Artificial Lift R&D Council

2021 International Sucker Rod Pumping Virtual Workshop

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Enhancing Downhole Gas and Solids Separation and Lowering Operational Risk by Taking Advantage of Multiphase Flow Reversals

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Downhole Separators have Under-Performed

Common Producer Wish List:

1. **Lower operational risk**
   - avoid the need for a packer or cup seal; want packerless
   - mitigate scaling in hole risks
2. **More gas separation capacity**
   - ability to handle inconsistent slug flows
   - achieve consistent pump fillage to maximize pump/rod life
   - ability to handle foamy fluids
3. **More solids separation capacity**
   - with low risk sump retention and retrievability
4. **Lower cost….**

Separation Research Revealed Opportunities

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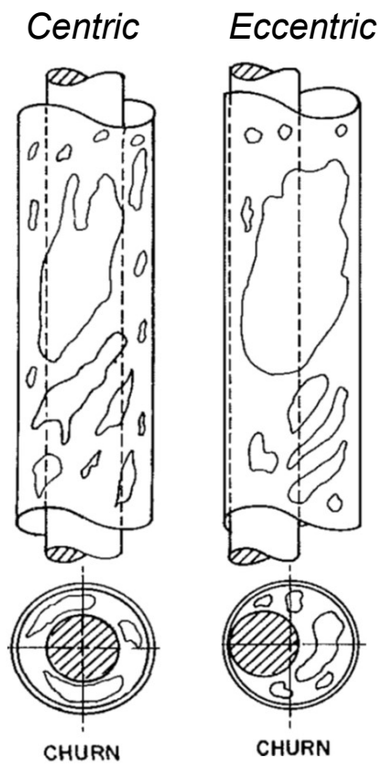
+30% improvement
eccentric positioning of pump intake's dip tube

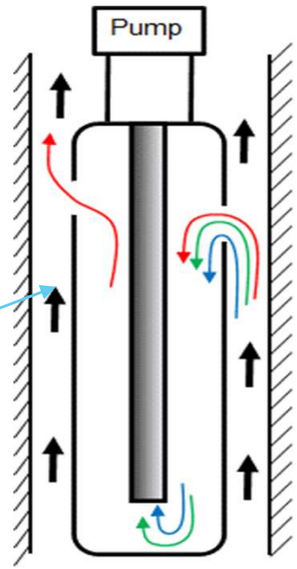


Caetano, Shoham, Brill,"Upward vertical two-phase flow through an annulus", The University of Tulsa, Tulsa, OK, 74104

+30% improvement
placing separator intake in largest cross-sectional area

High annular gas velocities adjacent to OD of separator prevent liquid from entering side slots / ports

> 6 ft/sec gas velocity side intake separators become limited, which is only half of critical liquid lifting gas velocity



http://alrdc.org/workshops/2013_2013AppalachianBasinGasWellWorkshop/Private/1%20-%202%20-%20Echometer%20---%20Downhole%20Gas%20Separator%20Selection.pdf

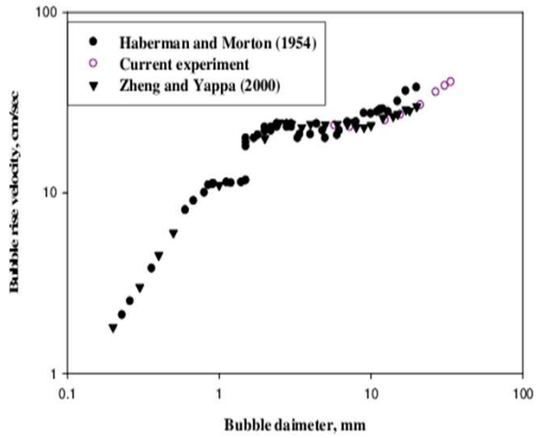
Karmon, II. Isaac D. G. B.Sc., M.P.H., "Quantifying a New Horizontal Well Gas Anchor Performance", Thesis, Texas Tech University, May 2019

+25% improvement
minimizing fluid agitation and turbulence

Fluid agitation / turbulence generate smaller gas bubbles, which are much more difficult to separate

1/8" bubble rises at ~3"/sec
1/32" bubble rises at ~1"/sec

This is a limitation of packer-style side discharge separators

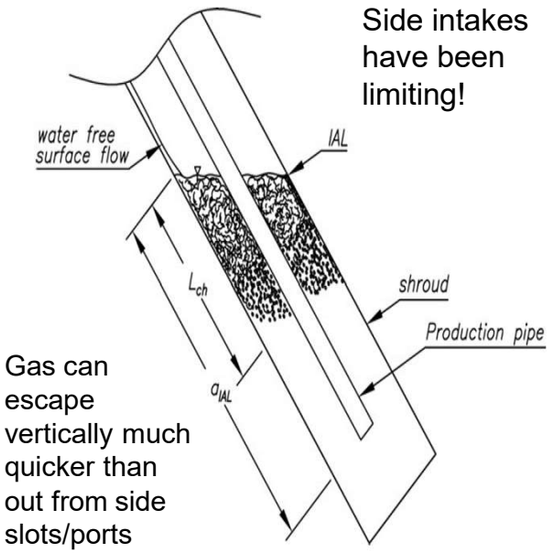


Hassan, N., Khan, M. Masud, Rasul, Mohammad, "A study of bubble trajectory and drag co-efficient in water and non-Newtonian fluids", 2008/01/01, vol 3, WSEAS Trans. Fluid Mech.

+50% improvement
re-orienting separator intake from side to facing upward

An upward facing separator intake takes advantage of multiphase flow reversals or liquid fallback

Side intakes have been limiting!



Gas can escape vertically much quicker than out from side slots/ports

Experimental investigation of gravitational gas separation in an inclined annular channel

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[b] Exploration and Production, E&P-ENGP/TPP/EE, PETROBRAS, Av. Rep. Chile, 330 – 7°, 20031-170, Rio, RJ, Brazil
[c] Exploration and Production, E&P-PDP/CTPDP/SUB, PETROBRAS, Av. Rep. Chile, 330 – 29°, 20031-170, Rio, RJ, Brazil

Large Open Mouth = More Separation

Why does a whale shark have such a big mouth?

