



# Simultaneous oil recovery and residual gas storage: A pore-level analysis using in situ X-ray micro-tomography

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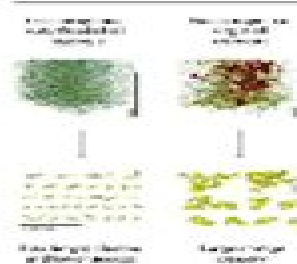
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## HIGHLIGHTS

- Waterflooding a reservoir prior to gas injection leads to significantly lower oil recovery.
- More oil can be produced by directly injecting gas into a virgin oil reservoir.
- Waterflooding a reservoir prior to gas injection leads to significantly lower gas storage capacities.
- More residual gas can be stored by directly injecting gas into an oil reservoir.
- Residual oil and gas clusters have a large cluster size distribution and surface area.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

### Article history:

Received 28 April 2012

Received in revised form 7 June 2012

Accepted 21 June 2012

Available online 28 August 2012

### Keywords:

Enhanced oil recovery

Carbon geo-sequestration

Residual oil

Residual gas

## ABSTRACT

We imaged sandstone cores at residual gas saturation ( $S_{gr}$ ) with synchrotron radiation at a nominal resolution of  $(19 \mu\text{m})^3$ . We studied two three-phase flooding sequences: (1) gas injection into a core containing oil and initial water followed by a waterflood (gw process); (2) gas injection into a waterflooded core followed by another waterflood (wgw process). In the gw flood we measured a significantly higher  $S_{gr}$  ( $\approx 20.4\%$ ;  $S_{gr}$  in the wgw flood was  $5.3\%$ ) and a significantly lower residual oil saturation ( $S_{or}$ ;  $S_{or}$  in the gw flood was  $21.4\%$  and  $S_{or}$  in the wgw flood was  $29.3\%$ ). We also studied the size distribution of individual trapped clusters in the pore space. We found an approximately power-law distribution  $N \propto r^{-\tau}$  with an exponent  $\tau = 2.02$ – $2.03$  for the residual oil clusters and  $\tau = 2.04$  for the gas clusters in the gw flood.  $\tau$  ( $\approx 2.32$ ) estimated for the gas clusters in the wgw process was significantly different. Furthermore, we calculated the surface area  $A$ –volume  $V$  relationships for the clusters. Again an approximate power-law relationship was observed,  $A \propto V^p$  with  $p = 0.75$ . Moreover, in the gw flood sequence we identified oil layers sandwiched between the gas and water phases; we did not identify such oil layers in the wgw flood. These results have several important implications for oil recovery, carbon geo-sequestration and contaminant transport: (a) significantly more oil can be produced and much more gas can be stored using a gw flood; (b) cluster size distributions for residual oil or gas clusters in three-phase flow are similar to those observed in analogue two-phase flow; (c) there is a large cluster surface area available for dissolution of the residual phase into an aqueous phase; however, this surface area is significantly smaller than predicted by percolation theory ( $p = 1$ ) which implies that  $\text{CO}_2$  dissolution trapping and contamination of aquifers by hazardous organic solvents is slower than expected because of reduced interfacial contact areas.

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# Simultaneous Oil Recovery And Residual Gas Storage A Pore

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Wang, Hai Sun, Lei Zhang, Kai Zhang**

## **Simultaneous Oil Recovery And Residual Gas Storage A Pore:**

*Imperial College Lectures In Petroleum Engineering, The - Volume 2: Reservoir Engineering* Martin Blunt, 2017-03-24

This book covers the fundamentals of reservoir engineering in the recovery of hydrocarbons from underground reservoirs. It provides a comprehensive introduction to the topic including discussion of recovery processes, material balance, fluid properties, and fluid flow. It also contains details of multiphase flow including pore scale displacement processes and their impact on relative permeability, with a presentation of analytical solutions to multiphase flow equations. Created specifically to aid students through undergraduate and graduate courses, this book also includes exercises with worked solutions and examples of previous exam papers for further guidance and practice. As part of the Imperial College Lectures in Petroleum Engineering and based on a lecture series on the same topic, *Reservoir Engineering* provides the introductory information needed for students of the earth sciences, petroleum engineering, and geoscience.

