Sucker Rod Lifting Horizontal & Highly Deviated Wells – Extended for Gas

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Background

• Originally presented: 2007 Sucker Rod Workshop
  – Norman W. Hein, Jr., P. E. – OGOS, Ltd.
  – Scott W. Long, P. E. – Flexbar
  – Mark Mahoney – Harbison-Fischer
  – Russell Stevens – Norris

• Modified, paper written & presented: 2008 SWPSC
  – Added: Jeffrey DaCunha, Ph.D. - Lufkin Automation

• Breakout discussion 2008 GWD Workshop
Literature Reviewed

- SPE 83621 - S. Joshi in 2003
- SPE 24764 – J. Cortines & G. Hollabaugh in 1992
- SPE 54115 – M. Zatka in 1999
- SPE 54646 – B. Evans & G. Muth in 1999
- PTTC – Horizontal Drilling, Real Michigan Field Experience in 2003
SPE 83621- S. Joshi in 2003

- 1927 first horizontal well; major thrust in 1980s
- Initial wells short radius ~250’ long
- 1985 first medium radius well drilled w/downhole mud motor; now most common
- ~17,300 horizontals in USA thru 2002
- ~43% of total in Austin Chalk
  - followed by Red River in North Dakota
• Majority USA horizontals in carbonate vs. Ca., Ak., offshore & International where clastic reservoirs most common
• Currently ~65% successful
• Drilling costs 1.5 to 2.5 times similar vertical wells
• Finding costs 25% to 50% less than buying reserves
• Operating costs ($/bbl) ≤ 50% vertical due higher productivity

Steel Slotted Bar
Fig. 2

Wheel Position
Fig. 4

Metallic Wheel
Thrust Bearing
Steel Slotted Bar
• Oryx horizontals in Pearsall field, Austin Chalk
• Originally flowing >1000 bopd; when 100-200 bopd started sucker rod lift
• Pumps in curve or lateral >80 of 150 wells
• Volumetric Efficiency & PIP declined when originally tried pumping above completion mainly due to gas interference
SPE 24764 – (con’t)

- Developed Max Length tool/dog leg severity equation:
  - \[ L = 2 \times Ro \times [1 - (Rx - Ro)^2]^{0.5} \]
  - where: \( Ro = R + 0.5 \times ID \); \( Rx = R - 0.5 \times ID + OD \); \( R = \frac{5730}{A} \) (angle dog leg in degrees/100 ft)

- Used 86 D rods with \( N = 6 \) to 9 spm

- Guided rods on portion in curve or horizontal w/8 per rod (~1200 ft horiz. + 300 ft above kick off point) & rotator
  - Kevlar\(^\circledR\) composite best, then nylon composite, then Ryton\(^\circledR\)

- Pumps were biggest challenge; tried normal “vertical” pumps with Cr barrel, SM plunger
  - Life went from <month to over 1 year
• Increased cross-sectional area at pump, replaced poor-boy ‘anchors’ with packer type gas anchors

• Then lowered pumps in curves
  – caused operational problems
  – but minimized with rod guides and pump designs
• Pumps evolved to 2 stage hollow valve rod pump
  – Carbonitried barrel
  – Carbide insert valve rod guide; Carbide balls & seats
  – Spray metal box end plunger; -0.004” clearance plunger
  – Plungers range 1.50” to 2.75”; most 1.75” to 2” insert
  – Tried spring activated balls but life less than a month due to mechanical ball wear
    • Practice abandoned when conventional ball & seat arrangements operated normally in horizontal wells
• Prior vertical Failure Frequency = 1.3 failures/well/year
• Horizontal FF = 2.5 f/well/y
Figure 9 - Typical Setup For Pumping A Horizontal Well In The Deviated Portion Of The Hole