- More efficient
- More volume capacity
- Minimal fluid flow disturbance

Separation in an annulus is limiting:

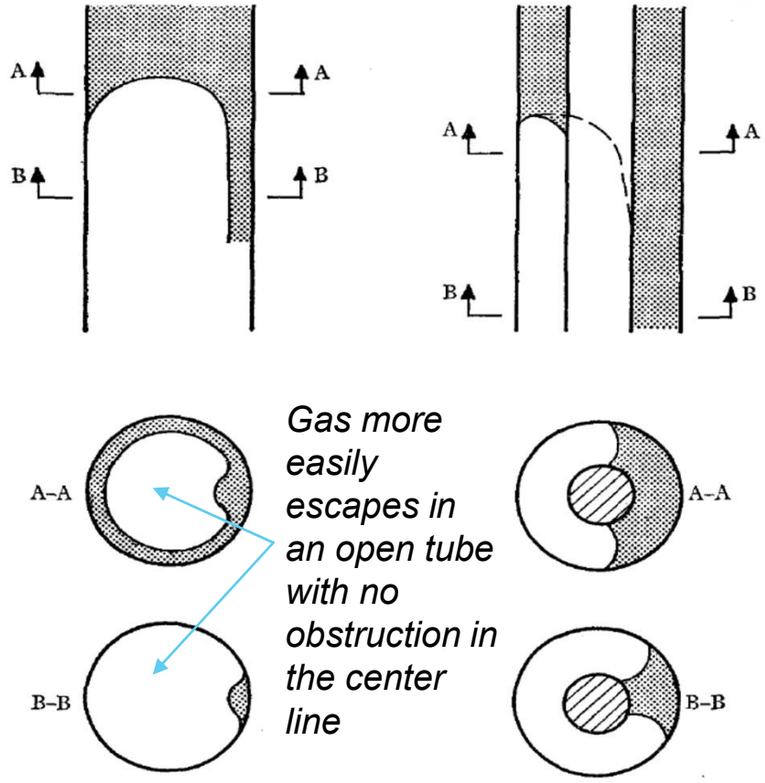


FIGURE 10. Two variant bubble shapes.

Zukoski, E.E., "Influence of viscosity, surface tension, and inclination angle on motion of long bubbles in closed tubes", J. Fluid Meek. (1966), vol. 25, part 4, pp. 821-837

Importance of Multiphase Flow Patterns

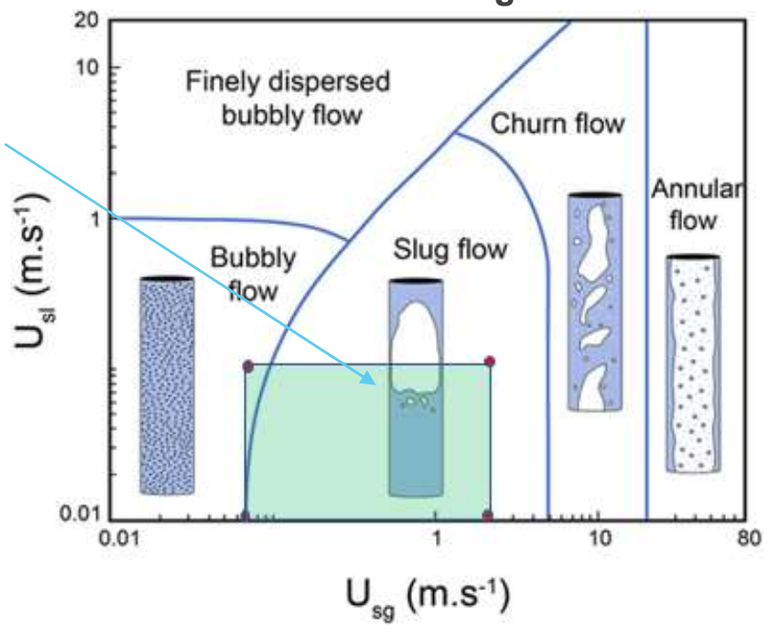
- Realization that during the sucker rod lifting artificial lift phase, most production rates (relative to its casing size) are contained within the **slug flow** and **churn flow** pattern/regimes

Production range at 150 psi pump intake pressure:

