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Technical Paper

Measurement Challenges of Enhanced Oil Recovery (EOR) Process due to the Phase Behaviour of CO_2

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1 INTRODUCTION

The utilisation of carbon dioxide (CO_2) as an injection gas in enhanced oil recovery (EOR) operations holds significant appeal due to its potential to concurrently facilitate CO_2 sequestration, thereby contributing to the reduction of greenhouse gas emissions. The successful design and execution of EOR operations involving gas injection, as well as associated separation and chemical reaction processes within petroleum refineries, necessitates precise forecasts of gas solubility in hydrocarbons and the produced formation water (aqueous phase). The solubility of non-hydrocarbon gases such as CO_2 in both the organic (oleic) and aqueous phases can exert a profound influence on the transport and fluid properties of these phases. This influence extends to critical parameters such as density and viscosity, particularly under conditions of varying temperature and pressure encountered in transportation pipelines and reservoir systems.

Hence, the determination of CO_2 solubility in both the produced oil and water phases during a CO_2 geological storage process considered as a critical thermodynamic properties in the planning of CO_2 injection strategies for geological formation-CO_2 storage initiatives. It is essential to address the issue of uncertainty inherent in multiphase flow measurement, particularly in the context of a standard flowmeter designed for surface-level multiphase flow applications. This necessity arises due to several factors, including the mutual solubilities that exist between the different phases within the multiphase flow system and the fluctuations in fluid properties observed throughout the operational lifespan of a production well, particularly following the implementation of a CO_2-storage process in depleted hydrocarbon reservoirs.

In this paper, our primary focus lies in modeling the solubility of CO_2 within both crude oil and water phases. This modeling effort will be based on variations in pressure, temperature, and the compositional profiles of each phase. Diverse thermodynamic models and equations of state (EoSs) will be employed to undertake this critical task, allowing for a comprehensive exploration of CO_2 solubility behavior within the complex multiphase systems encountered in EOR processes. This CO_2 solubility modelling is expected to yield invaluable insights into the feasibility and optimisation of CO_2 injection strategies for enhanced oil recovery applications.

2 SCENARIOS OF CO_2 STORAGE PROCESSES & THEIR THERMODYNAMICS

Several cases for CO_2 storage porocesses have been studied in this paper. The description of each case is presented as following:

1. *Base Case*: For a given composition, the maximum solubility of CO_2 under reservoir conditions has been determined.

2. Max CO_2 case: Based on the *Base Case*, it is assume the maximum CO_2 is now injected into the reservoir and the associated thermodynamic properties of the system have been determined.

3. The solubility of pure CO_2 in the aqueous phase for the pressure range of 300 – 5000 psi and temperature range of 70 – 200F has been determined to cover both near wellbore and pipeline operating conditions.

4. The effects of three types of impurities (i.e., H_2, CH_4, and N_2) on the CO_2 solubility in the aqueous phase at the abovementioned PT ranges (effect of 2 mol% of each impurity individually on the solubility of CO_2 in water) have been determined. These impurities have been selected to cover different blue hydrogen production and direct carbon capturing from Air scenarios.

5. The effect of impure CO_2 dissolution (compositional change) on the viscosity and density changes of the "aqueous phase" for the abovementioned PT ranges has been determined – i.e., monitoring the changes compared to the water density & viscosity without any dissolved CO_2.

3 RESULTS AND DISCUSSION

In this work, the CO_2 solubilities in both crude oil and water phases has been modeled as a function of pressure, temperature, and composition of each phase. Figure 1 presents the determined solubilities of carbon dioxide in Exxsol–D140 and crude oil at various isotherms from 50 to 122 F and pressures up to 150 bara using the most accurate EoS. As can be seen, the predicted solubilities of CO_2 in the oleic phase (Exxsol & Crude oil systems) shows higher solubility of gaseous CO_2 at higher pressures and lower temperatures.

