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Effects Of Gravity On Flow Behaviour Of Supercritical CO2 During Enhanced Gas Recovery (EGR) By CO2 Injection And Sequestration

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Summary

A core flooding experiment was carried out to simulate an Enhanced Gas Recovery (EGR) process to inject supercritical Carbon Dioxide (SCO2) into a core sample saturated with methane (CH4). This was done to investigate the flow behaviour of the injected SCO2 at the flow conditions when the injection orientation was switched from horizontal to vertical during the CH4 displacement. From the results, it was found that gravity has significant effects on the flow behaviour of SCO2 at lower flowrates; more pronounced is the seemingly lower permeability in the horizontal orientation compared with the vertical orientation. So the choice of the injection pattern or direction during EGR by SCO2 injection for the purpose of additional recovery of CH4 and subsequent sequestration of the injected CO2 should be made in conjunction with the determination of optimum injection rate for efficient injectivity.

Introduction

CO_2 underground storage for the purpose of reduction of anthropogenic greenhouse gas (GHG) emissions is gaining attention globally (Ganjdanesh & Hosseini 2017; Raza *et al*. 2017). These underground storage sites can be in the form of oil and gas reservoirs or deep saline aquifers. To effectively store the undesirable CO_2 underground, some economic incentives add additional shock-value to the process as a whole. These incentives come in the form of economies of scale derivable from the additional recovery of oil and gas resources from the CO_2 storage sites. Pre-existing techniques in the oil and gas industry, termed Enhanced Oil/Gas Recovery (EOR/EGR), are in place to produced additional oil and gas trapped in the reservoir after primary production of the hydrocarbon (HC) resource. These techniques have the potential to be promising methods of CO_2 storage and sequestration (Kalra & Wu 2014). Natural gas reservoirs have the potential to safely store this anthropogenic CO_2. There are a number of reasons, presented by (Kalra & Wu 2014), why the choice of natural gas reservoirs as best potential sequestration site (Raza *et al*. 2017). One of the reasons is its proven integrity in that they have stored natural gas for a million of years. Hence, the problems of leakages and contamination of adjacent fresh water aquifers for domestic use is solved. This calls for the development and optimisation of techniques to efficiently carryout these simultaneous advantages of storing and sequestering large volumes of CO_2 and at the same time recover additional HC resources.

Exploring this opportunity to its fullest, however, requires the investigation of the interplay between the gas species at underground/reservoir conditions. CO_2 injectivity is an area in CO_2 sequestration which is still under investigation. Injectivty is the sustainable flow capacity of CO_2 from the injection well i.e. the transmissivity or how fast can CO_2 be injected through the well. CO_2 reaches its critical point at a pressure of 73.7 bar (1070 psi) and temperature of 31ºC (87.8ºF). Gas reservoirs, however, are well above these critical conditions of CO_2 and CO_2 will be in its supercritical state and will exhibit certain behaviour which deviates from a normal gas and will have an influence on the injectivity. This work focuses on the flow behaviour of supercritical CO_2 at reservoir conditions in relation to its injection orientation to assess the effects of gravity. This is vital as it will provide reservoir engineers with tools to better characterise the transport of injected supercritical CO_2 in the reservoir for enhanced gas recovery and sequestration.

Methodology and Theory

This work employed an experimental approach where a laboratory core flooding process was carried out to simulate the displacement of natural gas (CH_4) by supercritical CO_2 during EGR at 1300 psig pressure, 50ºC temperature, and flowrate was varied from 0.2-0.5 ml/min. These conditions are chosen in accordance with the works of (Abba *et al*. 2017). The core flooding was carried out using a *Bandera Grey* sandstone core sample, 10 md permeability, in horizontal and vertical orientations. The results from both experiments were compared and analysed to evaluate the extent of the effect of gravity on the flow behaviour which may have an influence on the injectivity of the CO_2 in terms of efficient displacement. The governing transport equation that best describes the specie transport for EGR is the 1- D Advection Dispersion equation as described by (Perkins, T.K. Johnston 1963; Coats *et al*. 1964; Newberg & Foh 1988; Coats *et al*. 2009) and is given by:

$$K_l \frac{\partial^2 C}{\partial x^2} - u\frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \qquad 1$$

Where, C is the CO_2 concentration at location x at time t, K_l is the coefficient of longitudinal dispersion, and u is the interstitial velocity. Furthermore, D'Arcy equation, after Henry D'Arcy (1856), will be used to relate the pressure differential with time to simplify the flow behavioural depiction. The model is valid in for low injection rate, in our case, given that the inertial effect may not be significant to render the Darcy law assumption invalid (Mijic *et al*. 2014). It can adequately describe the flow in the experiment. Darcy equation is described as:

$$Q = \frac{kA\partial P}{\mu L} \qquad 2$$

Where Q is the flow rate (cm^3), k is permeability (md), P is pressure (atm), μ is viscosity (cp), A is cross sectional area (cm^2), and L is length of sample (cm).

