Why Do HP and HT Completions Require Rigorous Engineering Design?

SPE Distinguished Lecturer Series

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Presentation Topics

- Introduction
- Completion Design Considerations
- Stresses and Loads
- Downhole Equipment
- Other Operations
- Conclusions

Definitions

High Temperature (HT)

- Industry HT Norm
- 300 F (149 C)
- 250 F (121 C)

High Pressure (HP)

- Industry HP Norm
- 10K psi (69 MPa)
Why Are Details More Important?

- Rule of Thumb Assumptions
- Significant Temperature Variations
- Pressure Integrity
- Equipment Availability
- Potential Loss Impact

Completion Design Considerations

- Tubular Design
  - Metallurgy, Stress, Connections
- Downhole Equipment
- Completion Fluids
- Perforating
- Stimulation
- Contingency Planning
Materials Issues

- Temperature Deration
- H₂S and CO₂
- Tensile Ratings
- Metallurgy

Casing Considerations

- Design Stress Analysis
  - Production load cases
- Temperature Deration
- Primary Cement
  - Cement top, Fluid gaps
- Drilling Wear
- Pressure Testing
- Final Selection
  - Internal Diameter, Material, Connection
Tubing Forces & Loads

- Types of Loads
- Triaxial Stress (Von Mises)
- Significant Load Changes

Predicting Stresses & Loads
- Temperature and Pressure
- Extreme and Common Operating Conditions
- Potential Failure Impact Determination

Limitations of Vendor Determinations

- Static Conditions
- Average Conditions
- NO temperature prediction
- NO material deration (Temperature)
- DO NOT Consider Triaxial Stresses
- NO equivalent tubing Bending force

Applies to MOST Packer Vendors for HT/HP
Predicting Stresses & Loads

Design Factors

Applied, Induced, Shock, Cyclical LOADS
Bending, Triaxial Effects, Corrosion, Connection Make Up
Mill Defects, Damage, Estimations Errors

Nature of API Tubular Ratings
Design Safety Factors
Assumed Loading Conditions

Loading Conditions

Stress Analysis Sequence

1. Define Operating Loads
2. Packer Selection
3. Define Maximum Seal Movement
4. Tubing Grade/Weight Selection
5. Dynamic Temperature Simulations
6. Dynamic Tubing Stress Simulations
7. Check Design
8. Sensitivities
Defining Load Cases (1)

Reference Condition
Frequent Loads

Production Rates
FWHP
FHWT

Shut In
High SIWHP

Defining Load Cases (2)

Infrequent Loads

Pressure Tests
Pressure

Kill/Stimulation
Injection Rates
WHIP
WHIT

Evacuation
Empty Tubing
WHP=0

Hot Tubing Leak
Max WHP---Both Sides
Gas
Annulus Fluid

Subsequent Loads
• Tubing/Packer/Seal Assembly Removal, Drag
Temperature Simulation (1)

Fluid Temperature - Tubing/Workstring

- Dry Gas 40 MMscf/d
  - FWHT = 240°F
- Wet Gas 13 MMscf/d
  - FWHT = 315°F

Design Limit Plot (1)

Design Limits - 3 1/2" Production Tubing - Section 1 - OD 3.500 - Weight 15.80 - L1
Temperature Simulation (2)

Fluid Temperature - Tubing/Workstring

- Prod 10MM Dry
- Prod 10MM WGR 20b/MM
- Hot SI
- Cold SI
- Start Kill
- End Kill 2 BPM
- Undisturbed

Design Limit Plot (2)

Design Limits - 2 7/8" Production Tubing - Section 1 - OD: 2.875 - Weight: 8.70 - Grade L-80

- Burst 1.125
- Collapsed 1.125
- Tri-axial 1.250
- Tension 1.300

Note: Limits are approximate
Axial Loads (2)

Axial Loads - Prod 10MM WGR 20 b/MM - 2 7/8” Production Tubing

-125000
-100000
-75000
-50000
-25000
0
25000
50000
75000

Axial Load (lbf)

MD (ft)

Without bending
With bending

Tubing Bending (2)

Tubing Bending
73mm (2 7/8”) Tubing in 193.7mm (7 5/8”) Casing & 127mm (5”) Liner

DANGER AREA
for Connection Leakage
Separate Qualification Testing

Liner Top 2740 m
Liner Top 3550 m

Dogleg (deg/100 ft)

