

EXPERIMENTAL PERFORMANCE OF
SELECTIVE SIMULTANEOUS WATER
ALTERNATING NITROGEN (SSWAG-N₂)
TECHNIQUE FOR OIL RECOVERY IN
SANDSTONE AND CARBONATE

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DOCTOR OF PHILOSOPHY
(CHEMICAL ENGINEERING)

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We hereby declare that we have checked this thesis and, in our opinion, this thesis is adequate in terms of scope and quality for the award of Doctor of Philosophy (Chemical Engineering).

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I hereby declare that the work in this thesis is my own except for quotations and summaries, which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRAK

Penjejakan jari dan ketumpatan tumpuan yang membawa kepada Penembusan Air yang awal dan Penembusan Gas yang awal adalah masalah utama yang di temui oleh jurutera reserbor minyak semasa pelaksanaan Banjir Air (WF) dan Banjir Gas (GF), secara berturutan. Walaupun terdapat teknik yang digunakan untuk meminimumkan masalah-masalah ini, termasuklah teknik suntikan Gas-Nitrogen Berselang Air (WAG-N₂) (SSWAG), namun masalah pengasingan gas air ini tetap berlaku. Dalam kajian ini, teknik suntikan Gas Berselang Air Serentak secara terpilih diubahsuai dengan menyuntik gas nitrogen ke bahagian bawah zon penghasilan minyak sementara air disuntik ke bahagian atas zon penghasil minyak, bagi tujuan memanjangkan jarak masa di dalam reserbor sebelum berlakunya pengasingan air dan gas, untuk menanggukkan masa keterobosan air dan gas. Objektif utama kajian ini adalah untuk menyiasat kebolehpemolehan minyak dari batuan pasir dan batuan karbonat dan menyiasat pengaruh keterobosan Air dan Gas pada Faktor Pemolehan Minyak (ORF). Kajian ini juga menyiasat kebolehpemolehan minyak dalam kaedah Pemolehan Peningkatan Minyak konvensional seperti proses-proses WF, GF, WAG dan SSWAG, dan juga keterobosan awal Air dan Gas yang biasanya dikaitkan dengan proses-proses ini. Perbandingan terperinci kesan keterobosan awal Air dan keterobosan awal Gas telah di capai bagi setiap teknik pemolehan minyak di atas bagi batuan pasir dan batuan karbonat. Dalam batuan pasir, tiga tekanan suntikan: 2000 psi (137.9 bar), 1500 psi (103 bar), dan 1000 psi (68.95 bar) telah diuji dan dikaji pengaruh tekanan suntikan untuk menanggukkan keterobosan awal air dan dan keterobosan awal gas; dan kesannya, dapat memanjangkan jarak masa sebelum pemisahan air dan gas terjadi. Keputusan yang dapat disimpulkan dari kajian ini mengesahkan bahawa, apabila menyuntik N₂ dengan air garam menggunakan mod suntikan EOR dalam batuan pasir dan batuan karbonat, hasil yang lebih baik untuk pemolehan minyak diperolehi dengan menggunakan teknik SSWAG-N₂ yang diubah suai. Dalam batuan pasir, pemolehan minyak teknik-teknik SSWAG diubah suai, SSWAG konvensional, WAG selepas WF, dan WAG selepas GF secara berturutan adalah 73.44, 71.95, 71.20, dan 52.42%. Begitu juga, dalam batuan karbonat, faktor pemolehan minyak mempunyai susunan yang sama dengan keputusan berikut: SSWAG diubahsuai (73.72%), SSWAG konvensional (70.00%), WAG selepas WF (70.71%), dan WAG selepas GF (57.55%). Hasil keputusan Faktor Pemolehan Minyak (ORF,%) di antara batuan pasir dan batuan karbonat adalah hampir. Ini menambahkan lagi kebolehpemercayaan kepada hasil yang diperolehi di antara kedua batuan tersebut. Masa Keterobosan Gas (GBT) berlaku semasa pelaksanaan SSWAG diubah suai adalah pada 39 min dan bukannya 28 min jika dibandingkan dengan SSWAG konvensional dalam batu pasir. Begitu juga, GBT berlaku pada 35 minit dalam SSWAG diubah suai berbanding SSWAG konvensional (21 min) dalam batuan karbonat. Semasa pelaksanaan ketiga-tiga tekanan suntikan yang berbeza, yang digunakan pada batuan pasir menggunakan teknik SSWAG yang diubahsuai, hasil yang lebih baik diperolehi apabila menggunakan tekanan suntikan 2000 psi dan diikuti oleh tekanan 1000 psi; sedangkan, faktor pemolehan yang paling rendah dicapai apabila menggunakan tekanan suntikan 1500 psi

