Characterization and Modeling of Naturally Fractured Tensleep Reservoirs

Shaochang Wo, Peigui Yin, Scott Cooper, John Lorenz
Outline

• A Brief Overview of the Tensleep Reservoirs in Wyoming
• Previous Studies and Modeling Works
• Why Dual Porosity/Permeability Models Are Needed for Tensleep Reservoirs
• Key Technical Issues
• Objective and Approach
Characters of Tensleep Reservoirs

- Thick total pay interval of eolian sandstones (up to ~300 ft)
- Often with pervasive natural fracture systems
- Local compartments caused by dolomite beds and interbedded dolomite and anhydrite cementation
- Strong edge or bottom water driven
- Large range of oil API gravities
- Various wettability depending on reservoir oil and rock properties
- Decades of production history (> 40 years)
A natural fracture face that is partially mineralized with crystalline dolomite. The estimated \textit{in situ} total fracture width is one millimeter, with 40\% estimated remnant void space irregularly distributed along the fracture plane.
EOR Potential in Tensleep Reservoirs

• Tensleep is the largest oil producing formation in Wyoming; cumulative production $>1.6$ billion BO ($\sim 23\%$ of the total oil produced in Wyoming); $5.6$ million BO produced in 2010 with $98\%$ water cut.

• Estimated remaining oil above O/W contact (assuming $30\%$ to $40\%$ oil recovery): $2.4$ to $3.7$ Billion BO.

• More than $4$ billion BO may exist in the residual oil zones (ROZ) of Tensleep reservoirs.

• A large volume of the remaining oil ($>1$ billion BO) could be recovered by using available EOR techniques, such as CO2 flooding.
Previous Studies and Modeling Works On Tensleep Formation

• Reservoir Matrix Heterogeneity – *Peigui Yin*
  – Diagenetic analysis
  – Sedimentary texture
  – Compartmentalization
  – Log-core correlation of Tensleep sandstone facies at Teapot Dome, Mahoney Dome, Hatfield, East Salt Creek
  – 18 outcrops; 32 cores; 866 thin sections
• Fracture Characterization – *Scott Cooper & John Lorenz*
  
  – Literature search
  
  – Outcrop study
    • Zeisman Dome, Sheep Mountain Anticline, Flat Top Anticline, Alcova Recon, Sand Creek/Casper sandstone, Beer Mug Anticline
  
  – Subsurface study
    • Oregon Basin, Byron field, Little Buffalo Basin, South Casper Creek field, Circle Ridge field, Mahoney Dome, Hatfield, Teapot Dome
Is this a Fractured Reservoir?

10’ and 15’ average spacing

95 out of 100 cores will not contain a fracture

88 out of 100 wellbore image logs will not contain a fracture

From Cooper, 2010, SPE/AAPG Vail
Probability of a Vertical Fracture intersecting a Vertical Wellbore or Core

From Lorenz, 1992, WTGS Bull
• Modeling and Simulation – *Shaochang Wo & Michael Presho*

  – Development of a conceptual model for matrix-fracture system
  – Eclipse sector models of Mahoney Dome, Hatfield, East Salt Creek, Teapot Dome
  – Simulation of tracer transport in fractured reservoir
  – Simulation of the effect of deformation bands (cemented fracture clusters) on reservoir flow
Why Dual Porosity/Permeability Models Are Needed for Tensleep Reservoirs

- Single porosity model (SPM) is unable to accommodate the difference of multi-phase flow in matrix and fracture.
- Difficult for SPM to match the early breakthrough of aquifer water influx via fracture systems
- SPM is unable to simulate Imbibition-dominated matrix-fracture fluid transfer.
Relative Permeabilities of Matrix and Fracture

![Graph showing relative permeabilities](image)
Saturation Functions of Matrix and Fracture

Water Viscosity: $\mu_w = 0.6$ cp
Oil Viscosity: $\mu_o = 2$ cp

$F_{w_{matrix}}$ vs $S_w$ (Fractional Flow of Water vs Water Saturation, $S_w$)

$F_{w_{fracture}}$ vs $S_w$ (Fractional Flow of Water vs Water Saturation, $S_w$)
Dimensionless permeability distributions of matrix and fracture in a 2D case.
Case example with $\phi_m=17\%$ and $\phi_f=2\%$, Simulated by Michael Presho
The effect of fracture porosity on tracer breakthrough

*Simulated by Michael Presho*
Fluid Transfer between Matrix and Fracture

Transfer Functions in Dual Porosity/Permeability Models

-Single phase flow (Warren & Root):
\[ \tau = \sigma \frac{k_m}{\mu} (p_f - p_m) \]

-Oil-Water 2-phase flow with gravity effect (Kazemi & Gilman):
\[ \tau_w = \sigma \frac{k_m k_{rw}}{\mu_w} \left\{ (p_f - p_m) + \left( \frac{\sigma_z}{\sigma} \right) \gamma_w (h_{wf} - h_{wm}) \right\} \]

However, for Tensleep reservoirs, matrix-fracture fluid transfer is often dominated by imbibition. Away from wellbore, simulated pressure difference between \( P_f \) and \( P_w \) is usually insignificant.
Key Technical Issues

• Quantified (statistical) description of fracture spacing, trace length, width, and open aperture based on observed outcrop and core data
• Mapping of storage and conductive fractures
• Regional correlations of rock facies with reservoir flow units
• How to effectively incorporate an imbibition model into the transfer function
• Limited data for many small Tensleep reservoirs
Objective and Approach

• A key objective is to develop a methodology (work flow) that integrates the wealth of Tensleep log, core, and outcrop data to reservoir production history for a better prediction of the distribution of bypassed oil.

• Two-map approach to estimate apparent and conductive fracture distributions. Mapping apparent fracture intensity from log, core, outcrop and seismic measurements. Mapping conductive fracture networks from production-injection correlations, pressure tests and tracer tests.

• Distinguishing conductive fractures from storage fractures in the dual porosity/permeability model setting. Fracture porosity and permeability as well as other model parameters will be further tuned during history matching.

• Working with Wyoming producers to select representative Tensleep reservoirs, as case studies, to demonstrate and validate the proposed approach.
Thank You!