Contribution ID: **7** Type: **Poster + 3 Minute Pitch**

Insight into Influence of Crossflow in layered Sandstone porous media during Miscible and Immiscible CO2 WAG Flooding

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For the layered system, cross-flow is one of the mechanisms for recovery enhancement during an IOR/EOR process. Thus, the results from this paper are very important to overcome the current challenges in capturing the importance of cross-flow influence as well as mitigating the effect of geological uncertainties on current and future IOR/EOR projects.

This manuscript presents the results of an experimental investigation into the effect of cross-flow on ultimate oil recovery during miscible and immiscible CO2 WAG flooding in layered sandstone porous media. A manufactured core sample constructed by attaching two half-cylindrical homogeneous natural sandstone plugs of different permeabilities. The core flooding tests using n-Decane Synthetic brine CO2 were conducted at a constant temperature of 343 K and under two different pressure conditions, namely, 9.6 MPa and 17.23 MPa to attain both immiscible and miscible conditions, respectively.

The results indicated that cross-flow in the layered sample has a negative impact on the ultimate oil recovery (i.e. decreasing oil recovery factor). The degree of heterogeneity seems to strongly influence the effectiveness of cross-flow during CO2 EOR with the oil recovery decreases as the permeability ratio (PR) between the two half plugs included in every samples increase. For instance, during miscible CO2 WAG flooding, a decrease in incremental oil recoveries from 3.3% to 11.3% and eventually to only 4.8% occurred when the permeability ratios were increased from 2.5 to 5 and 12.5, respectively. Similarly, during immiscible displacement, the recorded oil recoveries were 6.1%, 6.9% and 4.7% reflecting the same increases in permeability ratios as above. These results revealed that cross-flow works against the influence of the dominant active forces. For instance, in non-communicating layers, the dominance of viscous forces prevailed while there is a preferential flow path exists in flow in communicating layers. However, with increasing permeability ratio a considerable channelling of CO2 into the high permeability layer leaving the low permeability layer touched partially, implying that heterogeneity in vertical direction indeed significantly affects remaining oil saturations, thus oil recovery.

References

AL-BAYATI, D., SAEEDI, A., MYERS, M., WHITE, C. & XIE, Q. 2018a. An Experimental Investigation of Immiscible CO2 Flooding Efficiency in Sandstone Reservoirs: Influence of Permeability Heterogeneity. SPE Europec featured at 80th EAGE Conference and Exhibition. Copenhagen, Denmark: Society of Petroleum Engineers.

AL-BAYATI, D., SAEEDI, A., MYERS, M., WHITE, C., XIE, Q. & CLENNELL, B. 2018b. Insight investigation of miscible SCCO2 Water Alternating Gas (WAG) injection performance in heterogeneous sandstone reservoirs. Journal of CO2 Utilization, 28, 255-263.

AL-BAYATI, D., SAEEDI, A., XIE, Q., MYERS, M. B. & WHITE, C. 2018c. Influence of Permeability Heterogeneity on Miscible CO2 Flooding Efficiency in Sandstone Reservoirs: An Experimental Investigation. Transport in Porous Media, 125, PP 341-356.

AL EIDAN, A. A., MAMORA, D. D. & SCHECHTER, D. S. 2011. Experimental and Numerical Simulation Studies of Different Modes of CO2 Injection in Fractured Carbonate Cores. Society of Petroleum Engineers.

AL HAMDAN, M. R. S. 2013. An experimental and numerical investigation of compositional displacements