ABSTRACT

Although there were techniques such as Water Alternating Gas-Nitrogen (WAG-N₂) to minimize the problems of viscous fingering and density tonging; however, water gas segregation problem occurred. Water gas segregation leads to early Water Breakthrough and Gas Breakthrough. In this study, a technique of selective simultaneous water alternating gas (SSWAG-N₂) was modified by injecting nitrogen gas at the lower part while water was injected at the higher part of the oil-producing zone. This technique was implemented to prolong the distance in the reservoir before water and gas segregation occurs; to delay water and gas breakthroughs. The main objective of this study was to investigate the effect of the modified SSWAG-N₂ on the recoverability of sandstone and carbonate sand packs and the influence of Water and Gas Breakthroughs on the Oil Recovery Factor (ORF). This study also investigated the recoverability in conventional Enhanced Oil Recovery methods such as WF, GF, WAG, SSWAG process, and the early Water and Gas Breakthrough that usually associate these processes in order to compare them with the modified SSWAG-N₂. A detailed comparison between the results of sandstone and carbonate sand packs has been achieved to investigate the effect of early water and gas breakthroughs on oil recovery of each method. In sandstone sand packs, three injection pressures: 2000 psi (137.9 bar), 1500 psi (103 bar), and 1000 psi (68.95 bar) were examined by studying the influence of injection pressure on delaying the water and gas breakthroughs; and consequently, prolong the distance before gas-water segregation. The better ORF inferred from this study when injecting N₂ with brine using EOR injecting modes in sandstone and carbonate sand packs, was obtained when applying modified SSWAG-N₂. In sandstone, the recoveries of the modified SSWAGN₂ and conventional SSWAGN₂, were 73.44, 71.95 respectively. Similarly, in carbonate, the recovery factor had the same arrangement with the following results: Modified SSWAG (73.72%), and conventional SSWAG (70.00%). The results of Oil Recovery Factor (ORF, %) in sandstone and carbonate sand pack cores were close. This added more reliability to the obtained results. Gas breakthrough (GBT) occurred at 39 min after implementation of the modified SSWAG; however, it occurred after 28 min in the conventional SSWAG in sandstone sand packs. Similarly, in carbonate sand packs, GBT occurred after 35 min in modified SSWAG compared with conventional SSWAG (21 min). During the implementation of the three different injection pressures, which were applied on sandstone sand packs using modified SSWAG technique, the better result of recovery was obtained when applying the injection pressure of 2000 psi and then followed by 1000 psi; whereas, the lowest recovery factor was when applying the injection pressure of 1500 psi.

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LIST OF ABBREVIATIONS

ΔP	Pressure drop (pressure difference)
μ	Viscosity
μ_{ing}	Displacing fluid viscosity
μ_{ed}	Displaced fluid viscosity
API	American Petroleum Institute
BV	Bulk Volume
BOPD	Barrel Oil Per Day
BWPD	Barrel Water Per Day
C1,.C7	Light hydrocarbons
CCS	Carbon Capture and Store
CGI	Continuous Gas Injection
CO ₂	Carbon Dioxide Gas
DDP	Double Displacement Process
EOR	Enhanced Oil Recovery
FAWAG	Foam Assisted WAG
G.O.C	Gas Oil Contact
GASWAG	Gas Assisted Simultaneous WAG
GBT	Gas Breakthrough Time
GF	Gas Flooding
GI	Gas Injection
GOR	Gas Oil Ratio
HC	Hydrocarbon
HCPV	Hydrocarbon pore volume
HWAG	Hybrid WAG
IFT	Interfacial Tension
IP	Injection Pressure
IST	In-situ-Combustion
IWAG	Immiscible WAG
<i>K</i>	Permeability

