2013-2014 Master in Petroleum Engineering and Operations

Well Unloading Technologies and Selection Criteria

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Stage Subject
Well Unloading Technologies and Selection Criteria

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- Project Scope
  - Theoretical concepts
  - Well Unloading Technologies description
  - Well Unloading Selection Criteria
  - Conclusions
Project Scope

- Technical Motivation
  Manage the liquid accumulation (water and/or condensate) in order to ensure the gas production

- Current technology status
  Industry is using different methods in order to mitigate the liquid loading effects (i.e. foamer, velocity string, wellhead compressor, plunger)

- Main activities for the scope
  - Physical mechanisms literature review
  - Technologies evaluation and comparison
  - Selection guidelines

- Industrial Impact and Expected Benefits
  Ensure the gas production and extend the life of wells affected by liquid accumulation
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Theoretical concepts
What is liquid loading

A well is suffering from liquid loading when its gas production rate has fallen sharply off its intended decline curve and remains there due to the accumulation of water or condensate at bottom of the wellbore.

**Drawbacks**

- Early well abandonment
- Production decrease
- Revenue falling
- Cost rising
- Unexpected mechanical stress (slug flow)
- Corrosion

ITALY TOTAL RECOVERED PRODUCTION ~ 500 kSm$^3$/day (3.2 kboed, 100 k€/d)
Theoretical concepts
Identification of liquid loading

Water sources
- Associated Water
- Water Produced from Another Zone
- Aquifer water
- Casing leak
- Water coning

Condensate sources
- Retrograde condensation

How to identify liquid loading

Theoretical models
- Critical velocity
- Well performance analysis

Monitoring actions
- Production parameters analysis
- Well history review

Diagnostic actions
- P/T surveys
- Surface / Downhole sampling
- Other investigations (i.e. Logs)
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Gas wells Unloading techniques Worldwide

- Intermittent production
  - Cycles of re-pressurizations
- Gas lift
  - Reducing liquid density
- Foamer Applications
  - Reducing surface tension between gas & liquid, and also the liquid density
- Velocity String
  - Increasing gas velocity by reducing the tubing flowing section
- Wellhead Compression
  - Increasing gas velocity by reducing wellhead pressure
- Plunger lift
- Downhole pumps (rod, PCP, ESP)
  - Artificially Liquid Lifting
Well Unloading Technologies description
Foamer applications

Foam preferentially adsorbs at the interface, lowering the surface tension between fluids (liquid and gas) and liquid density.

$$V_g = 1.92 \frac{\sigma^{1/4}(\rho_L - \rho_g)^{1/4}}{\rho_g^{1/2}}$$

**Turner equation**

**PROS**
- Cheap to apply
- Tolerance of particulates
- Versatile for different completions and environments

**CONS**
- Surfactant used may cause emulsion problems
- Wells with higher condensate may not foam well.

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Foamer selection

- Fluid compositions
  - WCR
  - Specific gravity

- Reservoir conditions (P&T)

- Lab tests
  - Reactivity (height of foam)
  - Foam Stability (Half-time)
  - Compatibility with fluids
  - Compatibility with treating equipment
  - Foam breaker (Defoamer selection)

Injection treatments

- Dropping soap sticks down the tubing
- Batch treatments
- Continuous Injection via Capillary String
- Continuous Injection via Production annulus
- Combined treatments

Batch injection

Capillary injection
Velocity string can be defined as the installation of a wellbore tubular (usually from 1” to 3-1/2” in diameter) to modify the hydraulic characterization of an existing completion tubing.

Evaluation of the best tubing size by Well Performance Analysis in order to:

- Maximize velocity ($v > v_T$)
- Minimize pressure losses

**PROS**
- Higher velocities for a given rate
- Medium-long term solution
- Good in tight gas reservoir

**CONS**
- Requires special tools
- High costs
- Further loading will be more severe than original
Well Unloading Technologies description
Wellhead Compressor

Used to lower the wellhead pressure to increase gas velocity, even lower than flowline back pressure

**PROS**
- Reduction of the THP and BHP (drawdown increase)
- Increasing & stabilization of production rate
- Wide operating range

**CONS**
- Surface modifications needed
- Maximum liquid production to be tolerated
- Not compatible with solid production and corrosive fluids
- Not suggested for low productivity wells

Sensitivities on WHP reduction to define

- WHC characteristics (type, size)
- Energy needed
- Surface modifications
Plunger lift system is an intermittent lift method that uses **only the energy of the reservoir** to produce the liquids.