The procedure followed a core flooding set up suited for gas-gas displacement process where the CO_2 was injected at a constant flowrate of 0.2-0.5 ml/min into the core sample from the accumulator. This was to displace the CH_4 earlier saturated in the core sample at a pressure of 1300 psig and a temperature of 50°C. The effluents rates were measured by flow meters and their composition were measured with a gas chromatograph until the volumes of the CH_4 were insignificant where the experiment came to an end. The sample procedure was used in both vertical and horizontal orientations.

Results and Discussion

Having carried out the experiment at varying flowrates and at different orientations to investigate the effect of gravity on the flow behaviour of supercritical CO_2, the results were presented in such way to observe the difference in the differential pressures (dP) during the flooding process against time for each of the investigated flowrates. From the results obtained, *Figure 1* to *Figure 4*, the dP during the displacement process of the CH_4 by CO_2 varies significantly with increase in injection rates as the orientation of the core sample was changed from horizontal to vertical. The most notable deviations were from the low injection rates of 0.2 and 0.3 ml/min (*Figure 1* and ***Figure 2*** respectively). The horizontal dP from these runs were higher, meaning that the permeability was lower, according to Darcy Law, in the horizontal orientation. Gravity is most influential at these flow rates and at this orientation and hence affects the flow behaviour of the supercritical CO_2 during EGR. However, *Figure 3* and *Figure 4* have almost similar trend in dP fluctuations and magnitude, i.e. the various supercritical CO_2 permeabilities to the core sample of the higher flow rates are not grossly affected by the orientation of the injection. Hence, gravity has the most effects on flow behaviour of the supercritical CO_2 at lower injection rates.

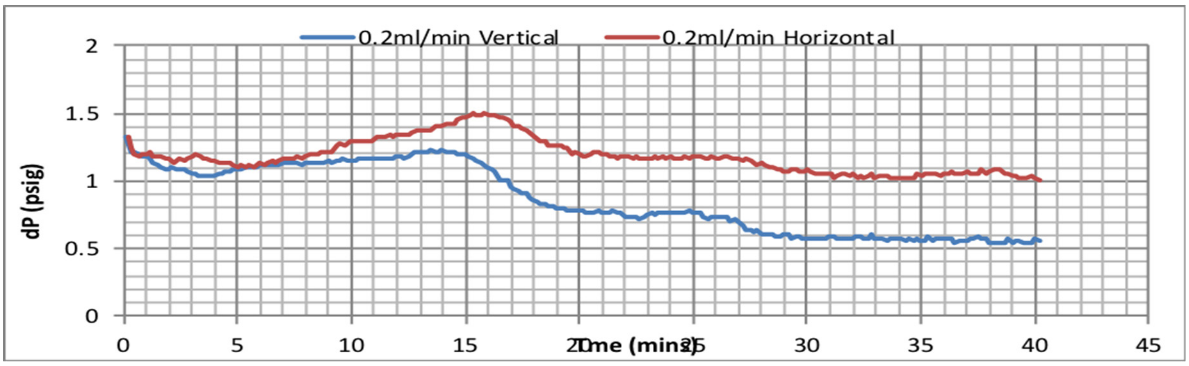

Figure 1 *Differential pressure as a function of time in vertical and horizontal orientations for 0.2 ml/min.*

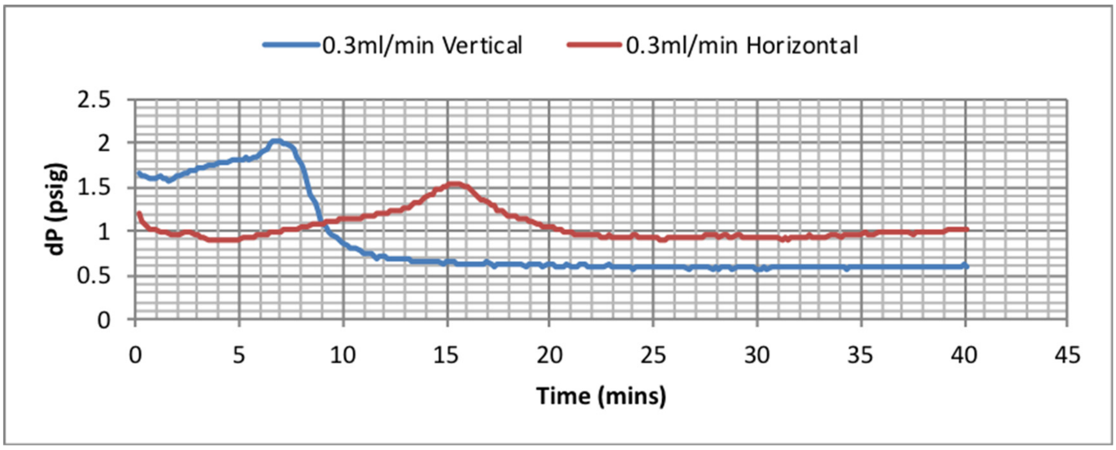

Figure 2 *Differential pressure as a function of time in vertical and horizontal orientations for 0.3 ml/min.*

