ESP instabilities due to multiphase flow

J.P. de Boer (TNO), P. Bruijnen (TAQA)
Project context

- TAQA offshore, horizontal oil well (A13z)

P15 Rijn oil field

Various production, injection wells
A13Z first horizontal well of Rijn
# Reservoir, well and fluid properties

<table>
<thead>
<tr>
<th>Reservoir and well properties</th>
<th>Fluid properties</th>
<th>Well performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir pressure</td>
<td>Oil gravity</td>
<td>Surface flowrate</td>
</tr>
<tr>
<td>150 - 200 bar</td>
<td>35 °API</td>
<td>3000 - 6000 bbls/day</td>
</tr>
<tr>
<td>Productivity index</td>
<td>Gas gravity</td>
<td>Total GOR</td>
</tr>
<tr>
<td>3.0 stb/day/psi</td>
<td>0.7 SG</td>
<td>80 Nm³/m³</td>
</tr>
<tr>
<td>Reservoir temperature</td>
<td>Water gravity</td>
<td>Watercut</td>
</tr>
<tr>
<td>80 °C</td>
<td>1.05 SG</td>
<td>50 - 80 %</td>
</tr>
<tr>
<td>Target reservoir thickness</td>
<td>Bubble point</td>
<td></td>
</tr>
<tr>
<td>3 m</td>
<td>145 bar</td>
<td></td>
</tr>
<tr>
<td>Target reservoir permeability</td>
<td>Oil viscosity @</td>
<td></td>
</tr>
<tr>
<td>50 - 1200 mD</td>
<td>bubble point</td>
<td></td>
</tr>
<tr>
<td>Wellhead temperature</td>
<td>1.0 cp</td>
<td></td>
</tr>
<tr>
<td>60 °C</td>
<td>Water salinity</td>
<td></td>
</tr>
<tr>
<td>Wellhead pressure</td>
<td>50000 ppm</td>
<td></td>
</tr>
<tr>
<td>10 bar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical well depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900 m TVDSS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well deviation @ ESP setting depth</td>
<td>60 °</td>
<td></td>
</tr>
<tr>
<td>Pump intake pressure (approx)</td>
<td>70 bar</td>
<td></td>
</tr>
<tr>
<td>Pump discharge pressure (approx)</td>
<td>160 bar</td>
<td></td>
</tr>
</tbody>
</table>

A13Z ESP instability analysis and mitigation
A13z completion schematic

A13z ESP instability analysis and mitigation

Well sump due to unexpected shallow top of the A-sand
Top A-sand shallower than expected

Note: vertical scale 15x exaggerated

TD @ 3425m MD
TD @ 1936m TVDSS

8 1/2” hole

Sandscreens 7” HP Porolock 32 lb/ft
L80-13Cr / 825 inconel filter / 250 mesh filter / swellpakcer

Fluid loss control valve

Inlet gauge + discharge gauge

ESP Packer 9 5/8”

180-13Cr (@2110m MD)

TOC @ 1732 MD

B A T A B

30” to 135m MD
20” to 404m MD
13 3/8” to 758m MD

9 5/8” to 2514m MD
Formation depth: 2511m MD

A13z ESP

A13Z ESP instability analysis and mitigation
A13z timeline

- August 2014 – First production A13Z (2500 bopd, WC 50%)
- October 2014 – Start instabilities (<1000 bopd, WC 50%)
- ESP failure, tubing & ESP workover
- Reoccurrence instabilities → project start
- January 2016 – ESP failure
- March 2016 – tubing, ESP workover
- Today
Field data: typical 9-hr interval

**Observed**
- Stable production for max. 8 hours
- Onset of oscillations (pressure, flow)
- ESP trip due to:
  - Gas lock
  - Emergency shut down (ESP temperature)
- Well restart (>100x)
Multidisciplinary approach

**Trial-and-error**
Changing operating conditions for increased stability

**Field data analytics**
Correlating (in)stable flow and well/reservoir operating conditions

**Transient multiphase flow simulations**
Root-cause study for fundamental understanding
Attempts to stabilise production:

- Modify ESP frequency  
- Modify well backpressure  
- **Both**  
- Deadheading, in combination with high back pressure  
- Change drive: frequency vs. amperage controlled  
- Shear FLCV (loss valve) permanently open?
Data analytics
Data analytics

- What is “stable”?

[Graph showing various data metrics over time]

- ESP frequency [Hz]
- THT [degC]
- ESP disch. pressure [bar]
- ESP current [A]
- ESP intake pressure [bar]
Numerical simulations
OLGA modelling
Well model input

Well plan in a consequence of the necessity to geosteer inside the A-sand.

