Consideration of Breakdown Pressures in Directional Wells

Based on SPE 173356

Robert D. Barree and Jennifer L. Miskimins
Introduction

- Purpose for this paper: Something that bothers us
  1. We design for transverse fractures to cover a large drainage area
  2. The fractures have to start at a cylindrical horizontal borehole
  3. How does (2) fit in with (1)?
- Basic Kirsch (1898) equations
- Modified Kirsch equations – well deviation and azimuth
- Breakdown conditions for various reservoir states
- Effects of laminations on horizontal well breakdown
- Impacts on diversion and completion design
Transverse Fractures with Interference

Do they act like this? Why should they initiate normal to the well?
Cylinders under internal pressure seem to fail along their axis. How do we get transverse fractures?
The Kirsch Equations (1898): Stresses Around a Borehole

\[
\sigma_r = \frac{\sigma_h + \sigma_H}{2} \left( 1 - \frac{r_w^2}{r^2} \right) + \frac{\sigma_h - \sigma_H}{2} \left( 1 - 4 \frac{r_w^2}{r^2} + 3 \frac{r_w^4}{r^4} \right) \cos 2\theta + \frac{r_w^2}{r^2} \left( P_w - \alpha P_o \right)
\]

\[
\sigma_t = \frac{\sigma_h + \sigma_H}{2} \left( 1 + \frac{r_w^2}{r^2} \right) - \frac{\sigma_h - \sigma_H}{2} \left( 1 + 3 \frac{r_w^4}{r^4} \right) \cos 2\theta - \frac{r_w^2}{r^2} \left( P_w - \alpha P_o \right)
\]

\[
\sigma_v = P_{ob} - \alpha P_o
\]

- \( P_o \) = far field pore pressure
- \( P_w \) = wellbore fluid pressure
- \( P_{ob} \) = overburden pressure
- \( r \) = distance from wellbore
- \( \sigma_H \) = maximum horizontal stress
- \( \sigma_h \) = minimum horizontal stress
- \( \theta \) = angle from direction of minimum stress
Deviated Wellbore Breakdown Calculations

Well Deviation

Well Azimuth

$D_{LV}$

$\alpha$

$\sigma_H$

$\beta$
Deviated Wellbore Breakdown Calculations

Transformed x-direction stress ($S_x$): $S_x = \sigma_H \sin(\beta)^2 + \sigma_h \cos(\beta)^2$
Transformed y-direction stress ($S_y$): $S_y = \cos(\alpha)^2 (\sigma_H \cos(\beta)^2 + \sigma_h \sin(\beta)^2) + \sigma_v \sin(\alpha)^2$
Transformed z-direction stress ($S_z$): $S_z = \sin(\alpha)^2 (\sigma_H \cos(\beta)^2 + \sigma_h \sin(\beta)^2) + \sigma_v \cos(\alpha)^2$
Shear stress in x-y plane ($S_{xy}$): $S_{xy} = \cos(\alpha) \sin(\beta) \cos(\beta) (\sigma_H - \sigma_h)$
Shear Stress in y-z plane ($S_{yz}$): $S_{yz} = \sin(\alpha) \cos(\alpha) (\sigma_v - \sigma_H \cos(\beta)^2 - \sigma_h \sin(\beta)^2)$
Shear Stress in z-x plane ($S_{zx}$): $S_{zx} = \sin(\alpha) \sin(\beta) \cos(\beta) (\sigma_h - \sigma_H)$

Radial well stress ($\sigma_r$): $\sigma_r = P_w - P_o$
Tangential well stress ($\sigma_t$): $\sigma_t = S_x + S_y - 2(S_x - S_y) \cos(2\lambda) - 4S_{xy} \sin(2\lambda) - \sigma_r$
Axial well stress ($\sigma_z$): $\sigma_z = S_z - 2v ((S_x - S_y) \cos(2\lambda) + 2S_{xy} \sin(2\lambda))$
Possible Breakdown Conditions

- Internal pressure exceeds minimum tangential stress plus rock strength
  - Longitudinal fracture
- Fluid pressure invades pore space or existing crack and exceeds axial stress
  - Transverse fracture
- Internal pressure stretches borehole and may induce failure along bedding planes
  - Possible horizontal fracture
Stress-Pressure Balance in the Fracture

Net fracture extension pressure (above minimum closure stress) is the sum of:
- Resistance to fracture extension
- Friction $\Delta P$ in fracture
- Entry tortuosity $\Delta P$
- Poroelastic effects

Fluid pressure is greatest at the fracture entrance (sandface of borehole).