- Tested gas anchor for ESPs
- Used 500 and 1000 cP oil
- 30 m³/d (~1000 bpd) & GLR = 2.71 (300 cf/bbl)
- 95% separation possible
- Separation gas/liquid mixtures easier with viscous liquids if slug flow
- But viscosity detrimental if dispersed bubble flow
Producing 6-9 °API bitumen from cyclic steam wells in Shell’s Peace River, Alberta, Canada

BHT as high as 420°F; precluding all but sucker rod lift

Based on D1280-305-240 w/100 Hp motors & VFD

Compared to #900 R320-360-288 Rotaflex w/75 Hp motor & VFD

All wells equipped w/ 3 3/4” tubing pump, 1” COROD, typically 4 1/2” production tubing, ~1900’ deep w/800’ lateral

Pumping speeds ~3.2 Rotaflexs vs. ~3.3 spm for Conventional

Found rates 41% higher and pump efficiency increased from 46.8% to 67.6%

but remember PD = 0.1166*S*N*D^2 (1511 vs. 1298 bpd)
Figure 1: Diagram of Muth Pumping system
PTTC – Horizontal Drilling, Real Michigan Field Experience

- Petroleum Technology Transfer Council (PTTC) Workshop in March 20, 2003
- Itemized a number of horizontal drilling, completion and lift issues
- Provided a summary paragraph on downhole rod pumping recommendations. These included:
  - Pumps can be placed in straight section above the curve, in the curved section & in horizontal itself
  - If placed above curve, one vertical well and pump may be able to drain multiple laterals; but backpressures high and gas separation a problem
  - Placement in the curve lowers backpressure but it places the most stresses on the pump & expected life only 30% vs. vertical
PTTC – Horizontal Drilling (con’t)

– Life may increase to 60% of vertical if pump placed in horizontal section
– Placing pump in horizontal can achieve lowest backpressure
– Pumps have been run thru curves; build rates up to 30°/100’
– However, most common build rates are 20° to 24°/100’
– Mold-on rod guides are advised
– Separation downhole is critical
Problems (not necessarily addressed)

• Valve action at the end of the stroke requires velocity to go to zero. Then balls fall on seats due to gravity. But, how does gravity work when pump not vertical. What can be done to help balls go on seat?

• What other pump concerns if pump in horizontal section?

• Sinker bars normally help reduce minimum loads, keep rods in tension, help reduce buckling; but no publication mentioned use. So should sinker bars be installed? If so, where and how many?
Problems – (con’t)

• Sucker rods normally like to be kept in tension (and required for FRP). How know if rods buckle, go into compression, have high side loads?

• How address wear of rods and/or tubing associated with buckling, over pumping, and well bore deviation?
  – Normal ROT if:
    • Deviation 0 to 3 degrees/100 ft. – no problem
    • Deviation 3 to 5 degrees/100 ft. – increased wear and friction
    • Deviation >5 degrees/100 ft. – will have problems (doesn’t mean can’t pump, just extra precautions may be required or may have increased operating costs, failures, etc.)
Well Design/Computation Recommendations

• Drilling design/profile has a major impact on SRL system

• Normal consideration includes:
  – pump depth vs. reservoir depth,
  – production rate,
  – casing – tubing size and downhole separation
  – pump type
  – pumping parameters, S, N, Fo/SKr, No/No’

• Added considerations includes:
  – impact of side loads, friction, dynamic effects on up and down stroke, buckling, wear, etc.
Well Design/Computation (con’t)

- Wave Equation for Vertical Wells

\[ \frac{\partial^2 u(s,t)}{\partial t^2} = 2 \cdot \frac{\partial^2 u(s,t)}{\partial s^2} - c \cdot \frac{\partial u(s,t)}{\partial t} + g \]

- Wave Equation for Non-Vertical Wells

\[ \frac{\partial^2 u(s,t)}{\partial t^2} = \sigma^2 \cdot \frac{\partial^2 u(s,t)}{\partial s^2} - c \cdot \frac{\partial u(s,t)}{\partial t} - C(s) + g(s) \]

\[ C(s) = \delta \cdot \mu(s) \left[ N(s) + T(s) \cdot \frac{\partial u(s,t)}{\partial s} \right] \]

\[ \delta = \frac{\partial u(s,t)}{\partial t} \left| \frac{\partial u(s,t)}{\partial t} \right| \]