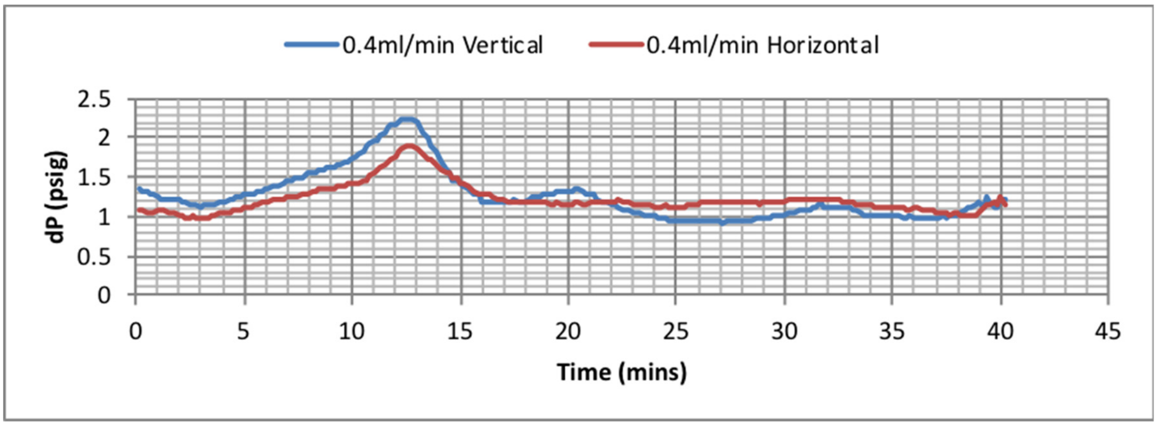

Figure 3 *Differential pressure as a function of time in vertical and horizontal orientations for 0.4 ml/min.*

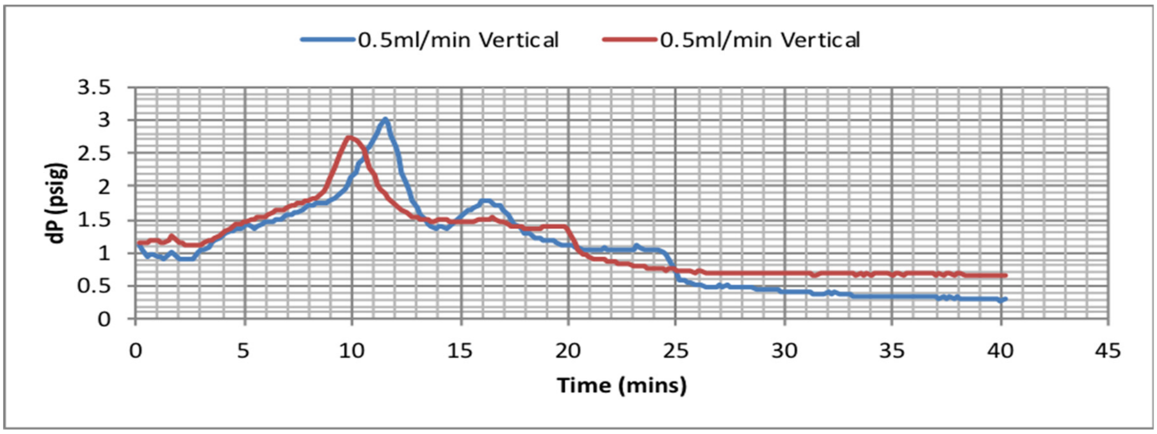

Figure 4 *Differential pressure as a function of time in vertical and horizontal orientations for 0.5 ml/min.*

Conclusion

The investigation of the gravity effects on the flow behaviour of supercritical CO_2 was successfully carried out. Gravity is more dominant at lower injection rates as presented. CO_2 permeability at these supercritical conditions is higher in the vertical orientation compared to the horizontal direction. Therefore, CO_2 injectivity may significantly be affected by the orientation of the injection into the displacing reservoir. Optimum CO_2 injection rate determination is vital in order to adequately and efficiently displace the nascent CH_4 with good sweep efficiency and minimise contamination of the recovered CH_4 with less injected fluid resident time.

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