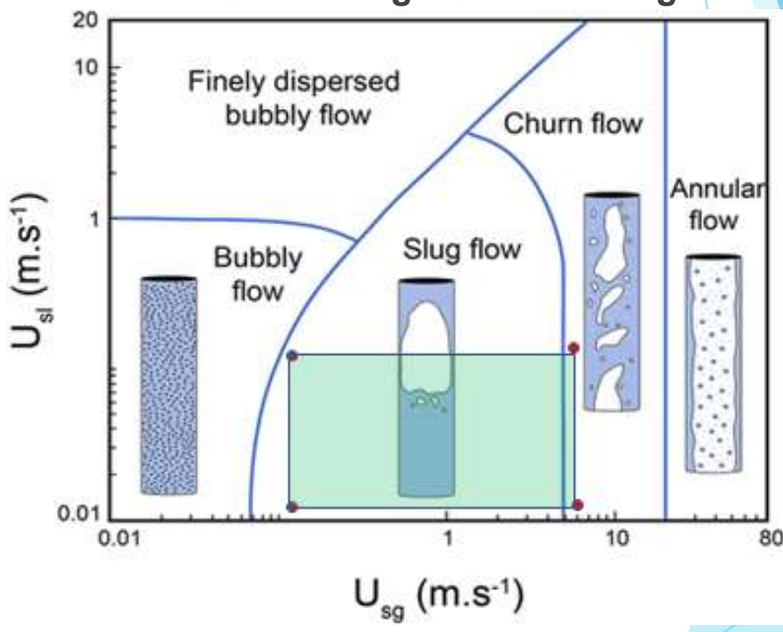
Liquid
30-600 bbl/day

Gas
30-1000 Mscf/day

5.5” 20# Casing



5.5” 20# Casing x 2-7/8” Tubing

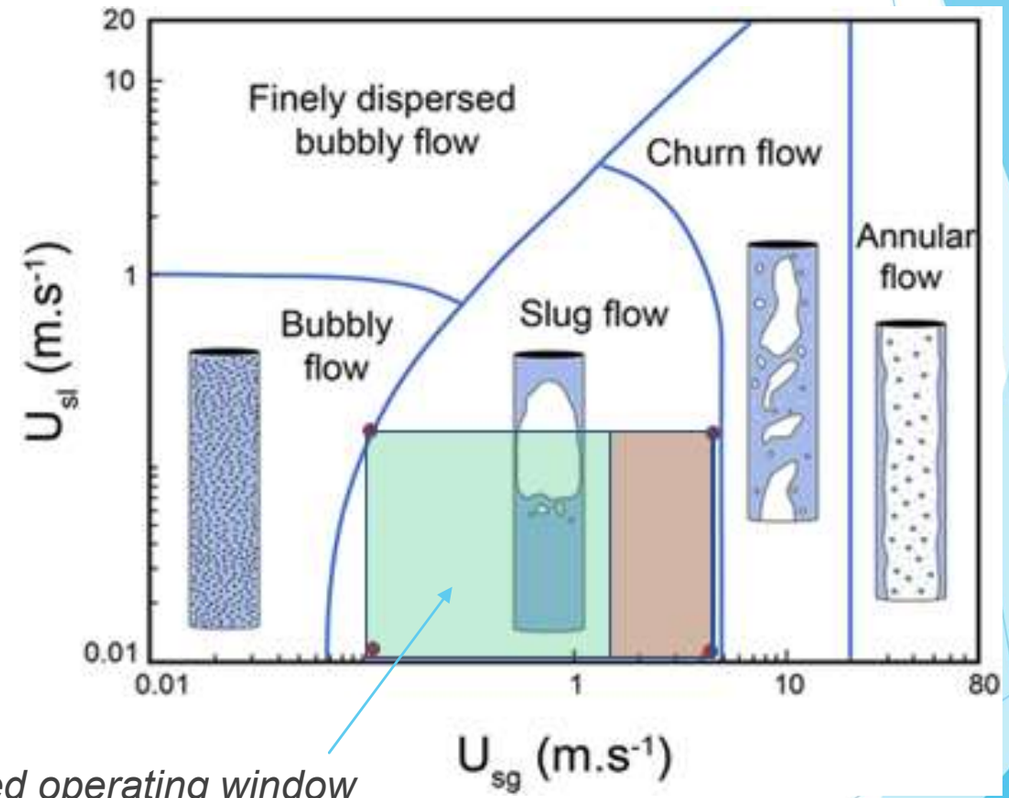


Guet, S., G. Ooms, “Fluid mechanical aspects of the gas-lift technique”, January 2006 Annual Review of Fluid Mechanics 38(1)

- Both flow regimes are characterized by **intermittent flow with frequent liquid phase flow reversals** (negative liquid flows or liquid fall back), concurrently in casing below a separator and quasi counter-current beside the separator and in the tubing annulus

Side Intake Separator Limits

- A 3.5” OD side intake poor-boy style separator in 5.5” x 20# casing:
  - 1.8 m/s (6 ft/s) superficial gas velocity or 340 Mscf/day at 150 psi PIP, the side intake starts becoming starved[1]
  - Fully starved at 3.6 m/s (12 ft/s) or 675 Mscf/day



Limited operating window

[1]Karmon, II. Isaac D. G. B.Sc., M.P.H., “Quantifying a New Horizontal Well Gas Anchor Performance”, Thesis, Texas Tech University, May 2019

Liquid Phase Flow Reversals

- Dr. Nagoo's MAPe superficial gas phase velocity for critical liquid lifting:

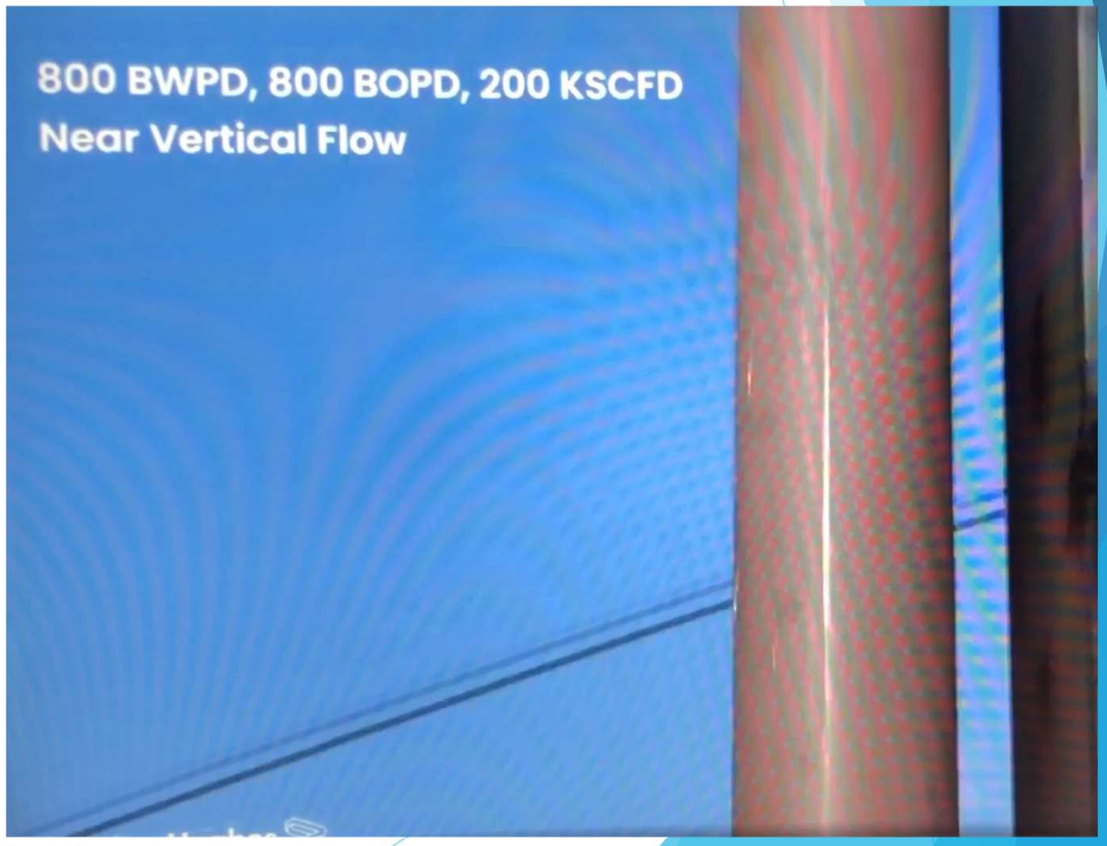
  (250 psi pump intake pressure, 200°F, 0.8 gas gravity, 65% water cut, 1.07 water SG, 35° API oil)

  - 5.5" casing is 13 meters/second (43 feet/second)
  - 5.5" casing by 2-7/8" tubing annulus is 3.3 meters/second (12 feet/second)

- Significantly more flow reversals occurring in an open tube versus an annulus

- The critical liquid lifting gas velocity occurs in the **churn flow regime** characterized by liquid phase flow reversals

- Baker Hughes'[1] recent flow loop testing appropriately demonstrates liquid phase flow reversals or liquid fall back under churn flow conditions:



[1] under written permission from Baker Hughes to present video, reference: https://www.linkedin.com/pulse/simulation-gas-liquid-flow-regimes-baker-hughes-flowloop-abrar-manzar/?trackingId=hnPY40suJPKI5djwNM%2FI1Q%3D%3D