l	Length
LPG	Liquefied Petroleum Gas
M	Mobility
MCF	Millie Cubic Foot
MMP	Minimum Miscibility Pressure
MWAG	Miscible WAG
MSCF	Millie Cubic Foot
N_2	Nitrogen Gas
N_c	Capillary pressure
O.W.C	Oil Water Contact
OIP	Oil In Place
OOIP, OIIP	Oil Original In place, Oil Initial In Place
ORF	Oil Recovery Factor
PSI	Pound per Square Inch, pressure measuring unit
Q	Flow rate
RP	Pressure Regulator
SSWAG	Selective Simultaneous Water Alternating Gas
SSWAG- N_2	Selective Simultaneous Water Alternating Gas Nitrogen
SWAG	Selective Simultaneous Water Alternating Gas
SWAG- N_2	Simultaneous Water Alternating Gas Nitrogen
S_{wc}	Connate water saturation
S_{wi}	Irreducible water saturation
V	Velocity
WAG	Water Alternating Gas
WBT	Water Breakthrough Time
WF	Water Flooding
WI	Water injection
σ	Interfacial tension
ϕ	Porosity

REFERENCES

- Abdulrazag, Z., & Jerbi, K. (2002). Economic evaluation of enhanced oil recovery. *Oil & Gas Science and Technology*, 57(3), 259-267.
- Adekunle, O. O., & Hoffman, B. T. (2014). Minimum Miscibility Pressure Studies in the Bakken. doi: 10.2118/169077-ms
- Afzali, S., Rezaei, N., & Zendehboudi, S. (2018). A comprehensive review on enhanced oil recovery by water alternating gas (WAG) injection. *Fuel*, 227, 218-246.
- Ahmed, M., Jaafar, M., Wan Sulaiman, W., & Hashim, M. (2014). Miscible Flood Performance of Heterogeneous Layered Reservoirs: Considering Profile Control Through Controlled Fluid Movements. Paper presented at the Offshore Technology Conference-Asia.
- Air.Productsand.chemicals.Inc. (2009). Increased production through enhanced-oil-recovery. Hamilton Boulevard PA 18195-1501: .
- Al-Anazi, B. D. (2007). Enhanced oil recovery techniques and nitrogen injection. [recorder]. *CSEG Recorder*, 29-33.
- Al-Ghanim, W., Gharbi, R., & Algharaib, M. K. (2009). Designing a simultaneous water alternating gas process for optimizing oil recovery. Paper presented at the EUROPEC/EAGE Conference and Exhibition.
- Al-Jarba, M., & Al-Anazi, B. D. (2010). Enhanced oil recovery techniques and CO₂ flooding. *Nafta*, 61(9), 391-395.
- Al-Mamari, F., Al-Shuraiqi, H., & Al-Wahaibi, Y. M. (2007). Numerical Simulation and Experimental Studies of Oil Recovery via First-Contact Miscible Water Alternating Gas Injection within Shaley Porous Media. Paper presented at the SPE/EAGE Reservoir Characterization and Simulation Conference-111105-MS, Abu Dhabi, UAE.
- Al Sayari, S. S. (2009). The influence of wettability and carbon dioxide injection on hydrocarbon recovery. PhD thesis, Imperial College London, London.
- Alagorni, A. H., Yaacob, Z. B., & Nour, A. H. (2015). An overview of oil production stages: enhanced oil recovery techniques and nitrogen injection. *Int. J. Environ. Sci. Dev*, 6(9), 693.
- Aleidan, A. A. S. (2010). Experimental and simulation studies to evaluate the improvement of oil recovery by different modes of CO₂ injection in carbonate reservoirs. PhD thesis, Texas A&M University, Texas.

