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Sucker Rod Pumping Horizontal & Highly Deviated Wells – A Review & RPs

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• Literature Review
• Problems
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• Summary
• 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 horizontal wells 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

- Considered rod centralizers for directional, heavy oil wells (Orinoco Belt in Venezuela)
- All metal centralizer developed, withstand downhole conditions, especially high (400 °F) BHT
- Used 2 ¾” plungers, ATH pumps, 144” stroke, 8.5 spm
- Centralizer bar had 6 rectangular slots set in helical array along bar with one wheel in each
- Wheel acts as thrust bearing; life increased by intermediate bearing
- As of May 1990, centralizers >249 day runtime vs. neighboring wells w/elastomeric guides only 90 days and no rod or tubing failure
SPE 21131 – (con’t)

STEEL SLOTTED BAR

WHEEL POSITION

PHASE ANGLE BETWEEN SLOTS (DEG)

FIG. 2

FIG. 4

METALLIC WHEEL

THRUST BEARING

STEEL SLOTTED BAR

THICKNESS
Oryx horizontals in Pearsall field, Austin Chalk

Originally flowing >1000 bopd; when 100-200 bopd started sucker rod lift

Pumps in curved or lateral >80 of 150 wells

Volumetric Efficiency & PIP declined when originally tried pumping above completion mainly due to gas interference
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© composite best, then nylon composite, then Ryton©

- 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
SPE 24764 – (con’t)

Figure 9 - Typical Setup For Pumping A Horizontal Well In The Deviated Portion Of The Hole
Optimization of heavy oil & problems pumping gassy fluids

Gas & liquid slugging familiar phenomenon horizontals

Previous solutions included:

- If vertical well, set pump below branch off point (sumping the pump)

- Place pump in horizontal portion but doglegs preventing flex during installation and solids are problems

- Use rotary gas separator but effective low gas fractions and slug flow

- Use dip tube/gas vent but friction losses high with viscous oil
- 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
• Originally D1824-305-240 pump units w/ 200Hp Toshiba Nema B motors & 200 Hp Allen Bradley Model 1336 VFD.
• Based on performance data, units changed to D1280-305-240 w/100 Hp motors & VFD
• Compared to #900 R320-360-288 Rotaflex w/75 Hp motor & VFD
SPE 54115 – (con’t)

• All wells equipped w/ 3 3/4” tubing pump, 1” COROD, typically 4 ½” production tubing, ~1900’ deep w/800’ lateral

• While originally planned 4 of each type, problems w/1 well & a motor resulted in 3 units each type on a pad

• Pumping speeds ~3.2 Rotaflexes vs. ~3.3 spm for Conventional pumping units

• Found rates 41% higher and pump efficiency increased from 46.8% to 67.6%
  – but remember PD = 0.1166*S*N*D² (1511 vs. 1298 bpd)

• Later decided to test “POCs” to maintain predetermined pump fillage
Results showed mechanical long stroke can offer a cost-effective surface lift unit.

The “advantages” from production uplift “outweigh” several operational, well servicing issues
Development of “Muth Pumping System” with “downhole conversion kit”

- Allows modification to dual string system (power and production strings)
- Effective mitigating pumping problems in horizontals
- Rods in power string connected to conventional insert, tubing or PCP; tubing filled water, light oil, KD, etc.
- Conversion kit includes polished pull rod, sealing unit, and crossover flow head.
- Production string sized to have high velocity to carry sand/solids & upper SV prevents back flow
Figure 1: Diagram of Muth Pumping system
In 1999, over 400 horizontal wells in Ca., mostly steam injection projects.

Difficulty gravel packing horizontal section (~1000’ to 1500’) slotted or perforated liners used.

Steam zones 1000-2000’ deep & sand unconsolidated

Some zones with “flour” sand; diameters 1/1000” or less

Tested in 4 wells w/11-13 °API crude

Pumps placed above liner top where well horizontal (~1000’ deep)
• Modified cages & spring loaded balls needed
• Early results showed sanding problem eliminated or greatly reduced
• Dynamometer data was being acquired
• 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 $30^0/100'$
- However, most common build rates are $20^0$ to $24^0/100'$
- 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.)
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.
Downhole Pump RPs (con’t)

- 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.
• 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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Sucker Rod RPs (con’t)

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

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Sucker Rod RPs (con’t)

• “Diagnosis and Design of Sucker Rod Pumping Systems” K.B. (Ken) Nolen Lufkin Automation
• (? Date)
Sucker Rod RPs (K. B. Nolen con’t)

- Wave Equation for Vertical Wells

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

- Wave Equation for Non-Vertical Wells

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

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

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

\[
\text{NON-VERTICAL}
\]
Sucker Rod RPs (K. B. Nolen con’t)
Summary

• Not many articles on rod pumping horizontal/ highly deviated wells

• 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 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
• Sinker bars very useful in horizontal wells to help prevent magnitude of buckling and reduce dynamic effects on downstroke. Sinker bars useful in transition region from vertical.
• Sinker bars should 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
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