Depth (m)

Deep Liner Top
Shallower Liner Top
Premium Connections

- Standard API – NOT suitable
- Extreme Stresses & Forces
- Simultaneous Forces
- Compression Rating
- Qualification – Proprietary
- New Standard Test Methodology
  - ISO 13679

Quantitative Risk Analysis - QRA

- Probabilistic Design Procedures
- “State of the Art” Tubular Design
  - Reliability Technology
  - + Materials Testing
- Stochastic Techniques
- Design to suit the Application
Optimization of Cost and Reliability

- **Increasing Reliability**
  - **Increasing Cost**
  - **Failure**
  - **Design**

- **Under Designed** vs **Over Designed**

**QRA Technology**

- **Multiple Predictive Models**
- **Data**
- **Probabilistic Theories**

**Load vs Resistance**

**Risk Weighted Cost Analysis**
Packer Selection

- Operating Envelope
- Elastomers
- Corrosion - CRA
- Seal Movement
  - Prevent or Limit
- ISO 14310 Standard Testing Procedure

Packer Envelope

Packer/Anchor Operating Envelope

![Graph showing Packer/Anchor Operating Envelope with various pressures and forces]
Other Downhole Equipment

- **Keep simple**
- **Flow Control Nipples**
- **Minimize ANY moving parts**
- **SSSV**
  - Complexity – not always required
  - Qualified
- **Monobore**

Perforating

- **Exposure Time**
- **System Qualification**
  - Carriers, Charges, Primacord, Detonators, Boosters, Firing Heads
- **Simulate In Situ Performance**
- **TCP Applications**
- **Minimize Braided Line**
- **Consider Slickline**

![In Situ Gun Performance Chart](chart.png)
Perforating Problems

- High Temperature Fluids
  - Proppant fracturing - Rheology
  - Acid - Corrosion & Rock Reactivity
- Horsepower
- Proppants
- Tubing Integrity

Stimulation
Completion Fluids

- Clear Brine
  - Preferred
  - Non-Corrosive Packer Fluid

- High Density Brines
  - Bromides – corrosive, expensive, additional handling safety, reclaim
  - Formates – benign, most expensive, reclaim, non-damaging, stable gels

- Mud Displacement

Contingency Planning

- Complexity LEADS to Uncertainty
- Detailed Alternatives – mitigate risks
- Specialized Equipment & Personnel
- Examples
  - Well Unloading
  - Stimulation
  - Cleanout
  - Gun Failure
  - Wireline/Slickline/Packer Problems
  - Intervention – Coil Tubing, Snubbing
Subsequent Operations

- Annulus Pressure/Fluid Management
- Through Tubing Intervention
- Emergency Procedures
  - Downhole tubing/equipment failure

Annulus Fluid Corrosion

Reference:
Paper SPE/IADC 67779
February 2001
Completion Design Methodology

DETERMINE COMPLETION PHILOSOPHY
- Packer vs. Packerless
- Monobore vs. Restrictive Bore
- Performance Strategy
- Prepare Preliminary Tubing Design
  - Design Functional Specs
- SSV Issues (Risk Assessment)
- Completion Fluid Selection
- Perforation Strategy

SELECT VENDORS
- Qualified Equipment
- Understand What Equipment Still Needs to be Qualified
- Costs and Timing of Qualification
- QA/QC Procedures/Costs
- Overall Price
- Previous Experience/Relationship

PREPARE DETAILED OPERATIONS PROCEDURES
- Review with Vendors
- Plan for Contingencies (Proper Equipment, Availability)

TUBING
- Qualified Connection Available?
  - Yes
    - Order Pipe
  - No
    - Select Alternate Vendor or Qualify Connection
    - Quality Alternate Vendor or Connection

COMPLETION EQUIPMENT
- Does All Equipment Qualify for Well Conditions?
  - Yes
    - Finalize Tubing Stress Analysis
    - Ensure Equipment Still Suitable
  - No
    - Run Qualification Tests
    - Select Alternate Product or Vendor

Rigorous Engineering Design Process

1. Initial Well Planning
2. “State of the Art” Simulations
3. Materials Selection
4. Qualified Premium Connections
5. QRA Technology
6. Qualified Equipment Systems/Personnel
7. Consider contingencies
8. Consider ALL Subsequent Operations