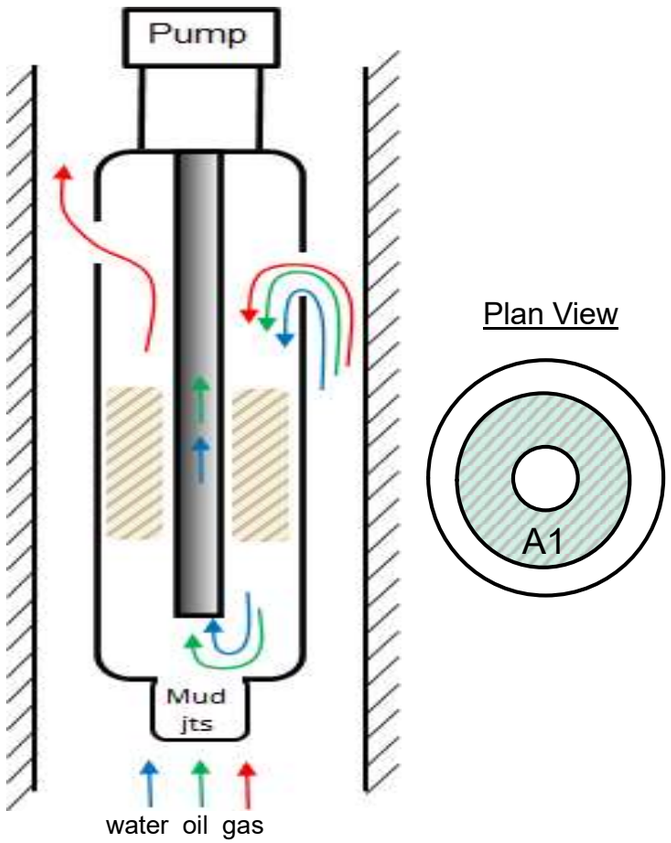
New Separator Concept Hypothesis

- It was hypothesized that downhole separation could be enhanced by:

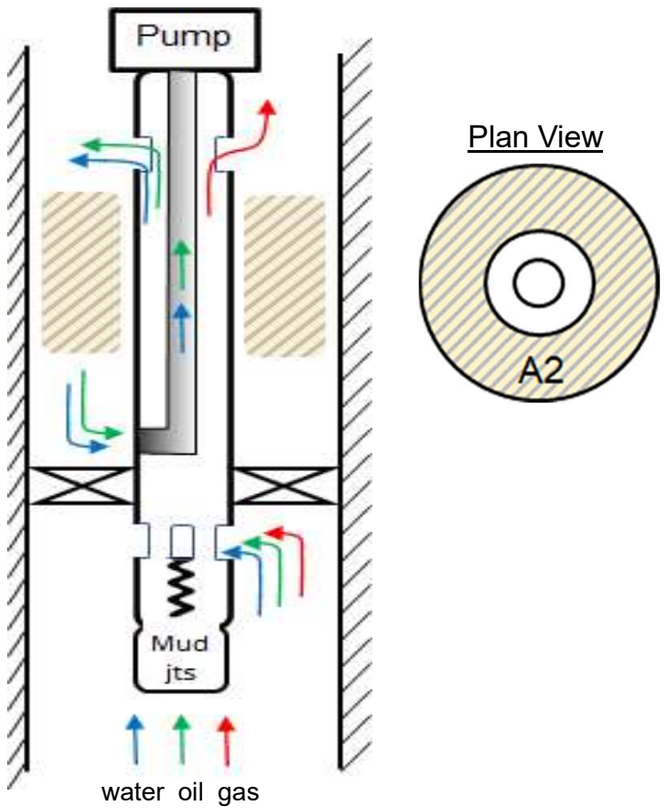
1. avoid being governed and limited by gas bubble rise velocities through taking advantage of liquid phase flow reversals (governed instead by how fast liquid falls)
2. orienting a separator's intake to face upwards to function as a collector of liquid fallback, thereby intentionally taking advantage of the transient, frequent, ongoing, liquid phase flow reversals and liquid fallback
3. reduce the annular clearance adjacent to the separator's collector to increase the multiphase fluid velocity for increasing its gas volume fraction (GVF) to reduce the amount of small sized bubbles (forcing bubble coalescence) and to maximize the mouth-size of the separator's collector intake
4. using an exceptionally large cross-sectional area with an "open tube, nothing obstructing the center line" eccentric separation region immediately above the collector to promote a greater amount of liquid fallback into the collector
5. Packerless – not using a packer or cup seal to minimize fluid turbulence while lowering operational risk

Separator Comparison – Where Does the Flow Go?