### PROS
- It is a rig-less operation
- Cheap to apply & maintain
- Requires no outside energy source

### CONS
- Not efficient in solid production wells
- Limited by GLR, cannot work in low GLR wells
- Not efficient in highly deviated and horizontal well
Well Unloading Technologies description
Foamers application Case histories (water)

**Batch injection**

<table>
<thead>
<tr>
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<th>PRE</th>
<th>POST</th>
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<tbody>
<tr>
<td>Gas rate (kSm3/d)</td>
<td>5</td>
<td>15</td>
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<tr>
<td>Liq rate (m3/d)</td>
<td>0.1</td>
<td>0.4</td>
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</table>

Benefit duration = 1 yr

Cost ~ 80 k€
Total Income ~ 1000 k€
POT = 1 month

**1/4” OD Capillary injection**

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<tr>
<td>Liq rate (m3/d)</td>
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Benefit duration = 2.5 yrs

Cost ~ 250 k€
Total Income ~ 6000 k€
POT = 1 month
Well Unloading Technologies description
Wellhead Compressor Case Histories (water)

10 installations in Italy since 2013

Well A

<table>
<thead>
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<tr>
<td>Gas rate (kSm3/d)</td>
<td>5*</td>
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<tr>
<td>Liq rate (m3/d)</td>
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Benefit duration = 1.5 yr (on going)

Cost ~ 300 k€
Total Income (till now) ~ 1600 k€
POT = 2.5 month
Well Unloading Technologies description
Plunger lift case histories (condensates)

Well A

Benefit duration = 1 yr

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<td>Gas rate (kSm3/d)</td>
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<td>2.5</td>
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<td>Liq rate (m3/d)</td>
<td>4</td>
<td>6</td>
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</table>

Cost ~ 75 k€
Total Income ~ 390 k€
POT = 2 months
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- Conclusions
Well Unloading selection criteria

Constraints
- HSE
- Logistic issues
- Authorizations

Technical Evaluation
- CAPEX, OPEX
- Income, POT, ROI

Economic Evaluation

FINAL SELECTION
# Well Unloading selection criteria

## Technical evaluation matrix

<table>
<thead>
<tr>
<th>Technical constants</th>
<th>Velocity String</th>
<th>Plunger Lift</th>
<th>Wellhead Compression</th>
<th>Foamer Batch</th>
<th>Foamer via Capillary</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No corrosive fluids</td>
<td>Deviation &lt; 3°/100ft Uniform tubing size No solid production Gas rate &lt; 350kScf/d GLR ≥ 400 Scf/bbl/1000ft Liquid rate &lt; 350bbl/d No corrosive fluids</td>
<td>No solid production Gas rate &lt; 700-875kScf/d Liquid rate &lt; 20 bbl/d (without surface modifications)</td>
<td>Deviation &lt; 12°/100ft GLR range: 1000-8000 scf/bbl Liquid rate range: 5-100 bbl/d</td>
<td>GLR range: 1000-8000 scf/bbl Liquid rate range: 5-100 bbl/d No corrosive fluids</td>
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<thead>
<tr>
<th>Liquid type</th>
<th>Only Water</th>
<th>Only Condensate</th>
<th>Water + Condensate</th>
<th>High Reservoir Pressure</th>
<th>Low Reservoir Pressure</th>
<th>Low Permeability</th>
<th>High Reservoir temperature</th>
<th>Deep well (&gt; 10,000 ft)</th>
<th>Large Tubing</th>
<th>Small Tubing</th>
<th>Restrictions in tubing</th>
<th>Maintenance frequency</th>
<th>Management frequency</th>
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<th>Only Condensate</th>
<th>Water + Condensate</th>
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<th>Low Reservoir Pressure</th>
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<th>Only Condensate</th>
<th>Water + Condensate</th>
<th>High Reservoir Pressure</th>
<th>Low Reservoir Pressure</th>
<th>Low Permeability</th>
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<thead>
<tr>
<th>Management</th>
<th>Liquid type</th>
<th>Only Water</th>
<th>Only Condensate</th>
<th>Water + Condensate</th>
<th>High Reservoir Pressure</th>
<th>Low Reservoir Pressure</th>
<th>Low Permeability</th>
<th>High Reservoir temperature</th>
<th>Deep well (&gt; 10,000 ft)</th>
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<th>Restrictions in tubing</th>
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</table>
Well Unloading selection criteria
Economic evaluation table

<table>
<thead>
<tr>
<th></th>
<th>POT (months)</th>
<th>Income (k€)</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost, k€</td>
<td>Typical Benefit duration, months</td>
<td>Delta prod 5 kSm3/d</td>
</tr>
<tr>
<td>Batch</td>
<td>80</td>
<td>6</td>
<td>3.1</td>
</tr>
<tr>
<td>Capillary String</td>
<td>250</td>
<td>36</td>
<td>9.8</td>
</tr>
<tr>
<td>Plunger</td>
<td>100</td>
<td>24</td>
<td>3.9</td>
</tr>
<tr>
<td>WHC</td>
<td>300</td>
<td>48</td>
<td>11.8</td>
</tr>
</tbody>
</table>

Velocity string not included; cost varies depending on the installation operation

Cost = average CAPEX + OPEX for Italy

* Gas price assumed equal to 0.17 €/Sm³
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Conclusions

- Nowadays, gas well loading impact is becoming more and more important when dealing with mature & depleted gas fields.

- HSE and Logistics constraints have to be always taken into account during the selection process.

- A proper understanding of the liquid accumulation problem and its impact is fundamental to design the most suitable unloading technique.

- The most suitable unloading technique to be applied must be chosen after proper technical and economic evaluations.
I would thank eni for permission to present this work and related results and TEOP colleagues for the technical support and needed assistance.
QUESTIONS?