**Chemical Enhanced Oil Recovery (cEOR)** Laura Romero-Zerón, 2016-10-19 Commercial application of chemical enhanced oil recovery (cEOR) processes is expected to grow significantly over the next decade. Thus, *Chemical Enhanced Oil Recovery (cEOR): A Practical Overview* offers key knowledge and understanding of cEOR processes using an evidence-based approach intended for a broad audience ranging from field operators and researchers to reservoir engineers dealing with the development and planning of cEOR field applications. This book is structured into three sections: the first section surveys overall EOR processes; the second section focuses on cEOR processes; while the final section describes the electrorheology technology. These sections are presented using a practical and realistic approach tailored for readers looking to improve their knowledge and understanding of cEOR processes in a nutshell.

**Development of Unconventional Reservoirs** Reza Rezaee, 2020-04-16 The need for energy is increasing, but the production from conventional reservoirs is declining quickly. This requires an economically and technically feasible source of energy for the coming years. Among some alternative future energy solutions, the most reasonable source is from unconventional reservoirs. As the name unconventional implies, different and challenging approaches are required to characterize and develop these resources. This Special Issue covers some of the technical challenges for developing unconventional energy sources from shale gas, oil, tight gas, sand, and coalbed methane.

*Multiphase Flow in Permeable Media* Martin J. Blunt, 2017-02-16 This book provides a fundamental description of multiphase fluid flow through porous rock based on understanding movement at the pore or microscopic scale.

**Fundamentals and Practical Aspects of Gas Injection** Reza Azin, Amin Izadpanahi, 2021-07-28 This book covers different aspects of gas injection from the classic pressure maintenance operation to enhanced oil recovery (EOR), underground gas storage (UGS), and carbon capture and storage (CCS). The authors detail the unique characteristics and specific criteria of each application, including material balance equations, phase behaviour, reservoir engineering, well design, operating aspects, surface facilities, environmental issues. Examples, data, and simulation codes are provided to enable the

reader to gain an in depth understanding of these applications Fundamentals and Practical Aspects of Gas Injection will be of use to practising engineers in the fields of reservoir engineering and enhanced oil recovery It will also be of interest to researchers academics and graduate students working in the field of petroleum engineering Progress and Challenge of Porous Media: Proceedings of the 16th Annual Meeting Conference on Porous Media Jun Yao,Yongfei Yang,Wendong Wang,Hai Sun,Lei Zhang,Kai Zhang,2025-04-08 This book is a compilation of selected papers from the 16th Annual Meeting Conference on Porous Media InterPore 2024 The work focuses on novel techniques for porous media materials transport mechanisms in porous media multiscale multiphysics pore scale modeling and porous media mechanics The contents make valuable contributions to academic researchers engineers in the industry and regulators of aviation authorities As well readers will encounter new ideas for problems in porous media science and engineering *Proceedings of the International Field Exploration and Development Conference 2023* Jia'en Lin,2024-03-04 This book focuses on reservoir surveillance and management reservoir evaluation and dynamic description reservoir production stimulation and EOR ultra tight reservoir unconventional oil and gas resources technology oil and gas well production testing and geomechanics This book is a compilation of selected papers from the 13th International Field Exploration and Development Conference IFEDC 2023 The conference not only provides a platform to exchanges experience but also promotes the development of scientific research in oil and gas exploration and production The main audience for the work includes reservoir engineer geological engineer enterprise managers senior engineers as well as students Proceedings of the Sixteenth World Petroleum Congress Institute of Petroleum,World Petroleum Congress,2001-03 *Proceedings - DOE Symposium on Enhanced Oil & Gas Recovery & Improved Drilling Methods* ,1977 **Innovations in Enhanced and Improved Oil Recovery - New Advances** Mansoor Zoveidavianpoor,2024-04-24 This book navigates the evolving landscape of Enhanced Oil Recovery EOR and Improved Oil Recovery IOR covering diverse topics such as lithological dynamics in CO2 EOR the impact of asphaltene precipitation in WAG implementation progress in CO2 EOR and storage technology in situ foam generation for unconventional fractured reservoirs electromagnetic radiation effects on heavy oil upgrading advancements in hydraulic fracturing in situ synthesis of nanoparticles and operational insights in the Bakken Shale This comprehensive volume serves as an indispensable resource for professionals and researchers in the ever changing field of enhanced and improved oil recovery **Fossil Energy Update** ,1982 Introduction to Modeling, Simulation and Optimization of CO2 Sequestration in Various Types of Reservoirs Ramesh Agarwal,Danqing Liu,2024-11-23 Carbon capture and sequestration has become an essential technology for addressing the mitigation of global warming and adverse climate change due to increasing CO2 emissions from fossil fuel combustion worldwide However the scientific engineering community still lacks thorough and practical knowledge about various types of reservoirs capable of effective long term CO2 sequestration Introduction to Modeling Simulation and Optimization of CO2 Sequestration in Various Types of Reservoirs pulls together the relevant basic