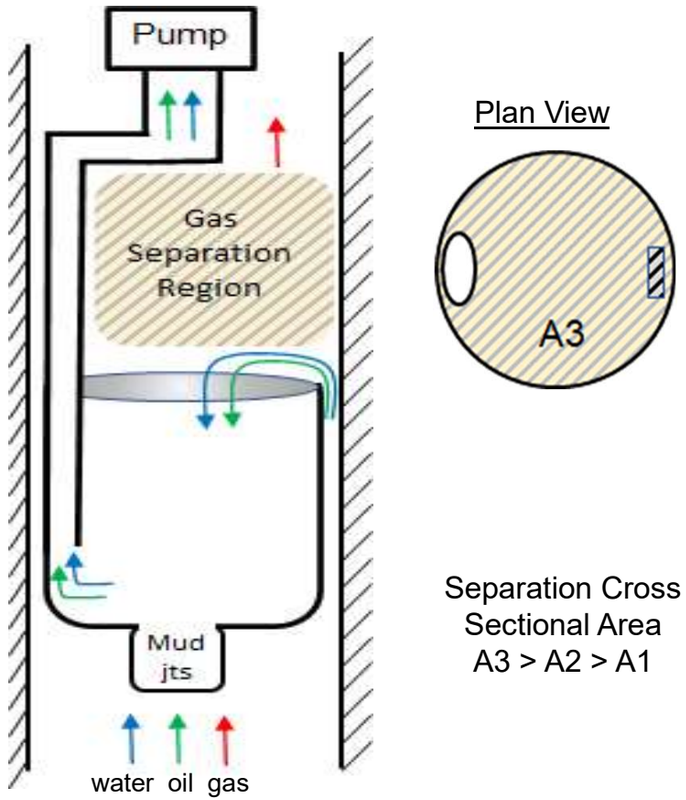
Poor-Boy Style



Packer Style



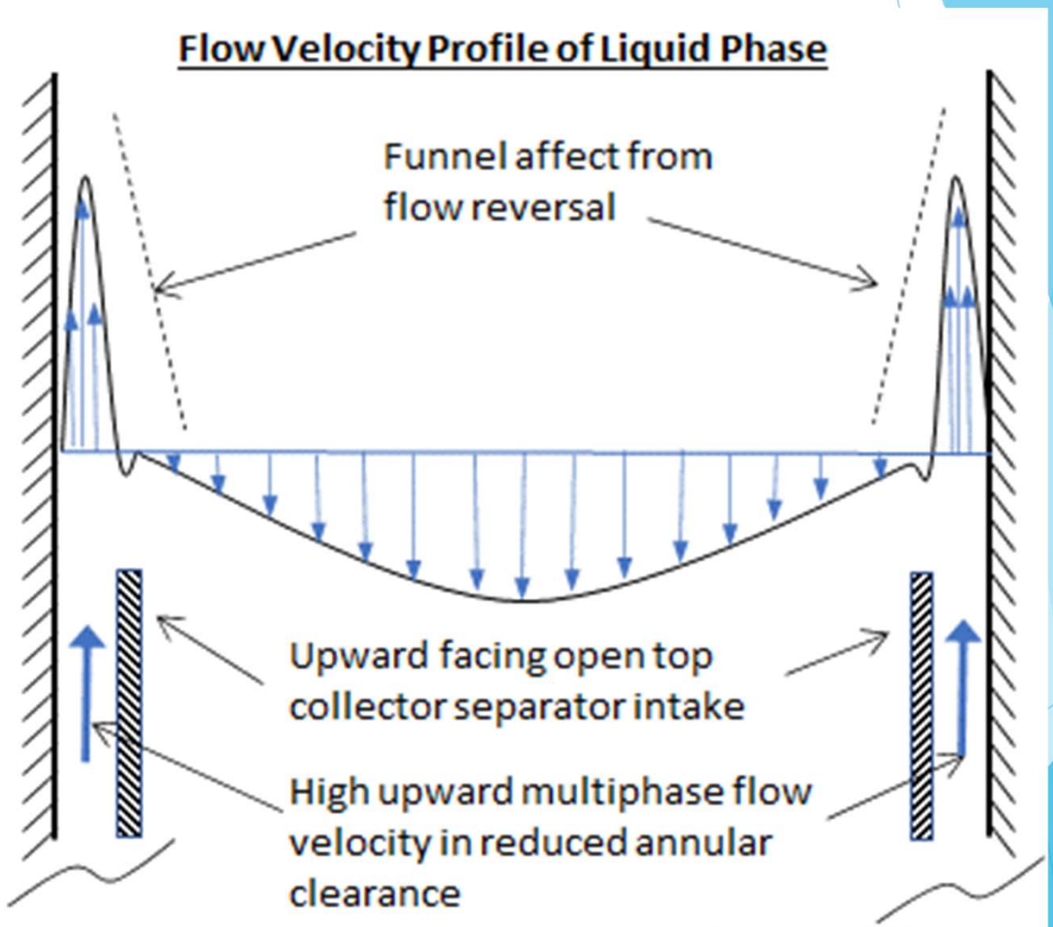
New Concept



Separation Cross Sectional Area
A3 > A2 > A1

Upward Facing Collector Design

- Minimal fluid disturbance
- Eccentric separation region promotes greater liquid fallback into collector
- The design permits high-rate flumping conditions (critical liquid lifting in the annulus and/or flowing out the casing annulus) while sustaining full pump cards

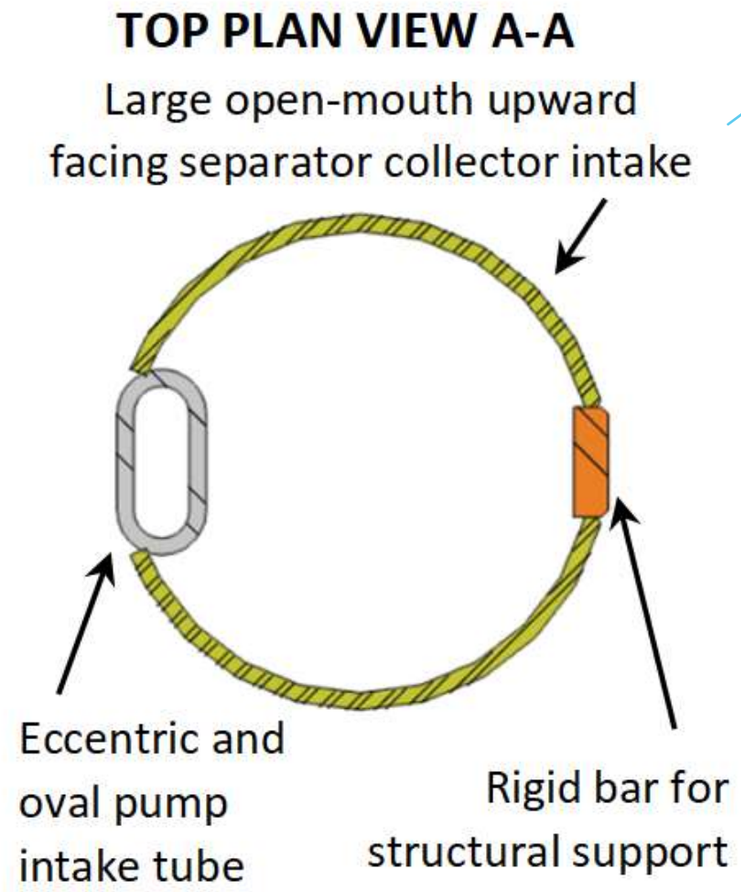


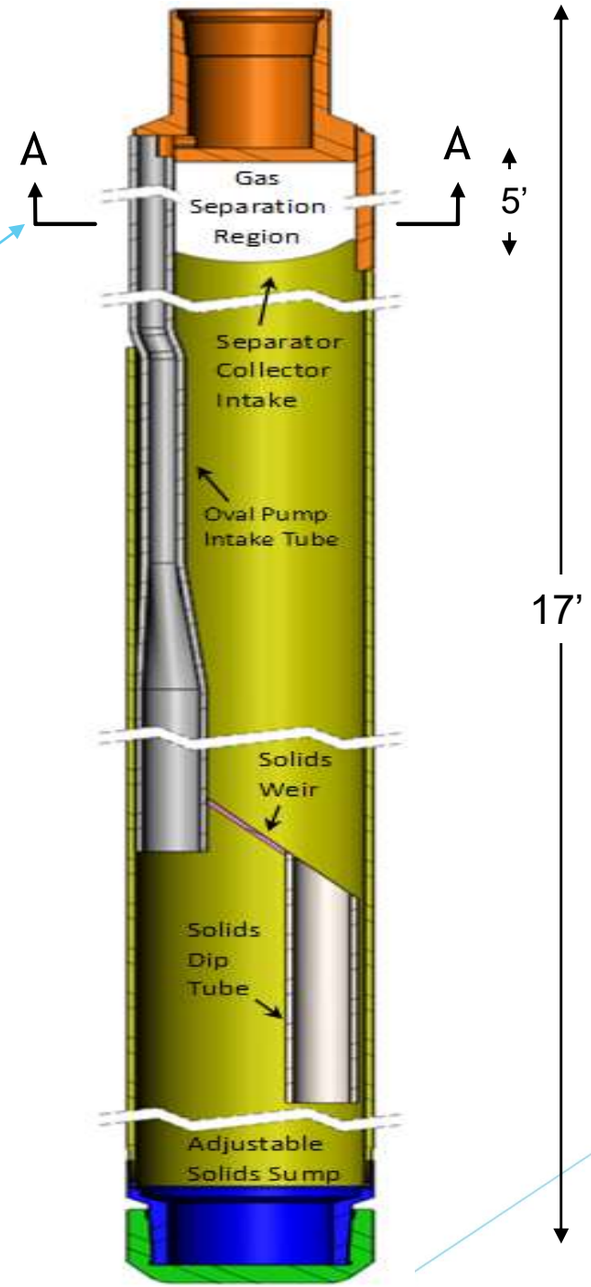
Flow Loop Testing Proof of Concept

Flow loop testing confirmed:

- achieved 100% separation efficiency
- eccentric and oval-shaped dip tube significant improves separator performance
- taking advantage of multiphase flow reversals with upward facing intake significantly enhances separation
- more efficient and greater capacity than packer-style separators
- ability to handle sluggy and inconsistent flows

WhaleShark[1] Separator





[1] Patent Pending and Trademarked

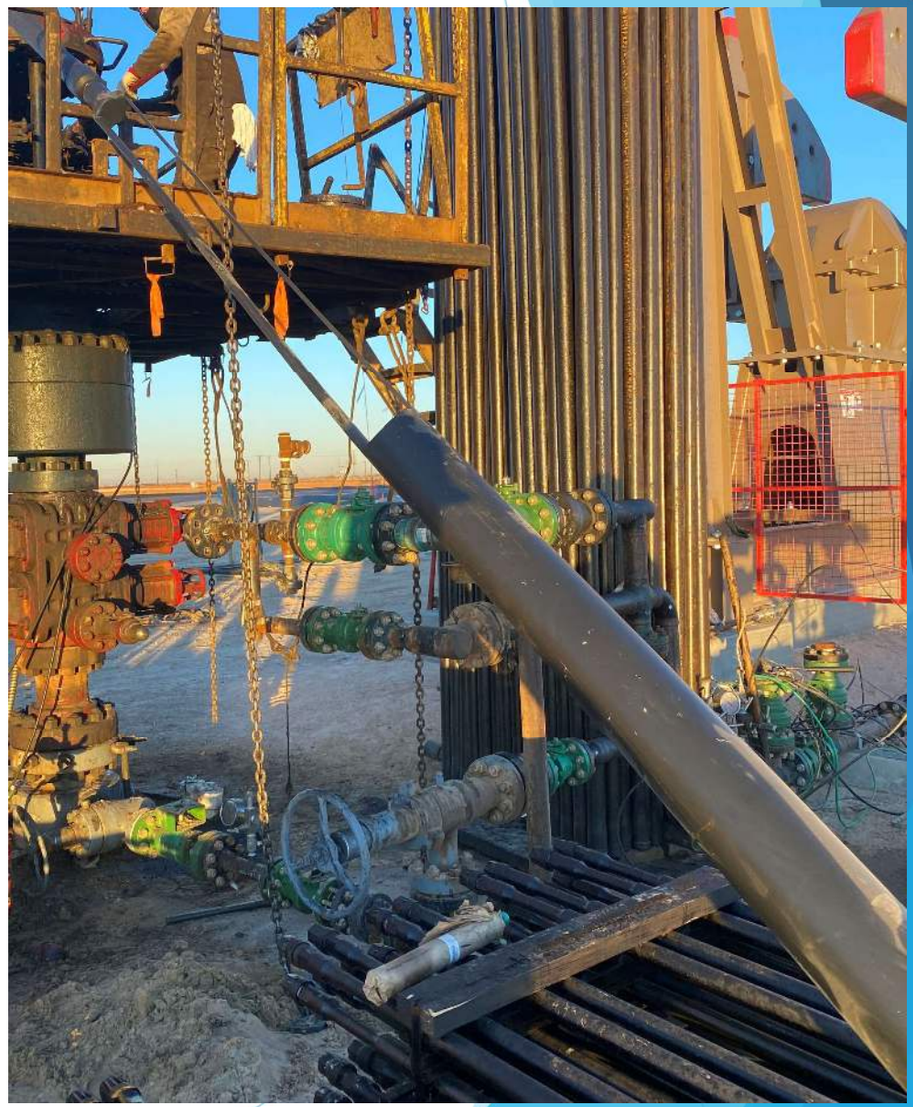
WhaleShark

Which fills faster?

1. Submerging an open top bucket

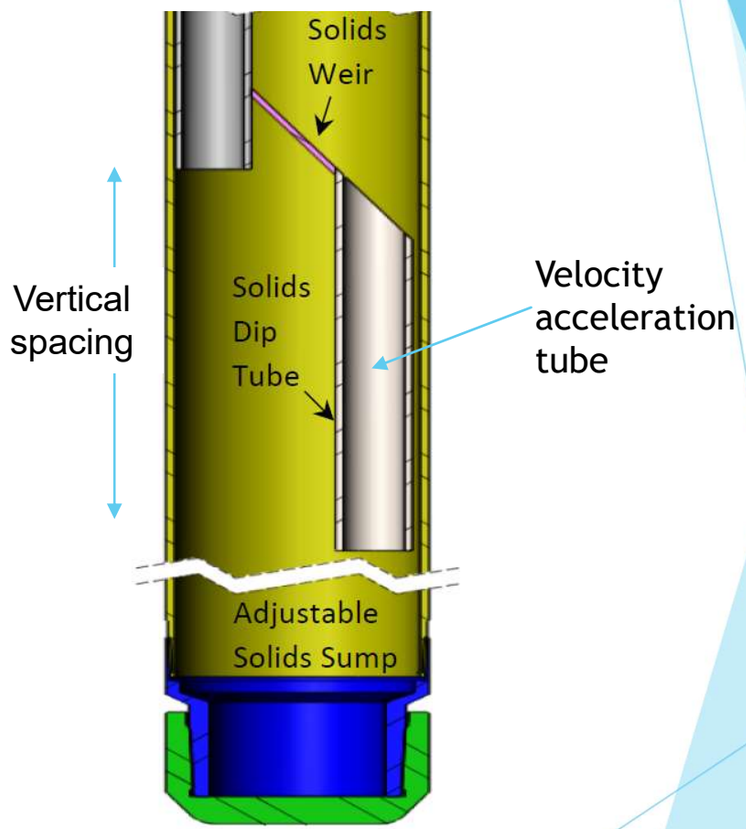
   or

2. Submerging a closed top bucket with side slots / ports



Solids Separation and Containment

- Process sequence is of critical importance for solids separation– must separate gas before attempting to separate solids
  - Limitation of packer separators, as challenging to separate solids under high multiphase fluid velocities before gas is separated
- WhaleShark uses proven surface separator technology – a weir and a velocity acceleration tube
  - Velocity tube speeds up the fall rate of the solids and therefore making it more difficult for solids to turn upwards towards the pump intake tube
- Adjustable and retrievable solids collection sump uses standard mud joints