in heterogeneous reservoirs. The University of New South Wales.
AL WAHAIBI, Y. M. & AL HADHRAMI, A. K. 2011. First-Contact-Miscible, Vaporizing- and Condensing-Gas Drive Processes in a Channeling Heterogeneity System. Society of Petroleum Engineers.
ALAJMI, A. F. & GRADER, A. Analysis of fracture-matrix fluid flow interactions using X-ray CT. SPE Eastern Regional Meeting, 2000. Society of Petroleum Engineers.
ALHAMDAN, M., CINAR, Y., SUICMEZ, V. S. & DINDORUK, B. 2012. Experimental and numerical study of compositional two-phase displacements in layered porous media. Journal of Petroleum Science and Engineering, 98, 107-121.
ALVARADO, V. & MANRIQUE, E. 2010. Enhanced oil recovery: an update review. Energies, 3, 1529-1575.
ASGHARI, K. & TORABI, F. 2008. Effect of Miscible and Immiscible CO2 Injection on Gravity Drainage: Experimental and Simulation Results. Society of Petroleum Engineers.
BAHRALOLOM, I. M., BRETZ, R. E. & ORR, F. M., JR. 1988. Experimental Investigation of the Interaction of Phase Behavior With Microscopic Heterogeneity in a CO2 Flood. Society of Petroleum Engineers Journal, 3, 662-672.
BIKKINA, P., WAN, J., KIM, Y., KNEAFSEY, T. J. & TOKUNAGA, T. K. 2016. Influence of wettability and permeability heterogeneity on miscible CO2 flooding efficiency. Fuel, 166, 219-226.
BLUNT, M., FAYERS, F. J. & ORR JR, F. M. 1993. Carbon dioxide in enhanced oil recovery. Energy Conversion and Management, 34, 1197-1204.
BROCK, D. & ORR JR, F. Flow visualization of viscous fingering in heterogeneous porous media. SPE Annual Technical Conference and Exhibition, 1991. Society of Petroleum Engineers.
BURGER, J., SPRINGATE, G. & MOHANTY, K. 1996. Experiments on bypassing during gasfloods in heterogeneous porous media. SPE Reservoir Engineering, 11, 109-115.
CAO, M. & GU, Y. 2012. Physicochemical characterization of produced oils and gases in immiscible and miscible CO2 flooding processes. Energy & Fuels, 27, 440-453.
CHAOUCHE, M., RAKOTOMALALA, N., SALIN, D. & YORTSOS, Y. 1993. Capillary effects in immiscible flows in heterogeneous porous media. EPL (Europhysics Letters), 21, 19.
DEBBABI, Y., JACKSON, M. D., HAMPSON, G. J., FITCH, P. J. R. & SALINAS, P. 2017a. Viscous Crossflow in Layered Porous Media. Transport in Porous Media, 117, 281-309.
DEBBABI, Y., JACKSON, M. D., HAMPSON, G. J. & SALINAS, P. 2017b. Capillary Heterogeneity Trapping and Crossflow in Layered Porous Media. Transport in Porous Media, 120, 183-206.
DINDORUK, B. & FIROOZABADI, A. 1997. Crossflow in Fractured/Layered Media Incorporating Gravity, Viscous, and Phase Behavior Effects: Part I-Formulation and Features in Layered Media. SPE Journal, 2, 120-135.
DING, M., YUAN, F., WANG, Y., XIA, X., CHEN, W. & LIU, D. 2017. Oil recovery from a CO2 injection in heterogeneous reservoirs: The influence of permeability heterogeneity, CO2-oil miscibility and injection pattern. Journal of Natural Gas Science and Engineering, 44, 140-149.
DING, M., YUE, X. A., ZHAO, H. & ZHANG, W. 2013. Extraction and Its Effects on Crude Oil Properties During CO2 Flooding. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 35, 2233-2241.
DONALDSON, ERLE, CHILINGARIAN, G. V. & YEN, T. F. 1985. Enhanced Oil Recovery. I. Fundamentals and Analysis, The Netherlands, Elsevier Science.
FAYERS, F. J. & LEE, S.-T. 1992. Crossflow Mechanisms by Gas Drive in Heterogeneous Reservoirs. Society of Petroleum Engineers.
GEORGIADIS, A., LLOVELL, F., BISMARCK, A., BLAS, F. J., GALINDO, A., MAITLAND, G. C., TRUSLER, J. P. M. & JACKSON, G. 2010. Interfacial tension measurements and modelling of (carbon dioxide+n-alkane) and (carbon dioxide+water) binary mixtures at elevated pressures and temperatures. The Journal of Supercritical Fluids, 55, 743-754.
GREENKORN, R. A. & KESSLER, D. 1969. Dispersion in heterogeneous nonuniform anisotropic porous media. Industrial & Engineering Chemistry, 61, 14-32.
GRIGG, R. B. & SCHECHTER, D. S. 1997. State of the Industry in CO2 Floods. Society of Petroleum Engineers.
HAQ, S. & REIS, J. C. 1993. Predicting Capillary Crossflow in Layered Reservoirs. SPE Annual Technical Conference and Exhibition. Houston, Texas: Society of Petroleum Engineers.
HICKS JR, P. J., NARAYANAN, R. & DEANS, H. A. 1994. An experimental study of miscible displacements in heterogeneous carbonate cores using X-ray CT. SPE Formation Evaluation, 9, 55-60.
HOLM, L. & JOSENDAL, V. 1974. Mechanisms of oil displacement by carbon dioxide. Journal of petroleum Technology, 26, 1,427-1,438.
KAMALI, F., HUSSAIN, F. & CINAR, Y. 2016. An Experimental and Numerical Analysis of Water-Alternating-Gas and Simultaneous-Water-and-Gas Displacements for Carbon Dioxide Enhanced Oil Recovery and Storage. SPE Journal, 22, 521 - 538.
KATZ, M. L. & TEK, M. R. 1962. A Theoretical Study of Pressure Distribution and Fluid Flux in Bounded Stratified Porous Systems with Crossflow.