- Algharaib, M. K., Gharbi, R. B., Malallah, A., & Al-Ghanim, W. (2007). Parametric investigations of a modified swag injection technique. Paper presented at the SPE Middle East Oil and Gas Show and Conference-105071, Kingdom of Bahrain.
- Alvarado, V., & Manrique, E. (2010). Enhanced oil recovery: An update review. *Energies*, 3(9), 1529-1575.
- Aminshahidy, B., & Foroozanfar, M. (2013). Comparison between gas injection and water flooding, in aspect of secondary recovery in one of Iranian oil reservoirs. *Global Journal of Science, Engineering and Technology*(11), 87-92.
- Bailey, B., Crabtree, M., Tyrie, J., Elphick, J., Kuchuk, F., Romano, C., & Roodhart, L. (2000). Water control. *Oilfield Review*, 12(1), 30-51.
- Barnawi, M. T. (2008). A simulation study to verify Stone's simultaneous water and gas injection performance in a 5-spot pattern. Master thesis, Texas A&M University. Texas A&M University. Available electronically from <http://hdl.handle.net/1969>.
- Bednarz, P., & Stopa, J. (2014). Enhanced Oil Recovery methods on offshore fields in the light of world literature. *AGH Drilling, Oil, Gas*, 31No 2.
- Beeson-Jones, T. (2018). Controlling Viscous Fingering. University of Cambridge.
- Berge, L. I., Stensen, J. Å., Crapez, B., & Quale, E. A. (2002). SWAG injectivity behavior based on Siri field data. Paper presented at the SPE/DOE Improved Oil Recovery Symposium, Oklahoma.
- Bondar, V., & Blasingame, T. (2002). Analysis and interpretation of water-oil-ratio performance. Paper presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, Sept.
- Bourdet, J., Kempton, R., & Michael, K. (2015). Palaeo-formation water evolution in the Latrobe aquifer, Gippsland Basin, south-eastern Australia continental shelf. *Geofluids*, 15(4), 503-526. doi: 10.1111/gfl.12116.
- Christensen, J. R., Stenby, E. H., & Skauge, A. (2001). Review of WAG field experience. *SPE Reservoir Evaluation & Engineering*, 4(02), 97-106.
- Christensen, J. R., Stenby, E. H., & Skauge, A. (2003). Review of WAG field experience. Paper presented at the International petroleum conference and exhibition of Mexico.
- Chukwudeme, E. A., & Hamouda, A. A. (2009). Enhanced Oil Recovery (EOR) by Miscible CO₂ and Water Flooding of Asphaltenic and Non-Asphaltenic Oils. *Energies*, 2(3), 714-737. doi: 10.3390/en20300714

- Clancy, J., Gilchrist, R., Cheng, L., & Bywater, D. (1985). Analysis of Nitrogen-Injection projects to develop screening guides and offshore design criteria. *Journal of petroleum technology*, 37(06), 1,097-091,104.
- Cobanoglu, M. (2001). A Numerical Study To Evaluate The Use Of WAG As An EOR Method For Oil Production Improvement At B. Kozluca Field Turkey. Paper presented at the SPE Asia Pacific Improved Oil Recovery Conference SPE 72127, Kuala Lumpur, Malaysia.
- Darvishnezhad, M. J., Moradi, B., Zargar, G., Jannatrostami, A., & Montazeri, G. H. (2010). Study of Various Water Alternating Gas Injection Methods in 4-and 5-Spot Injection Patterns in an Iranian Fractured Reservoir. Paper presented at the Trinidad and Tobago Energy Resources Conference, SPE-132847-MS, Port of Spain, Trinidad.
- Dechongkit, P., & Prasad, M. (2011). Recovery factor and reserves estimation in the Bakken petroleum system (Analysis of the Antelope, Sanish and Parshall fields). Paper presented at the Canadian Unconventional Resources Conference.
- Dermanaki Farahani, Z., & Khorsand Movaghar, M. R. (2017). Improving Oil Recovery Using Miscible Selective Simultaneous Water Alternating Gas (MSSWAG) Injection in One of the Iranian Reservoirs. *Arabian Journal for Science and Engineering*. doi: 10.1007/s13369-017-2667-z
- Dong, M., Forai, J., Huang, S., & Chatzis, I. (2002). Analysis of immiscible water-alternating-gas (WAG) injection using micromodel. Paper presented at the Canadian International Petroleum Conference.
- Duchenne, S., Puyou, G., Cordelier, P., Bourgeois, M., & Hamon, G. (2014). Laboratory investigation of miscible CO₂ WAG injection efficiency in carbonate. Paper presented at the SPE EOR Conference at Oil and Gas West Asia.
- El Ela, M. A., Samir, M., Sayyoub, H., & El Tayeb, S. (2008). Thermal heavy-oil recovery projects succeed in Egypt, Syria. *Oil and Gas Journal*, 106(48), 40.
- Evison, B., & Gilchrist, R. (1992). New developments in nitrogen in the oil industry. Paper presented at the SPE Mid-Continent Gas Symposium SPE-24313-MS, Amarillo, Texas.
- Ezekiel, J. C. (2017). Screening of Gas Injection Techniques for IOR in Low Permeability Reservoirs: Case Study of Q131 block in Liaohe Master, China University of Petroleum (East China), China.
- Fahandezhsaadi, M., Amooie, M. A., Hemmati-Sarapardeh, A., Ayatollahi, S., Schaffie, M., & Ranjbar, M. (2019). Laboratory evaluation of nitrogen injection for enhanced oil recovery: Effects of pressure and induced fractures. *Fuel*, 253, 607-614.