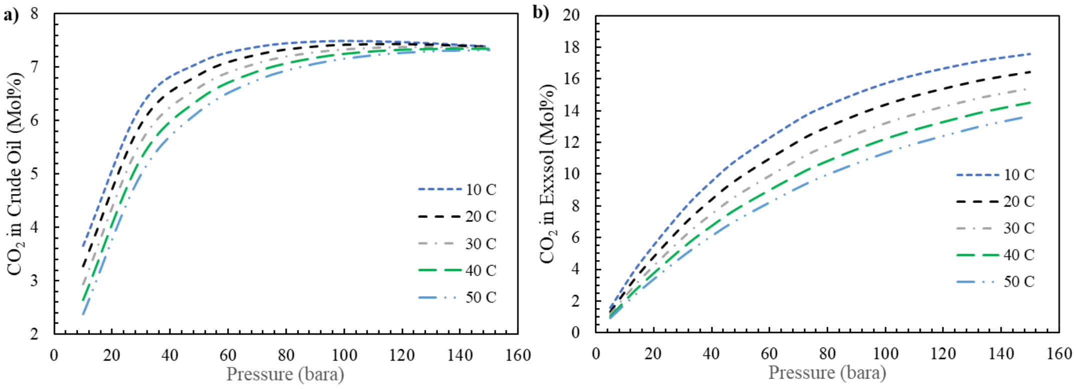

Figure 1. Solubility predictions of CO_2 (mol%) in a) Crude oil, and b) Exxsol-D140 at different temperature isotherms and pressures up to 150 bara.

The effects of these compositional changes of the aqueous phase owing to the CO_2 solubilities (in presence of impurities) in the aqueous phase on the thermodynamic properties of the aqueous phase have also been studied.