KRAUSE, M. H., PERRIN, J.-C. & BENSON, S. M. 2011. Modeling permeability distributions in a sandstone core for history matching coreflood experiments. SPE Journal, 16, 768-777.
LAKE, L. & JENSEN, J. 1989. A review of heterogeneity measures used in reservoir characterization. SPE.
LAKE, L. W. & HIRASAKI, G. J. 1981. Taylor's dispersion in stratified porous media. Society of Petroleum Engineers Journal, 21, 459-468.
LAKE, W. 1989. Enhanced oil recovery.
LEI, H., YANG, S., ZU, L., WANG, Z. & LI, Y. 2016. Oil Recovery Performance and CO2 Storage Potential of CO2 Water-Alternating-Gas Injection after Continuous CO2 Injection in a Multilayer Formation. Energy & Fuels, 30, 8922-8931.
MACALLISTER, D., MILLER, K., GRAHAM, S. & YANG, C. 1990. Application of X-ray CT scanning to the determination of gas-water relative permeabilities. SPE, 20494, 23-26.
MORANVILLE, M., KESSLER, D. & GREENKORN, R. 1977. Dispersion in layered porous media. AIChE Journal, 23, 786-794.
NAGARAJAN, N. & ROBINSON JR, R. 1986. Equilibrium phase compositions, phase densities, and interfacial tensions for carbon dioxide+ hydrocarbon systems. 2. Carbon dioxide+ n-decane. Journal of Chemical and Engineering Data, 31, 168-171.
NOBAKHT, M., MOGHADAM, S. & GU, Y. 2008. Mutual interactions between crude oil and CO 2 under different pressures. Fluid phase equilibria, 265, 94-103.
PANDE, K. & ORR, F. M. 1994. Effect of Viscous Crossflow on Miscibility Development in a Two-Layer Flow System: Part I - Ternary Vaporizing Gas Drives.
PERKINS, T. K., JOHNSTON, O. C. & HOFFMAN, R. N. 1965. Mechanics of viscous fingering in miscible systems. Society of Petroleum Engineers Journal, 5, 301-317.
PERRIN, J.-C. & BENSON, S. 2010. An Experimental Study on the Influence of Sub-Core Scale Heterogeneities on CO2 Distribution in Reservoir Rocks. Transport in Porous Media, 82, 93-109.
PETERS, B. M., ZHOU, D. & BLUNT, M. J. Experimental Investigation of Scaling Factors that Describe Miscible Floods in Layered. SPE/DOE Improved Oil Recovery Symposium, 1998. Society of Petroleum Engineers.
RAO, D. N. & LEE, J. I. 2003. Determination of gas–oil miscibility conditions by interfacial tension measurements. Journal of colloid and interface science, 262, 474-482.
RAPOPORT, L. & LEAS, W. 1953. Properties of linear waterfloods. Journal of Petroleum Technology, 5, 139-148.
SAEEDI, A. 2012. Experimental study of multiphase flow in porous media during CO2 Geo-Sequestration processes, Springer Science & Business Media.
SCHEIDEGGER, A. E. 1961. General theory of dispersion in porous media. Journal of Geophysical Research, 66, 3273-3278.
SHAVER, R., ROBINSON, R. & GASEM, K. 2001. An automated apparatus for equilibrium phase compositions, densities, and interfacial tensions: data for carbon dioxide+ decane. Fluid phase equilibria, 179, 43-66.
SHEDID, S. 2009. Influences of different modes of reservoir heterogeneity on performance and oil recovery of carbon dioxide miscible flooding. Journal of Canadian Petroleum Technology, 48, 29-36.
SONG, Y., ZHU, N., ZHAO, Y., LIU, Y., JIANG, L. & WANG, T. 2013. Magnetic resonance imaging study on near miscible supercritical CO2 flooding in porous media. Physics of Fluids, 25, 053301.
SORBIE, K., SHEB, M., HOSSEINI, A. & WAT, R. Scaled miscible floods in layered beadpacks investigating viscous crossflow, the effects of gravity, and the dynamics of viscous slug breakdown. SPE Annual Technical Conference and Exhibition, 1990. Society of Petroleum Engineers.
SORBIE, K. S. & SERIGHT, R. S. 1992. Gel Placement in Heterogeneous Systems With Crossflow. SPE/DOE Enhanced Oil Recovery Symposium. Tulsa, Oklahoma: Society of Petroleum Engineers.
TRIVEDI, J. & BABADALI, T. 2006. Optimal Injection Strategies for CO2 and Flue Gas Sequestration During Tertiary Oil Recovery. OIL GAS European Magazine
TUNIO, S. Q., TUNIO, A. H., GHIRANO, N. A. & EL ADAWY, Z. M. 2011. Comparison of different enhanced oil recovery techniques for better oil productivity. International Journal of Applied Science and Technology, 1.
VERMA, M. K. 2015. Fundamentals of carbon dioxide-enhanced oil recovery (CO2-EOR): A supporting document of the assessment methodology for hydrocarbon recovery using CO2-EOR associated with carbon sequestration, US Department of the Interior, US Geological Survey.
VINEGAR, H. J. & WELLINGTON, S. L. 1987. Tomographic imaging of three-phase flow experiments. Review of Scientific Instruments, 58, 96-107.
WANG, S. Y., HUANG, Y., PEREIRA, V. & GRYTE, C. C. 1985. Application of computed tomography to oil recovery from porous media. Applied optics, 24, 4021-4027.
WELLINGTON, S. & VINEGAR, H. CT studies of surfactant-induced CO2 mobility control. SPE Annual Technical Conference and Exhibition, 1985. Society of Petroleum Engineers.