- Faisal, A. (2009). Injectivity and Gravity Segregation in WAG and SWAG Enhanced Oil Recovery. Master thesis, Delft University of Technology, The Netherlands.
- Farias, M. J., & Watson, R. W. (2007). Interaction of Nitrogen/CO₂ Mixtures with Crude Oil Pennsylvania State University, University Park, PA, USA: Pennsylvania State University, University Park, PA, USA.
- Filho, R. D. G. D. F. (2017). Dissolution Of Carbonate Rocks In High Pressure Co₂/Brine Systems: Effects On Porosity And Permeability. master, Campinas.
- Fleshman, R., & Lekic, O. (1999). Artificial lift for high-volume production. *Oilfield Review*, 11, 48-63.
- Foroozanfar, M., & Aminshahidy, B. (2013). Efficiency evaluation of immiscible water alternating gas (IWAG) process in one of Iranian oil reservoirs. *Global Journal of Science, Engineering and Technology*(14, 2013,), 76-81.
- Forrest, J. K., Hussain, A., Orozco, M., & Bourge, J. (2009). Samarang Field–Seismic To Simulation Redevelopment Evaluation Brings New Life to an Old Oilfield, Offshore Sabah, Malaysia. Paper presented at the International Petroleum Technology Conference IPTC13162, Doha, Qatar.
- Glover, P. (2001). Formation Evaluation MSc Course Notes. Aberdeen University, 19-26.
- Han, L. (2015). Optimum Water-Alternating-Gas (CO₂-WAG) Injection In The Bakken Formation. Degree of Master of Applied Scienc, University of Regina.
- Heinemann, Z. E. (2005). Fluid flow in porous media. Montanuniversität Leoben, Petroleum Engineering Department Textbook Series, 65-82.
- Hemmati-Sarapardeh, A., Ayatollahi, S., Zolghadr, A., Ghazanfari, M.-H., & Masihi, M. (2014). Experimental Determination of Equilibrium Interfacial Tension for Nitrogen-Crude Oil during the Gas Injection Process: The Role of Temperature, Pressure, and Composition. *Journal of Chemical & Engineering Data*, 59(11), 3461-3469.
- Heucke, U. (2015). Nitrogen Injection as IOR/EOR Solution For North African Oil Fields. Paper presented at the SPE North Africa Technical Conference and Exhibition.
- Hudgins, D. A., Llave, F. M., & Chung, F. T. (1990). Nitrogen miscible displacement of light crude oil: a laboratory study. *SPE Reservoir Engineering*, 5(1), 100-106.
- Isco, T. (2012). Enhanced_Oil_Recovery: Syringe Pump Application Note AN7 www.isco.com/WebProductFiles/.../105/.