NON-VERTICAL
Well Design/Computation (con’t)
Downhole Pump RPs

• What is the well profile and where can we land the pump?
• L profile is the best with a pump landing as close to 90 deg as possible
• S profile or multi-profile can be problematic but sometime possible
• Use the well bore deviation survey to find an area with the least amount deflection and least rate change (unplanned deviation) over an area of at least 1-1/2 to 2 times the pump length
• Need to know if the pump is a top hold-down or bottom hold-down to position seat nipple to be in the desired landing spot.
Downhole Pump RPs (con’t)

South Texas horizontal wells

• Rod pumps worked with build rates from 6 degrees to 16 degrees per hundred on most wells with a few in the 18-20 degree per-hundred build rate.

• Ideal conditions would have the dogleg severity less than 5 degree per hundred (within the planned build rate). It is important to understand build rate (planned deviation) and dogleg (unplanned deviation).

• In vertical well drilling any deviation was considered a dogleg.
This setup was used very successfully in the Pearsall-Dilley, Texas area to stop plugging off the pump intake and separate some gas from the pump.
• Some wells pumped in the curved section at 30-45 degrees into a 90 degree curve. Build rates were 7-16 degrees per hundred

• Carbide sleeves were used in the pull tube guide to stop wear but plunger and barrel still had accelerated wear and pump life was less than a year

• Plungers show a distinct tear drop shaped wear on each end of the plunger usually around 180 degrees opposite
Downhole Pump RPs (con’t)

- Sucker rod pump valves open by pressure and close by flow
- Pumps in vertical wells also have gravity to help but it is not necessary for valve function
- If late valve closing is observed spring loaded cages like the Baird Snubber Cage have been used
- Pump friction, the resistance to rod fall caused by the plunger/barrel fit and fluid flow through the valves and plunger must be adjusted to the lowest as possible
Downhole Pump RPs (con’t)

- POSITIVE VALVE SEATING
- GOOD FOR GAS WELLS THAT TEND TO "HEAD UP AND FLOW"
- SOME HORIZONTAL WELLS BENEFIT WITH USE
- EXTRA PARTS TO WEAR OUT AND JAM WITH SCALE OR OTHER SOILDS
- RE-SEAT BALL IN SAME SPOT
Sinker bar RPs

- Use a computer predictive program (RODSTAR-D or SROD) to establish an “Existing Conditions” design of your Horizontal / Deviated well
- All future designs can then be compared to this “Existing Conditions” design to determine if design changes have improved your design
- For **New Wells**, model “Existing Conditions” first without Sinker bars
- For **Existing Wells**; model “Existing Conditions” with existing rodstring design
Sinker bar RPs (con’t)

- Segment your Horizontal / Deviated well into “Vertical” sections, if possible
- **First**, consider adding Sinker bars to the bottom of each “Vertical” section
- Make first computer run with “Buoyancy Effects” turned **OFF** to check for buckling at the bottom of each “Vertical” section
- Adjust Sinker bar footage so all buckling is contained within each Sinker bar section
- Make second computer run with “Buoyancy Effects” turned **ON** to check for all other loadings
Sinker bar RPs (con’t)

• **Second;** consider adding a smaller Sinker bar section to the top of each lower “Vertical” section (usually not required in top section)

• These Sinker bar sections may assist the rodstring as it travels through the turns or your Horizontal / Deviated Well

• After each design change, make computer runs with “Buoyancy Effects” turned OFF and ON to check for buckling and all other loading

• With each design change, record changes to buckling and all other loading to direct you to your best design
Sucker Rod String RPs