Case Study: Anadarko Basin, Mississippian Lime

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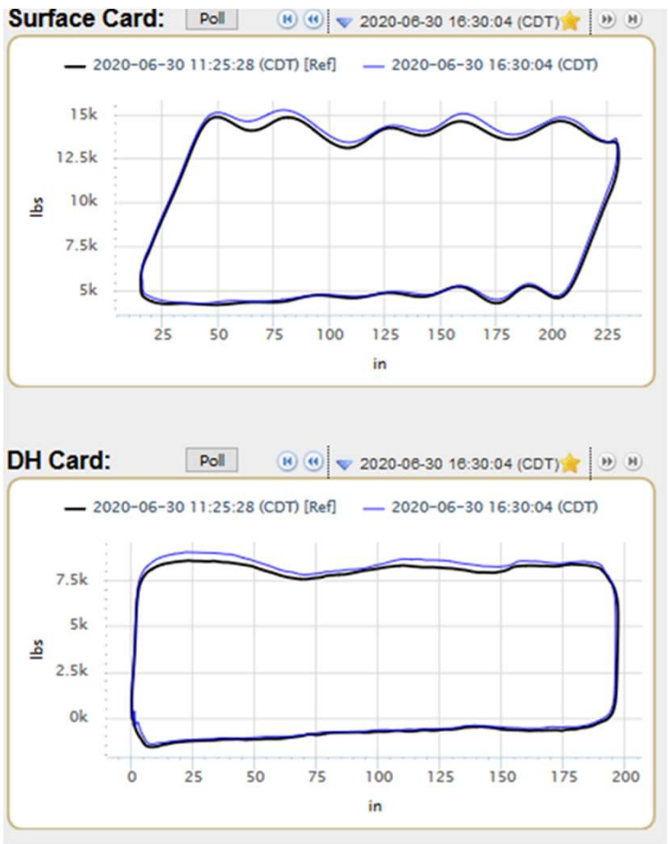
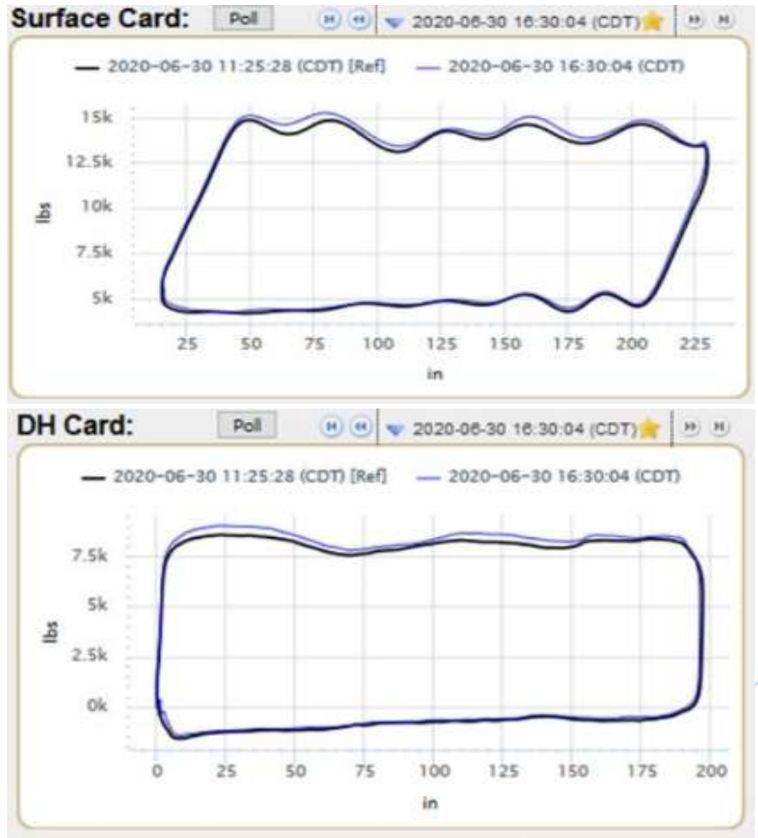
- High water cut gas wells, 5.5” casing
- Replaced gas lift system with rod pumping with WhaleShark
- Complete and consistent pump fillage at 500-600 bbls/day liquid and 1.3-1.8 MMscf/day gas