- Jaturakhanawanit, S., & Wannakomol, A. (2011). Water Alternating Gas Injection For Enhanced Oil Recovery In The Phitsanulok Basin. *Suranaree Journal of Science & Technology*, 18(4).
- Jensen, T., Harpole, K., & Østhus, A. (2000). EOR screening for Ekofisk. Paper presented at the EUROPEC: European petroleum conference SPE 65124-MS, Paris, France,.
- John, F. O. (2015). Optimization of a Water Alternating Gas Injection. MSc, Tecnico Lisboa.
- Kirk Raney, S., Subhash Ayirala, S., Robert Chin, S., & Paul Verbeek, S. (2011). Surface and subsurface requirements for successful implementation of offshore chemical enhanced oil recovery. *Society of Petroleum Engineers Journal* OCT21188.
- Knappskog, O. A. (2012). Evaluation of WAG injection at Ekofisk. MASTER'S THESIS, University of Stavanger.
- Kulkarni, M. M. (2003). Immiscible and miscible gas-oil displacements in porous media. Master thesis, Louisiana State University.
- Kulkarni, M. M. (2005). Multiphase mechanisms and fluid dynamics in gas injection enhanced oil recovery processes. PhD thesis, Louisiana State University.
- Kumar, J., Agrawal, P., & Draoui, E. (2017). A Case Study on Miscible and Immiscible Gas-Injection Pilots in a Middle East Carbonate Reservoir in an Offshore Environment. *SPE Reservoir Evaluation & Engineering*, 20(01), 19-29.
- Li, W., Dong, Z., Sun, J., & Schechter, D. S. (2014). Polymer-alternating-gas simulation: A Case Study. Paper presented at the SPE EOR Conference at Oil and Gas West Asia.
- Lun, Z., Xi, C., Li, C., Renyi, C., Zhang, X., Jia, L., & Fachao, S. (2015). Effects of oil recovery rate on water-flooding of homogeneous reservoirs of different oil viscosity. *Petroleum Exploration and Development*, 42(3), 384-389.
- Masalmeh, S. K., Hillgartner, H., Al-Mjeni, R. A.-M., & Jing, X. (2010). Simultaneous Injection of Miscible Gas and Polymer (SIMGAP) to Improve Oil Recovery and Sweep Efficiency from Layered Carbonate Reservoirs. Paper presented at the SPE EOR Conference at Oil & Gas West Asia SPE-129645-MS, Muscat, Oman.
- Melzer, L. S., & Midland, T. (2012). Carbon Dioxide Enhanced Oil Recovery (CO₂ EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery. Paper presented at the CO₂ Consultant and Annual CO₂ Flooding Conference-
neori.org/Melzer_CO2EOR_CCUS_Feb2012.pdf.

- Meshal, A., Rida, G., & Adel, M. (2007). A parametric Investigations of SWAG injection technique. SPE paper, 105071.
- Meyer, J. P. (2007). Summary of carbon dioxide enhanced oil recovery (CO₂EOR) injection well technology (pp. 54). Plano, Texas: American Petroleum Institute.
- Michael Mitariten, P. E. (2009). Economic-N₂-Removal-Hydrocarbon-Engineering. Hydrocarbon Engineering Magazine.
- Mohamed, I. M. (2012). Formation Damage Due To Co₂ Sequestration In Saline Aquifers. PhD, Texas A&M University, Texas.
- Moissis, D. (1988). Simulation of viscous fingering during miscible displacement in nonuniform porous media. Tech. Rep. 88-9Dep. of Math. Sci., Rice Univ., Houston, Tex.
- Moore, C. H., & Wade, W. J. (2013). Carbonate reservoirs: Porosity and diagenesis in a sequence stratigraphic framework (Vol. 67): Newnes.
- Moreno, J., Liu, Y., Al-Kinai, A., & Cakir, N. (2014). EOR Advisor system: A comprehensive Approach to EOR selection.
- Muggeridge, A., Cockin, A., Webb, K., Frampton, H., Collins, I., Moulds, T., & Salino, P. (2014). Recovery rates, enhanced oil recovery and technological limits. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 372(2006), 20120320.
- Nangacovié, H. L. M. (2012). Application of WAG and SWAG injection Techniques in Norne E-Segment. Master thesis, Norwegian University of Science and Technology, Norway.
- Nejad, K., & Danesh, A. (2005). Visual investigation of oil depressurization in pores with different wettability characteristics and saturation histories. Paper presented at the proceedings, presented at the SPE EUROPEC/EAGE Annual Conference, Madrid, Spain, SPE 94054, Madrid, Spain.
- newsletter, I. w. (2010). drilling, oil Spill Solutions Retrieved 20 Feb, 2014, from <http://www.oilspillsolutions.org/isco.htm>
- Nicolaidis, C., Jha, B., Cueto- Felgueroso, L., & Juanes, R. (2015). Impact of viscous fingering and permeability heterogeneity on fluid mixing in porous media. Water Resources Research, 51(4), 2634-2647.
- Olawale Adegunle, B. T. H. (2014). Minimum Miscibility Pressure Studies in the Bakken. SPE(SPE SPE-169077-MS). doi: 10.2118/169077-MS