scientific knowledge and applications to help reservoir engineering practitioners learn and utilize the potential of CO<sub>2</sub> sequestration in saline oil gas shale basalt and geothermal reservoirs After presenting the fundamental properties of various reservoirs the authors describe each type of reservoir and explain basic parameters benchmark cases experimental data optimization strategies for CO<sub>2</sub> sequestration prospects and outlook Rounding out the text with a glossary and consideration of future developments this book delivers the necessary tools for engineers to better understand carbon sequestration and advance the energy transition Introduces the physical characteristics of saline oil gas shale basalt and geothermal reservoirs Describes the physics and chemistry of CO<sub>2</sub> sequestration in different types of reservoirs and their modeling Applies numerical simulation and optimization methodology to various reservoirs with real world examples Reviews machine learning applications to carbon capture and sequestration

**Quantitative Characterization and Engineering Application of Pores and Fractures of Different Scales in Unconventional Reservoirs - Volume II** Wenlong Ding,Hu Li,Shuai Yin,2023-04-05

**Journal of the Institute of Petroleum** ,1963 **Science of Carbon Storage in Deep Saline Formations** Pania Newell,Anastasia Ilgen,2018-09-06 Science of Carbon Storage in Deep Saline Formations Process Coupling across Time and Spatial Scales summarizes state of the art research emphasizing how the coupling of physical and chemical processes as subsurface systems re equilibrate during and after the injection of CO<sub>2</sub> In addition it addresses in an easy to follow way the lack of knowledge in understanding the coupled processes related to fluid flow geomechanics and geochemistry over time and spatial scales The book uniquely highlights process coupling and process interplay across time and spatial scales that are relevant to geological carbon storage Includes the underlying scientific research as well as the risks associated with geological carbon storage Covers the topic of geological carbon storage from various disciplines addressing the multi scale and multi physics aspects of geological carbon storage Organized by discipline for ease of navigation

*Computational Models for CO<sub>2</sub> Geo-sequestration & Compressed Air Energy Storage* Rafid Al-Khoury,Jochen Bundschuh,2014-04-17 A comprehensive mathematical and computational modeling of CO<sub>2</sub> Geosequestration and Compressed Air Energy Storage Energy and environment are two interrelated issues of great concern to modern civilization As the world population will soon reach eight billion the demand for energy will dramatically increase intensifying the use of fossil fuels Ut

**Abstracts of the Journal** Institute of Petroleum (Great Britain),1962 **CO<sub>2</sub>-Reservoir Oil Miscibility** Dayanand Saini,2018-06-25 This SpringerBrief critically examines the latest experimental and non experimental approaches used for the fast and reliable characterization and determination of CO<sub>2</sub> reservoir oil miscibility in terms of the minimum miscibility pressure MMP This book serves as a one stop source for developing an enhanced understanding of these available methods and specifically documents analyses and evaluates their suitability and robustness for depicting and characterizing the phenomenon of CO<sub>2</sub> reservoir oil miscibility in a fast and cost effective manner Such information can greatly assist a project team in selecting an appropriate MMP determination method as per the project s need at a given project s stage be

that screening design or implementation CO2 Reservoir Oil Miscibility Experiential and Non Experimental Characterization and Determination Approaches will be of interest to petroleum science and engineering professionals researchers and undergraduate and graduate students engaged in CO2 enhanced oil recovery EOR and or simultaneous CO2 EOR and storage projects and related research It may also be of interest to engineering and management professionals within the petroleum industry who have responsibility for implementing CO2 EOR projects     Petroleum Engineering Handbook Larry W. Lake,2007     **Journal of the Institute of Petroleum** Institute of Petroleum (Great Britain),1963

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