WITHJACK, E. 1988. Computed tomography for rock-property determination and fluid-flow visualization. SPE formation evaluation, 3, 696-704.
YAMAMOTO, J., SATOH, T., ISHII, H. & OKATSU, K. An Analysis of CO2 WAG Coreflood by Use of X-ray CT. SPE Asia Pacific Oil and Gas Conference and Exhibition, 1997. Society of Petroleum Engineers.
YOKOYAMA, Y. & LAKE, L. W. The effects of capillary pressure on immiscible displacements in stratified porous media. SPE Annual Technical Conference and Exhibition, 1981. Society of Petroleum Engineers.
YONGMAO, H., ZENGGUI, W., BINSHAN, J., YUEMING, C. & XIANGJIE, L. 2004. Laboratory Investigation of CO2 Flooding. Society of Petroleum Engineers.
ZAPATA, V. J. & LAKE, L. W. 1981. A Theoretical Analysis of Viscous Crossflow. Society of Petroleum Engineers.
ZHAO, F., HAO, H., HOU, J., HOU, L. & SONG, Z. 2015. CO2 mobility control and sweep efficiency improvement using starch gel or ethylenediamine in ultra-low permeability oil layers with different types of heterogeneity. Journal of Petroleum Science and Engineering, 133, 52-65.
ZHOU, D., FAYERS, F. J. & ORR, F. M., JR. 1994. Scaling of Multiphase Flow in Simple Heterogeneous Porous Media.
ZHOU, X., AL-OTAIBI, F. M., KOKAL, S. L., AL-HASHBOUL, A. A., BALASUBRAMANIAN, S. & AL-GHAMD, F. A. 2015. Novel Insights into IOR/EOR by Seawater and Supercritical CO2 Miscible Flooding Using Dual Carbonate Cores at Reservoir Conditions. Saudi Aramco Journal of Technology.
ZHOU, X., ALOTAIBI, F., KOKAL, S., ALHASHBOUL, A. & AL-QAHTANI, J. 2017. A New Approach of Pressure Profile and Oil Recovery during Dual and Single Carbonate Core Flooding by Seawater and CO2 Injection Process at Reservoir Conditions. SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition. Jakarta, Indonesia: Society of Petroleum Engineers.

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