EXPERIMENTAL PERFORMANCE OF SELECTIVE SIMULTANEOUS WATER ALTERNATING NITROGEN (SSWAG-N_2) TECHNIQUE FOR OIL RECOVERY IN SANDSTONE AND CARBONATE

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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-N_2) (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 menangguhkan masa keterobosan air dan gas. Objektif utama kajian ini adalah untuk menyiasat kebolehperolehan minyak dari batuan pasir dan batuan karbonat dan menyiasat pengaruh keterobosan Air dan Gas pada Faktor Perolehan Minyak (ORF). Kajian ini juga menyiasat kebolehperolehan minyak dalam kaedah Perolehan Peningkatan Minyak konvensional seperti peroses-peroses 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 perolehan 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 menangguhkan 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 perolehan minyak diperolehi dengan menggunakan teknik SSWAG-N2 yang diubah suai. Dalam batuan pasir, perolehan 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 perolehan 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 Perolehan Minyak (ORF,%) di antara batuan pasir dan batuan karbonat adalah hampir. Ini menambahkan lagi kebolehpercayaan 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 perolehan yang paling rendah dicapai apabila menggunakan tekanan suntikan 1500 psi

ABSTRACT

Although there were techniques such as Water Alternating Gas-Nitrogen (WAG-N_2) 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-N_2) 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-N_2 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-N_2. 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 N_2 with brine using EOR injecting modes in sandstone and carbonate sand packs, was obtained when applying modified SSWAG-N_2. In sandstone, the recoveries of the modified SSWAGN_2 and conventional SSWAGN_2, 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
K	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

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