- Platt, C., Houtzager, F., Piyatad, T., Theeranun, L., McClure, J., Kienast, V., . . . Wachiragorn, P. (2013). High Water-Cut Production Remedy by Inflow Control Solution in Challenging Intermittent Channeled Sands Oil Recovery in Gulf of Thailand Offshore. Paper presented at the IPTC 2013: International Petroleum Technology Conference.
- Quijada, M. G. (2005). Optimization of A CO₂ Flood Design Wasson Field-West Texas. master thesis, Texas A&M University.
- Reza, H., Arman, A., & Ghazal, H. (2016). Comparative study on oil recovery enhancement by WAG injection technique in a fractured oil reservoir in the southwest of Iran. *Journal of Petroleum & Environmental Biotechnology*, 7, 263.
- Robert de Kler (TNO), (TNO), F. N., (TNO), M. N., Peter Brownsort (SCCS, E., (Ecofys), J. K., (TNO), S. B., (TNO), D. L. (2016). Transportation and unloading of CO₂ by ship - a comparative assessment CATO PROGRAM (pp. 1-117).
- Romero-Zerón, L. (2012). Advances in Enhanced Oil Recovery Processes C. E. D. University of New Brunswick & Canada (Eds.),
- Rossen, W. R., & Boeije, C. (2013). Gas Injection Rate Needed for SAG Foam Processes to Overcome Gravity Override. Paper presented at the SPE Annual Technical Conference and Exhibition-166244-MS, New Orleans, Louisiana, USA.
- Ruidiaz, E., Winter, A., & Trevisan, O. (2018). Oil recovery and wettability alteration in carbonates due to carbonate water injection. *Journal of Petroleum Exploration and Production Technology*, 8(1), 249-258.
- Sahimi, M., Rasaei, M. R., & Haghghi, M. (2006). Gas injection and fingering in porous media *Gas Transport in Porous Media*. (pp. 133-168): Springer2006.
- Salehi, M. M., Safarzadeh, M. A., Sahraei, E., & Nejad, S. A. T. (2014). Comparison of oil removal in surfactant alternating gas with water alternating gas, water flooding and gas flooding in secondary oil recovery process. *Journal of Petroleum Science and Engineering*, 120, 86-93.
- Santidhananon, O. (2011). Evaluation of production performance of selective simultaneous water alternating gas (SSWAG) and gas assisted gravity drainage (GAGD) in steeply dipping reservoir. Msc Master thesis, Chulalongkorn University.
- Scheidegger, A. (1958). *The physics of flow through porous media*: University Of Toronto Press: London.
- Schutjens, P., Hanssen, T., Hettema, M., Merour, J., De Bree, P., Coremans, J., & Helliesen, G. (2004). Compaction-induced porosity/permeability reduction in sandstone reservoirs: data and model for elasticity-dominated deformation. SPE

Reservoir Evaluation & Engineering, 7(03), 202-216.

- Shahrekordi, A. P. (2014). Simulation Study of Hot Gas Injection in GAGD Process in a Fractured Medium Oil Reservoir. *IJPGE* 2 (3): 230-238, 2014.
- Shahverdi, H. (2012). Characterization of three-phase flow and WAG injection in oil reservoirs. Heriot-Watt University.
- Shetty, S. (2011). Evaluation of Simultaneous Water and Gas Injection Using CO₂. Master thesis, B. E. Visvesvaraya Technological University, India.
- SinoAustraliaOil&GasPtylimited. (2013). An Introduction to Enhanced Oil Recovery Techniques. www.sinoaustoil.com/. Sino Australia Oil & Gas Pty Limited, retrieved 26/02/2014.
- Siregar, S., Hidayaturobbi, A., Wijaya, B., Listiani, S., Adiningrum, T., Irwan, I., & Pratomo, A. (2007). Laboratory experiments on enhanced oil recovery with nitrogen injection. *Journal of Engineering and Technological Sciences*, 39(1), 20-27.
- Skauge, A., & Sorbie, K. (2014). Status of fluid flow mechanisms for miscible and immiscible WAG. Paper presented at the SPE EOR Conference at Oil and Gas West Asia.
- Slack, W. W., & Ehrlich, R. (1981). Immiscible displacement of oil by simultaneous injection of water and nitrogen. Paper presented at the SPE/DOE Enhanced Oil Recovery Symposium SPE 9807, Tulsa, Oklahoma.
- Sohrabi, M., Fatemi, S., Farzaneh, S., Jami, M., Ireland, S., & Ahmed, K. (2012). Performance of SWAG injection versus alternating and continuous injection of water and gas in low gas-oil IFT and mixed-wet system. Paper presented at the International Symposium of the Society of Core Analysts SCA2012-17, Aberdeen, Scotland, UK.
- Sohrabi, M., Tehrani, D., & Al-Abri, M. (2007). Performance of near-miscible gas and swag injection in a mixed-wet core. Paper presented at the Proceedings of the International Symposium of the Society of Core Analysts, Calgary SCA2007-26, Calgary, Canada,.
- Sørbel, J. (2015). Water Alternating Gas in Stratified Reservoirs-A Sensitivity Study of WAG Parameters. NTNU.
- Stoisits, R., Krist, G., Ma, T., Rugen, J., Kolpak, M., & Payne, R. (1995). Simultaneous water and gas injection pilot at the Kuparuk River Field, surface line impact. Paper presented at the Society of Petroleum Engineers. Annual technical conference SPE-30645-MS, Dallas, Texas.

