b, and c) provided an impetus for designing a gas experiment to examine and validate the field application of immiscible gas EOR.

In the experimental phase, it has been identified that porosity inversely affects apparent viscosity under certain conditions of porosity <20% and pressure >1.4bar (Figure 2a). Beyond this threshold, the viscosity becomes self-sufficient of pressure. Hence any change in porosity and pressure have insignificant or no effect on the apparent viscosities of the EOR gases. As porosity approach unity, the gas viscosity for N_2, Air, and CO_2 approach equality except for CH_4. By the nature of the respective gas plots in Figure 2a, it can be concluded that CH_4 is the least competitive in attaining the desirable condition of mobility (<1) mentioned in [4] and favorable apparent viscosity ratio (<1) for any coupled pressure and porosity.

Figure 2b shows that N_2 is consistently the most responsive to pore size variation in reservoirs. In contrast, CH_4 is the least. Their respective thermodynamic properties cannot explain the order of the magnitude of the slopes.
Figure 2c shows a quadratic relation exists for the apparent viscosity-aspect ratio. Before attaining the aspect ratio of 5.00×10^4, the relationship is inverse but becomes positive after that point. For all isobars, N_2 is consistently more responsive to aspect ratio than the other gases. In contrast, CH_4 is the least responsive.
Summatively, it is concluded that $N_{2\ viscosity}$ responds to reservoir structural parameters than the other EOR gases. This information is useful for managing the injection of gases and the displacement of trapped oil in a reservoir with structural variation (heterogeneity).

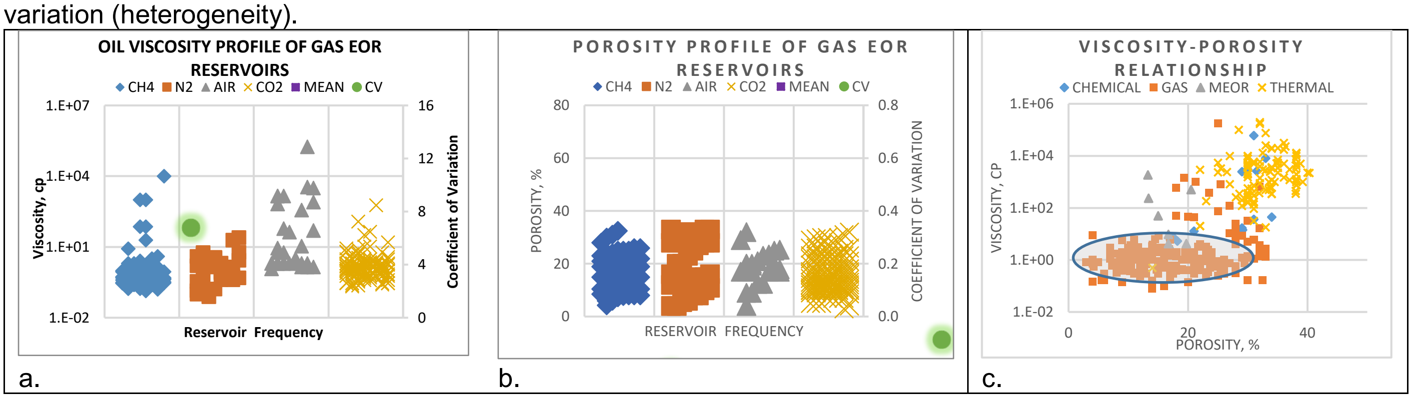

Figure 1 Showing the viscosity (a) and Porosity (b) characterisation, and the viscosity-porosity relationship (c) of EOR reservoirs

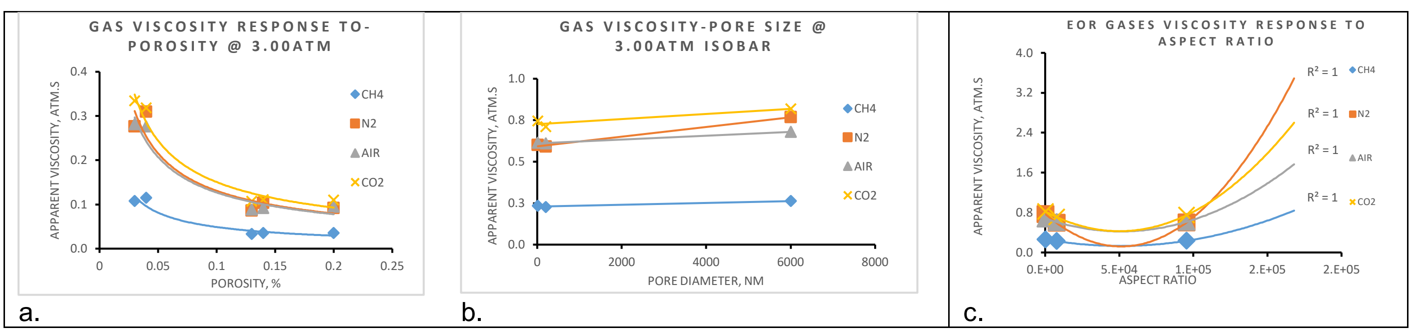

Figure 2 Showing the viscosity-porosity (a) viscosity-pore size (b) viscosity-aspect ratio (c) relationships of EOR gases.

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