- Consider reducing rod coupling wear by using spray metal coating
  - since coupling harder they will wear less (?)
- ARCO, S. M. Bucaram, reported to 1980 API Committee on Standardization of Production Equipment lab test results where percentage change in coupling wear from T class versus spray metal coupling from 6 manufacturers
- Also considered J55 (H40) tubing percentage wear and percentage penetration
- Tests at 100, 50 & 25 in-lbs torque using water and then just crude oil
Sucker Rod RPs (con’t)

- Results of 100 in-lb applied torque with water
- With 50 in-lb; Average wear -73% coupling, 286% tubing, 130% depth
- With 25 in-lbs; Average wear -74% coupling, 380% tubing, 67% depth

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<th>Manufacturer</th>
<th>Coupling (SM vs. T)</th>
<th>% Weight Loss</th>
<th>Depth of Tubing</th>
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</table>

AVERAGE: -82, 399, 117
Sucker Rod RPs (con’t)

- Results of 100 in-lb applied torque with crude oil

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<th>Manufacturer</th>
<th>Coupling (SM vs. T)</th>
<th>J55 Tubing</th>
<th>Penetration (%)</th>
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Extension & Considerations for GWD (or any producing well)

- Natural gas separator; while best, may still allow gas to go through pump
General Natural Gas Separator

15' ± BELOW LOWEST ACTIVE CASING PERFORATION

N-11— ___ IN. O.D. ——

STRAINER NIPPLE ___ IN. NOM. L.P. ___ SLOTS __ IN. x ____ IN. ——

SEATING NIPPLE

SEATING CUP COUPLING, S-16— ___

COLLAR SLOTS __ IN. x ____ IN. ——

MUD ANCHOR

ORANGE PEEL

2' ±

ANCOR O.D. ___ IN. ——

ORANGE PEEL OR I.D. PLUG

5' ±

CASING I.D. ___ IN. ——

PLUGGED BACK DEPTH

2009 Gas Well Deliquification Workshop
Denver, Colorado
Capacity Graph – various completions, PIP, Gg=0.65
Extension & Considerations for GWD (or any producing well)

- Horizontal undulations or “sumps” cause slug flow unless controlled
SPE 75249 – Yaliz, Chapman & Downie in 2002
Extension & Considerations for GWD (or any producing well)

• Pumping vertical provides lowest rod loading and least tubular contact/wear; but, if pump hung high, limits drawdown and production

• Combine concepts by drilling vertical sump, short radius horizontal with heel lower than toe, and placing pump in sump

• Concept successfully used multilaterals & ESPs
Horizontal with Pump in Sump

- Casing
- Tubing
- Sucker Rod String
- Downhole Pump
Requires changes to drilling plans
Summary

- Not many articles on rod pumping horizontal/ highly deviated wells; none for GWD
- Preplanning well and deviation/build for horizontal well design should be done as a team with appropriate computer simulation if/when sucker rod lift used (L-profile probably best)
- Once drilled, accurate deviation survey is very important (degrees/100 ft. – **minimum**)
- Recheck preliminary rod design, using accurate deviation and appropriate wave equation program
Summary (con’t)

- Downhole gas separation important; pump being able to handle gas is critical
- While gravity may help valve action, need flow to close valve
- Spring assisted cage may help, especially if pumping viscous fluid, to close valve (but a concern is ball wear)
- Pump friction should be minimized
- Sinker bars very useful in horizontal wells to help prevent magnitude of buckling and reduce dynamic effects on downstroke
Summary (con’t)

- Sinker bars useful in transition region from vertical
- Sinker bars may be considered on bottom of each rod section
- Rod guides/centralizers important to reduce wear; rod, coupling and/or tubing
- SM couplings have been redesigned since 1980 ARCO work; but updated testing should be considered before use to prevent friction and wear
Summary (con’t)

• Roller rod guides have been used, especially for higher downhole temperatures, but solids may be a concern

• Composite rod centralizers, molded on the rods, up to 8/rod has been successfully used to mitigate wear

• Modifying producing well to add well sump and tight, short radius should allow best gas separation, lowest rod loading scenario, and least tubing wear problems, while maximizing production of all fluids
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