ABSTRAK

OPTIMISASI *WELL SPACING* DAN SKENARIO *CO_2 HUFF-N-PUFF INJECTION* MENGGUNAKAN *PARTICLE SWARM OPTIMIZATION* PADA *SHALE OIL UNCONVENTIONAL RESERVOIR*

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Permeabilitas matriks yang sangat rendah pada reservoir *shale oil* non-konvensional menyebabkan perolehan primer hanya menguras 3-7% dari *Original Oil In Place* (OOIP), sehingga injeksi CO_2 siklik (*Huff-n-Puff*) menjadi solusi EOR yang menjanjikan. Namun, efektivitasnya sangat bergantung pada kombinasi optimal antara *well spacing*, parameter operasional injeksi, dinamika geomekanika, dan difusi molekuler CO_2 ke dalam matriks batuan ketat yang sulit untuk dilakukan secara efisien menggunakan metode konvensional.

Penelitian ini membangun model konseptual tiga dimensi reservoir *shale oil* Eagle Ford menggunakan simulator komposisional tNavigator dengan tiga sumur horizontal berlengkap *multi-stage hydraulic fracturing*. Analisis sensitivitas *Tornado Chart* digunakan untuk mengidentifikasi parameter paling berpengaruh, dilanjutkan optimasi menggunakan algoritma *Particle Swarm Optimization* (PSO) berfungsi objektif ganda. Geomekanika dan difusi molekuler dievaluasi melalui distribusi *Effective Stress Tensor* (σ_{XX}) dan *Oil Molar Fraction* CO_2 menggunakan Korelasi Sigmund.

Hasil penelitian membuktikan bahwa laju injeksi CO_2 dan *well spacing* merupakan parameter paling dominan terhadap perolehan minyak. PSO berhasil mengidentifikasi kombinasi parameter optimal yang meningkatkan *Recovery Factor* secara signifikan hingga 14% dengan efisiensi CO_2 yang lebih baik dibandingkan kondisi tanpa optimasi. *Well spacing* optimal terbukti meminimalkan interferensi tekanan antar sumur sehingga menghasilkan kondisi matriks yang lebih kondusif untuk difusi CO_2 yang merata. Analisis geomekanika membuktikan bahwa CO_2 *Huff-n-Puff* bekerja sebagai *stress cycling mechanism* yang periodik memulihkan konduktivitas rekahan, sementara fase *soaking* terbukti sebagai tahap paling kritis yang menentukan penetrasi dan redistribusi CO_2 dari rekahan ke matriks.

Kata kunci: Difusi Molekuler, *Huff-n-Puff* CO_2, *Particle Swarm Optimization*, *Stress Redistribution*, *Well Spacing*

ABSTRACT

OPTIMIZATION OF WELL SPACING AND CO_2 HUFF-N-PUFF INJECTION SCENARIO USING PARTICLE SWARM OPTIMIZATION IN SHALE OIL UNCONVENTIONAL RESERVOIR

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The ultra-low matrix permeability of unconventional shale oil reservoirs limits primary recovery of only 3-8% of the Original Oil In Place (OOIP), making cyclic CO_2 injection (Huff-n-Puff) a promising EOR solution. However, its effectiveness is highly dependent on the optimal combination of well spacing, injection operational parameters, geomechanical dynamics, and CO_2 molecular diffusion into the tight rock matrix, a combination that is difficult to achieve efficiently using conventional methods.

This study constructed a three-dimensional conceptual model of an Eagle Ford shale oil reservoir using the tNavigator compositional simulator with three horizontal wells equipped with multi-stage hydraulic fracturing. Tornado Chart sensitivity analysis was employed to identify the most influential parameters, followed by optimization using a dual-objective Particle Swarm Optimization (PSO) algorithm. Geomechanical and molecular diffusion analyses were evaluated through the Effective Stress Tensor (σ_{XX}) distribution and Oil Molar Fraction CO_2 using the Sigmund Correlation.

Results demonstrate that CO_2 injection rate and well spacing are the most dominant parameters governing oil recovery. PSO successfully identified an optimal parameter combination that significantly increased the Recovery Factor up to 14% with better CO_2 efficiency compared to the unoptimized scenario. The optimal well spacing minimized inter-well pressure interference, producing a more conducive matrix condition for uniform CO_2 diffusion. Geomechanical analysis confirmed that CO_2 Huff-n-Puff operates as a stress cycling mechanism that periodically restores impaired fracture conductivity, while the soaking phase was proven to be the most critical stage determining CO_2 penetration and redistribution from fractures into the matrix.

Keywords: CO_2 Huff-n-Puff, Molecular Diffusion, Particle Swarm Optimization, Stress Redistribution, Well Spacing