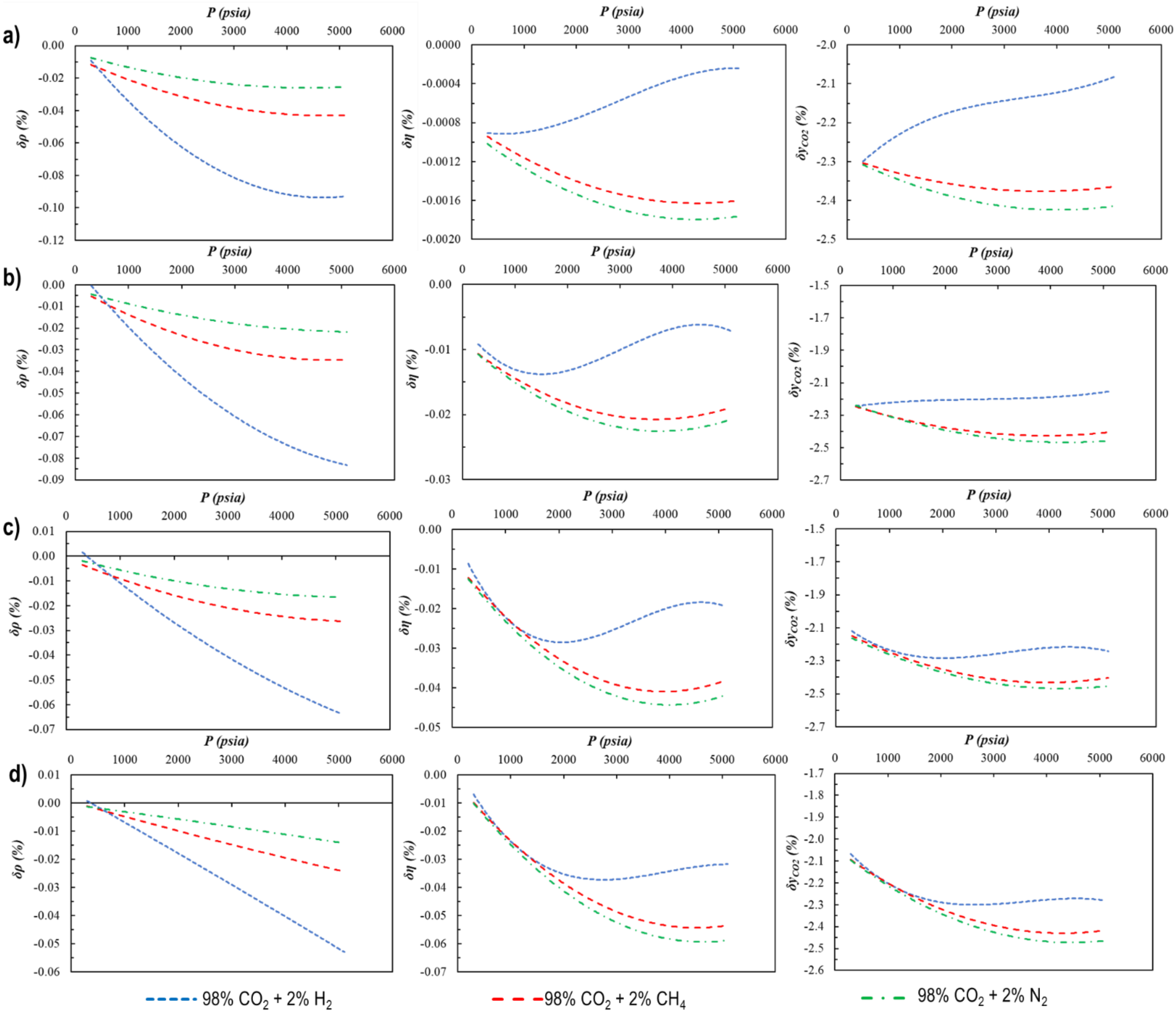

Figure 2. The effects of impure CO_2 dissolution in the aqueous phase on thermodynamic properties compared to the pure CO_2 dissolution at: a) 70 F, b) 100 F, c) 150 F, and d) 200 F.

Figure 2 presents the impacts of CO_2 rich streams in presence of 2 mol% H_2, N_2, and CH_4 as impurities on the density, viscosity, and solubility of CO_2 in the aqueous phase compared to the pure CO_2 system at different pressures and temperatures of 70, 100, 150, and 200 F. The effects of the compositional changes of the aqueous phase on its respective thermodynamic properties owing to the CO_2 solubilities in presence of impurities can be observed in Figure 2. The results demonstrate that the presence of impurities would cause relatively significant deviations in CO_2

solubility in the aqueous phase and also deviations in thermophysical properties of water such as density and viscosity which must be taken into account for reducing CO_2 flow measurement uncertainties. Additionally, with elevating the pressure this deviation would be more noticeable due to higher of gas dissolution in the aqueous phase.With increasing the pressure, the density of the liquid phase would be reduced since more CO_2 is being dissolved in the aqueous phase. In contrast, with increasing the temperature the solubility of the CO_2 in the aqueous phase would be reduced and consequently, the density of the liquid phase would be higher compared to lower temperature consitions. At higher temperatures, the density of the gaseous phase would be lower rather than the density of the gas phase at lower temperatures.

4 CONCLUSIONS

Multiphase flow meters play a critical role in accurately measuring multiphase flows, necessitating a precise understanding of the density and viscosity of each constituent phase within the system, while operating under dynamic pressure and temperature conditions. These determinations are vital for converting the obtained differential pressure data into flow rate estimates for each phase. In the context of this research, we have undertaken a comprehensive exploration of how changes in these critical thermodynamic properties of the predominant formation fluids would potentially impact the performance of multiphase flow meters. The presence of 2 mol% impurity in the CO_2 rich fluid (98 mol% CO_2) could make a shift of 2.5% in solubility of CO_2 in the aqueous phase, and also make a shift of up to 0.1% and 0.06% in density and viscosity, respectively. Therefore, for the case of the presence of higher concentrations of impurities and higher degrees of solubility of CO_2 in the liquid phase (up to 10 mol%, or even more as depicted in Figure 1), we have much more significant deviations in both density and viscosity of the liquid phase, as well as the gas phase.

This study underscores the crucial importance of accounting for compositional variations within multiphase flow meters. The outcomes presented in this paper elucidate the necessity of considering the influence of these compositional changes on the functionality and accuracy of multiphase flow meters.

The implications of this research extend far beyond its academic significance. The findings hold substantial practical relevance for engineers and scientists working within energy operators, particularly those involved in the design and implementation of CO_2 injection processes into depleted hydrocarbon reservoirs or deep saline aquifers. By shedding light on the intricacies of multiphase flow meter performance under varying fluid compositions, this work equips professionals with valuable insights to enhance the efficiency and reliability of CO_2 injection processes, thereby contributing to the sustainable utilisation of subsurface reservoirs.

5 NOTATION

ρ	Density
η	Viscosity
P	Pressure
EoS	Equation of State
EOR	Enhanced Oil Recovery

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