If this pressure exceeds the maximum horizontal stress then vertical fractures can open at any azimuth. Tangential stress around the borehole practically guarantees a longitudinal fracture.
Stress Varies Around the Hole

- Tangential or hoop stress changes significantly around the circumference of the borehole.
- Breakdown occurs when well pressure exceeds minimum tangential stress by the rock tensile strength.
- The following slides show required breakdown pressure and position of the minimum stress.
Deviation/Azimuth Impacts on Breakdown

- Well depth = 10,000 ft; well azimuth 90° - 270°
- Pore pressure variations
  - PR = 0.35, differential = 1500 psi
  - 0.3 psi/ft, 0.5 psi/ft, 0.7 psi/ft, and 0.9 psi/ft
- Low pore pressure:
  - Generally expect low frac pressure
  - But, low pore pressure adds load to the net or framework stress
- High pore pressure:
  - Breakdown must exceed pore pressure, so higher treating pressures expected
  - Decreases net stress and makes rock more susceptible to shear failure
Pore Pressure Examples

Max Stress or Fracture Direction

0.3 psi/ft

0.5 psi/ft
Deviation/Azimuth Impacts on Breakdown

• Well depth = 10,000 ft; well azimuth 90° - 270°
• Poisson’s ratio
  • Pore pressure = 5000 psi, differential = 1500 psi
  • 0.15, 0.25, 0.35, and 0.48
• Low Poisson’s Ratio:
  • Low horizontal stress and breakdown pressure
• High Poisson’s Ratio:
  • High stress and breakdown pressures
  • May tend to make all stresses more equal
  • Can lead to horizontal fracture initiation
Poisson’s Ratio Examples

Max Stress or Fracture Direction

0.15

0.25

---
Poisson’s Ratio Examples

Max Stress or Fracture Direction

0.35

0.48

---
Deviation/Azimuth Impacts on Breakdown

- Well depth = 10,000 ft; well azimuth 90° - 270°
- **Horizontal stress differentials**
  - PR = 0.30, pore pressure = 6000 psi
  - 500 psi, 1000 psi, 1500 psi, and 2000 psi
- Low stress differential:
  - Expect more fracture “complexity”
  - If breakdown or net extension pressure exceeds the stress differential then longitudinal fractures are inescapable
- High stress differential:
  - Strong directional control of planar fractures
  - Can increase breakdown pressure to more than overburden
Implications of Tangential Stress Variation

- Extreme case; 0.92 psi/ft pore pressure and 2,000 psi stress differential
- TVD = 13,475 feet

Breakdown Pressures

Top: 20,560 psi
Sides: 19,390 psi

Top: 17,180 psi
Sides: 19,060 psi
**Effects of Rock Fabric:** Isotropic and homogeneous vs. laminated systems

- Fracture initiation occurs as predicted, based on tangential stress, in isotropic and homogeneous media.
- Laminations and planes of weakness parallel to the borehole can overcome stress concentration.
Implications on Treatment Design and Analysis

- Perforation orientation
  - Perforations at many angles will not break down
  - Perforations in high stress arc may collapse on drawdown
- Tortuosity
  - Increases treating pressures and screenout risk
  - May overcome stress differential and enable longitudinal fractures
  - Extended wellbore decompression obscures ISIP in DFIT analysis
  - Near-wellbore conductivity reduced by pinch points
- Longitudinal fracture initiation and propagation
  - Longitudinal fracture may connect multiple perforation clusters
  - Pressure drop through perfs is ineffective for limited-entry design
- Impact on openhole packer diversion
  - Packer element decreases tangential stress
  - Longitudinal fractures may bypass packers
Complexity Around Perforations

- Longitudinal fracture initiation
- No breakdown of perf tunnel
- Slurry flow through cement-formation annulus
Nearly 1500 psi excess pressure drop from tortuosity. Decompression of wellbore fluid takes several minutes to bleed off through restriction.

Actual extension pressure in fracture (Correct ISIP)
Transverse and Longitudinal Fracture Interaction

- High tortuosity can cause pressure on sand-face to exceed tangential stress and maximum horizontal stress
- Fluid exiting each perforation set feeds the longitudinal fracture which supplies all transverse fractures with minimal resistance
- Transverse fractures interfere with each other
Longitudinal Fracture Initiation

- High tracer concentration around packer may indicate a low stress point
- Tracer along entire well suggests an extensive longitudinal fracture
- Once this fracture starts, subsequent stages communicate and packer isolation fails
Conclusions

• Both tangential stress and rock fabric control borehole breakdown
  – Rock fabric, laminations, and planes of weakness are too often ignored

• Combinations of reservoir pressure, stress differential, rock properties, and well orientation can make breakdown at safe operating pressures impossible
Conclusions

- Tangential stress variation should be considered in perforation phasing and orientation
- When net pressure or entry friction exceeds the horizontal stress difference longitudinal fractures are likely
- Longitudinal fractures impact completion designs and execution
  - Perforation cluster spacing and diversion
  - Packer isolation effectiveness
  - Tortuosity and screenout potential
Thank You / Questions