- Surguchev, L., Korbol, R., Haugen, S., & Krakstad, O. (1992). Screening of WAG injection strategies for heterogeneous reservoirs. Paper presented at the European Petroleum Conference SPE 25075, Cannes. France.
- Syed, F. I., Tunio, A. H., & Ghirano, N. A. (2011). Compositional Analysis and Screening for Enhanced Oil Recovery Processes in Different Reservoir and Operating Conditions. *International Journal of Applied*, 1(4).
- Taber, J., Martin, F., & Seright, R. (1997). EOR screening criteria revisited-Part 1: Introduction to screening criteria and enhanced recovery field projects. *SPE Reservoir Engineering*, 12(03), 189-198.
- Terry, R. E. (2000). Enhanced oil recovery. In R. A. Meyers (Ed.), *Encyclopedia of physical science and technology* (Vol. 18, pp. 503-518).
- Terry, R. E., Rogers, J. B., & Craft, B. C. (2015). *Applied petroleum reservoir engineering*: Pearson Education.
- Thomas, S. (2008). Enhanced oil recovery-an overview. *Oil & Gas Science and Technology-Revue de l'IFP*, 63(1), 9-19.
- Touray, S. (2013). Effect of water alternating gas injection on ultimate oil recovery. Master thesis, Dalhousie University, Halifax, Nova Scotia.
- Tunio, A. H. (2008). To investigate the use of air injection to improve oil recovery from light oil reservoir. PhD thesis, Mehran University of Engineering & Technology, Jamshoro, Mehran, Iran.
- Tunio, S. Q., Chandio, T. A., & Memon, M. K. (2012). Comparative study of FAWAG and SWAG as an effective EOR technique for a Malaysian field. *Research Journal of Applied Sciences, Engineering and Technology*, 4(6): 645-648, 2012.
- 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 No. 5.
- UsDepartmentofEnergy. (2017). *Carbon Dioxide Enhanced Oil Recovery*: US Department of Energy.
- Walker, J., & Turner, J. (1968). Performance of Seeligson zone 20B-07 enriched-gas-drive project. *Journal of petroleum technology*, 20(04), 369-373.
- Wang, S. (2014). Measurement of Relative Permeabilities at Low Saturation using a Multi-step Drainage Process. University of Calgary.

- Watt, K. (2012). EORI conference alternative gas injection processes. Paper presented at the the linde group.
- Wei, H., Yue, X., Zhao, Y., Li, L., & Jia, D. (2013). The injection pattern of immiscible nitrogen displacement after water flooding in an ultra-low permeability reservoir. *Petroleum Science and Technology*, 31(21), 2304-2310.
- Wu, X., Ogbe, D., Zhu, T., & Khataniar, S. (2004). Critical design factors and evaluation of recovery performance of miscible displacement and WAG process. Paper presented at the Canadian International Petroleum Conference, PAPER 2004-192, Calgary, Alberta, Canada.
- Yang, Z., & Urdaneta, A. (2017). A Practical Approach to History Matching Premature Water Breakthrough in Waterflood Reservoir Simulation: Method and Case Studies in South Belridge Diatomite Waterflood. *SPE Reservoir Evaluation & Engineering*, 20(03), 726-737.
- Yu, G. (2015). Analytical and Simulation Study of Sweep Efficiency in Gas-Injection EOR.
- Zahoor, M., Derahman, M., & Yunan, M. (2011). Wag process design—an updated review. *Brazilian Journal of Petroleum and Gas*, 5(2), 109-121.
- Zandkarimi, G., & , G. (2016). Simulation of Water and Gas Injection in an Oil Reservoir Intermittently. *Geosciences*, 6(1), 21-28.