True vertical depth sub-sea [m]

B-sand: average permeability = 1-3 mD
C-sand: average permeability = 1-3 mD
A-sand: average permeability = 50-1200 mD

Well model input

Top A-sand shallower than expected

Well sump due to unexpected shallow top of the A-sand

2400 m MD
2500 m MD

20° to 404 m MD
30° to 135 m MD
13 3/8" to 758 m MD

Control line

Flow model input

ESP Packer 9 5/8"
180-13Cr (@2110 m MD)

TOC @ 1732 m MD

Formation depth: 2511 m MD

ESP @ 60 deg

Fluid loss control valve

Inlet gauge + discharge gauge

Sandscreens 7" HP Pollock 32 lb/ft
L80-13Cr / 825 inconel filter / 250 mesh filter / swellpaker

TD @ 3425 m MD
TD @ 1936 m TVDSS

8 1/2" hole

9 5/8" to 2514 m MD
15 Inflow variations

Case 9

Case 12

Case 14

FFT (BHP)     ESP press.  Q

Amplitude Spectrum of liquid production

Amplitude Spectrum of liquid production
Dynamics of horizontal only

- Should isolate flow instabilities if caused by multiphase flow in horizontal

- Results: **No oscillations**

Inflow zones unchanged

ESP intake pressure constant

~115m
Dynamics of vertical only

- Should isolate flow instabilities if caused by multiphase flow in vertical

- Results: No oscillations

~1800m

Concentrated inflow zone just upstream ESP (unchanged PI)

THP unchanged

A13Z ESP instability analysis and mitigation
Numerical simulations – match to field data

OLGA match:
- Match of ESP intake pressure to field data of A13Z
- Absolute match & order of magnitude oscillations OK
- OLGA: no escalation of oscillations/fluctuations

![Graph showing numerical simulations and field data comparison]

Discharge pressure [bar] vs. Time [hour]

ESP discharge pressure [bar]
ESP inlet pressure [bar]

Discharge pressure - field data
Discharge pressure - OLGA
Current - field data
Two instabilities observed

Mechanism #1
- OLGA + no Slug Tracking
- Stably oscillating (+/- 1 bar pk/pk)

Mechanism #2
- OLGA + Slug Tracking
- Violent oscillations, semi-periodic, >10 bar pk/pk
Mechanism #1

A13Z ESP instability analysis and mitigation
Link to A13z observations

I. Temporarily increased gas entrainment with liquid flow into ESP.
II. All gas dissolves into oil within ESP (discharge pressure > bubble point pressure).
III. Temporarily increased gas liberation downstream of ESP
IV. Reducing head on ESP and lowering ESP intake pressure
I. Temporarily increased gas entrainment with liquid flow into ESP.
II. All gas dissolves into oil within ESP (discharge pressure > bubble point pressure).
III. Temporarily increased gas liberation downstream of ESP
IV. Reducing head on ESP and lowering ESP intake pressure
V. Escalating gas fraction entrained with liquid flow into ESP
VI. Increasingly reduced ESP intake pressure → ultimately gas lock
Workover recommendations
Recommendation #1

- Simulated behaviour of completion with tailpipe

OLGA, without Slug Tracking

OLGA, with Slug Tracking

- Even with slug tracking (forcing Mechanism #2) no escalated instability observed

- Practical limitations: TAQA limited in available tubings & limited weight allowed under ESP (dogleg)
ESP #1

(a): First completion

ESP #2

(b): Second completion

ESP #3

(c): Third completion

Lir

A13Z ESP
instability analysis and mitigation
Recommendation #2 (future control actions)

- Active control of valve at annulus (surface) to stabilize any reoccurring fluctuations

- Active control of gas flow at annulus is able to stabilize liquid column in annulus
A13z timeline

- **Dec ‘14**
  - August 2014 – First production A13Z
  - October 2014 – Start instabilities  
    (Trip every 8 hrs)
- **Dec ‘15**
  - ESP failure, tubing & ESP workover
  - Reoccurrence instabilities → **project start**  
    (Trip every 50 hrs)
  - January 2016 – ESP failure
  - March 2016 – tubing, ESP workover
- **Dec ‘17**
  - Today (3rd ESP running)  
    → **Not trips since March 2016**  
    (confirmed last week)
Recap of A13Z production challenge

- Onset of instabilities, within hours/days after start-up
- No prescriptive action to stabilize well (as well has never been really stable)

Multidisciplinary approach required to

- Fundamentally understand behaviour → justify another workover
- Define modifications to avoid initiation of instable flow
- Increase chance of success by triple-ensuring gas handling abilities (tailpipe, avoider, packer, stages, tubing)
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