Liquid Loading in Horizontal Wells

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Outline

- Flow in a Horizontal Gas Well
- Why Flow Matters?
- Similarities and Differences Between Pipe and Horizontal Well Flows
- Review of Multiphase Pipe Flow
- Multiphase Flow in Horizontal Wells
Flow in a Horizontal Gas Well

- **Single-phase Flow**
  - Dry Gas
    - Desired but Not Always Possible

- **Multiphase Flow**
  - Gas Flow with Frac-Liquid
    - Happens During Flow Back After Frac Operation in Gas Shales
  - Gas Flow with the Formation Water
    - Some Gas Shales Produce Water
    - Fracture May Extend to Water zones
    - Condensed Water
  - Gas Flow with Condensate Dropout
Fractured Horizontal Gas Well Sketch

Shale or tight sand

Water

gas
Heel-to-Toe velocity decreases along horizontal section
Why Flow Matters? …

• Early on Relatively High Gas Flow Rates and Velocities
• Later Gas Flow Rate and Velocities Decrease Significantly

• What Does This Mean for Water?
  – Can We Produce the Water Along With Gas?
  – What Happens If Gas cannot Efficiently Carry Water?
    • Liquid Loading
    • Reduction in Gas Flow Rate Due to Liquid Buildup
    • Liquid Flow Back or Diffusion in to the Formation
How can We Predict Loading?

- **First Attempt**
  - Use Techniques Developed for Vertical and Deviated Wells Such as Turner, Coleman, Etc.

- **Do They Work?**
  - Physics Used in Turner, Coleman, etc. Primarily are Based on Upward Movement of Liquid Droplets and Film
  - At Low Gas Velocities and Horizontal and Near Horizontal Configurations
    - Liquid Droplets and Annular Flow May not Exist

- **Not Expected to Work**
What Do We Do?

- Flow in Horizontal Wells Resembles the Flow in Pipelines
- There is Vast Amount of Know-How Already Developed and Available for Flows in Pipelines
- Opportunity to Tap into This Know-How and Develop Suitable Loading Prediction Tools
- Need to Assess the Compatibility Between Horizontal Well and Pipeline Flows
Similarities and Differences Between Horizontal Well and Pipeline Flows

• Similarities
  – Simultaneous Flow of Gas and Liquid
  – Undulating Geometry

• Differences
  – Pipelines Have Single Source While Horizontal Wells Have Multiple Source (Open Hole, Perforations, Fractures)
    • Varying Flow Rates Along Horizontal Well
  – Horizontal Wells are Considerably Shorter
  – Flow in Horizontal Wells May not Be Fully Developed
Review of Pipeline Flow

• Show and Tell
  – Relatively High Flow Rates
    • Low Liquid Loading Flow in a Horizontal Pipe (6 in. ID Pipe)
  – Relatively Low Flow Rates
    • Two-phase Flow at a Dip (3 in. ID Pipe)
  – Severe Slugging for a Pipeline-Riser System (May Resemble Up-dip Horizontal Well Configuration)
    • Two-phase Severe Slugging in a 3 in. ID Pipe
High Flow Rates

- High Flow Rates
  - Horizontal and Downward Inclined
    - Stratified Smooth and Wavy Flows
    - Annular Flow
  - Upward Inclined
    - Intermittent Flow in Addition to Above Flow Patterns
Stratified Smooth

**Side View**

**Axial View**

Gas $v_{SG} = 16$ ft/sec

Water $v_{SL} = 0.016$ ft/sec
Stratified Wavy

Side View

Axial View

Gas \quad v_{SG} = 32 \text{ ft/sec}
Water \quad v_{SL} = 0.032 \text{ ft/sec}
Stratified Wavy with Entrainment

Side View

Gas $v_{SG} = 57.5$ ft/sec
Water $v_{SL} = 0.12$ ft/sec
Low Flow Rates

- Hilly-Terrain Pipe Flow (Flow in a Dip)
  - Video Clip-1 (No Liquid Input at Inlet)
  - Video Clip-2 (Liquid Input at Inlet)
• **Toe-up Configuration (Severe Slugging Phenomenon)**

- Slug
- Slug Production
- Blowout
- Liquid Fallback
Low Flow Rates …

• Severe Slugging Video
Multiphase Flow Predictive Tools

- All Purpose Predictive Tools Not Capable of Predicting Complex Flow Behavior Accurately
  - TUFFP Studied Extensively Low Liquid Loading, Hilly Terrain Pipeline Flow, and Severe Slugging
  - Developed Predictive Tools
Multiphase Flow in Horizontal Wells

- No Reliable Predictive Tools
- Pipeline Flow Prediction Tools cannot be readily applied since the flow rates in horizontal wells are significantly low and physics of the flow is significantly different as evidenced from videos.
- There is a need to further studies to develop liquid loading prediction tools for horizontal wells.
Conclusions

• Existing Conventional Liquid Loading Prediction Tools are not Applicable for Horizontal Wells
• No Available Predictive Method for Liquid Loading in Horizontal Gas Wells
• Similarities and Differences Between Pipeline and Horizontal Well Flows Are Demonstrated
• Knowhow Developed for Pipeline Flow can Be Used in the Understanding of Liquid Loading in Horizontal Gas Wells
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