Well #1

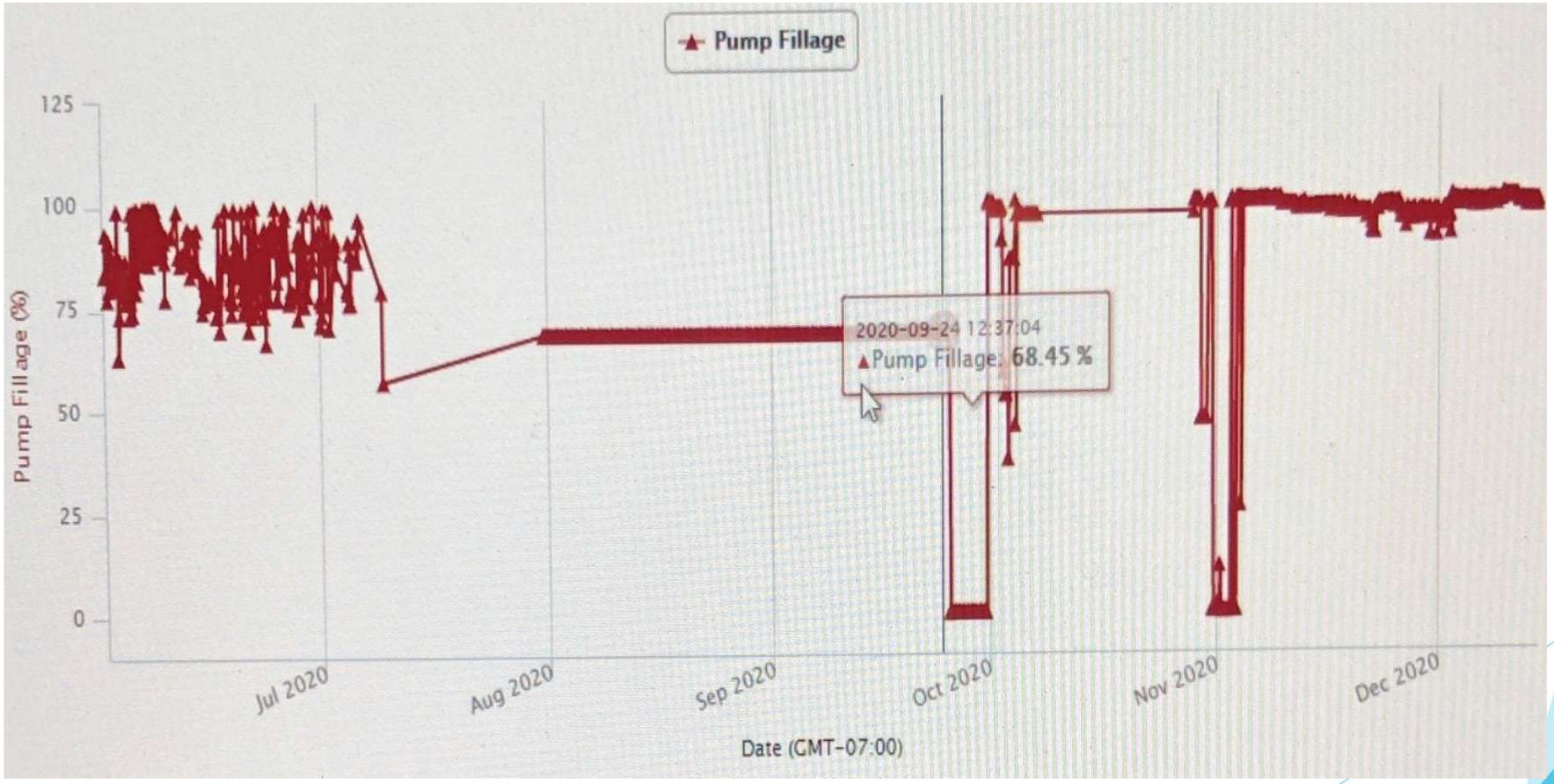


Well #2



Case Study: DJ Basin, Niobrara

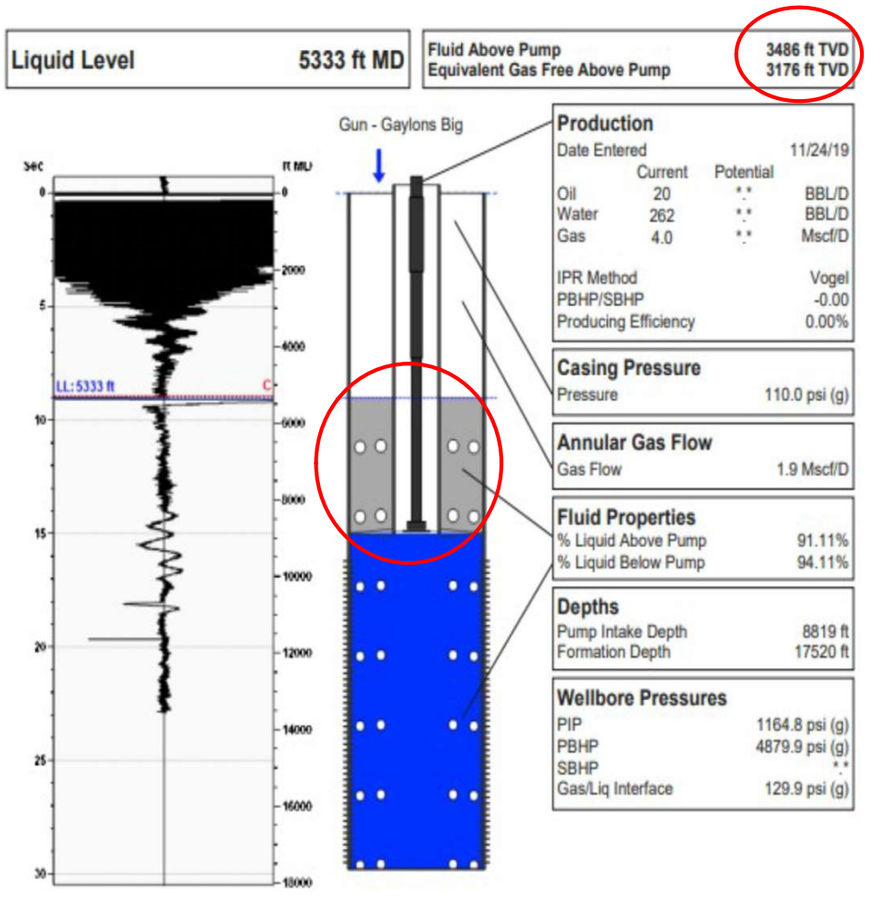
- Gassy oil
- Replaced poor-boy style separator
- Stable and consistent high pump fillage



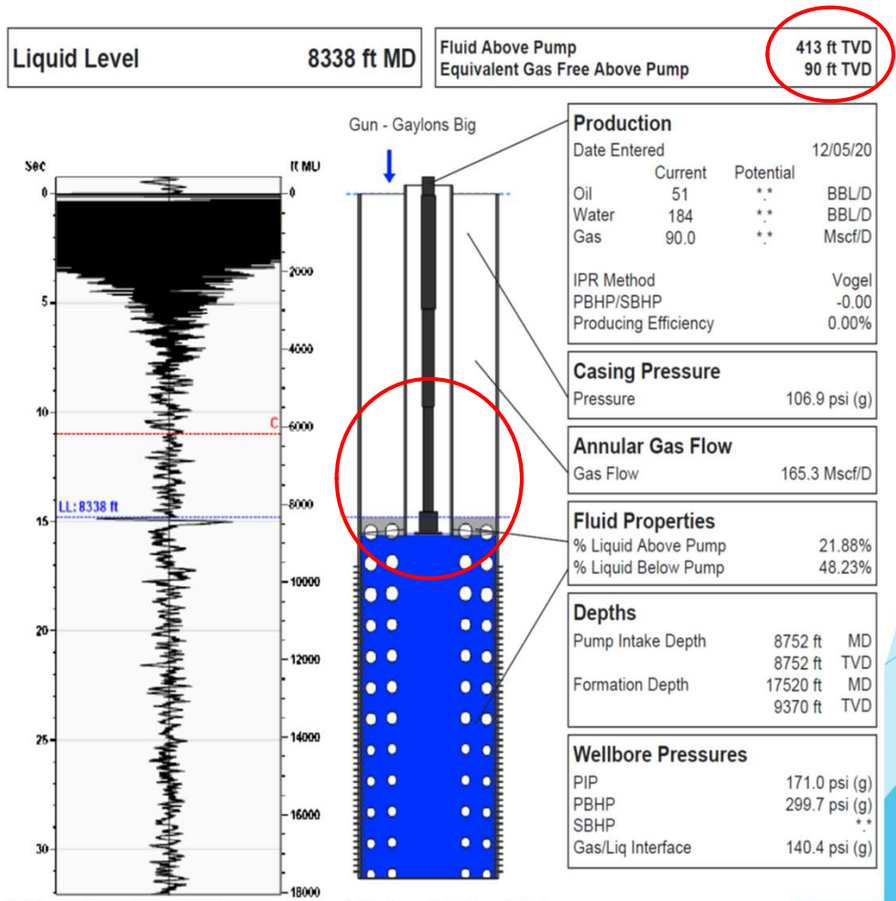
Case Study: Permian, Wolfcamp

- Gassy foamy oil/water
- Replaced packer-style separator
- Successfully pumped well off with consistent full pump cards

BEFORE

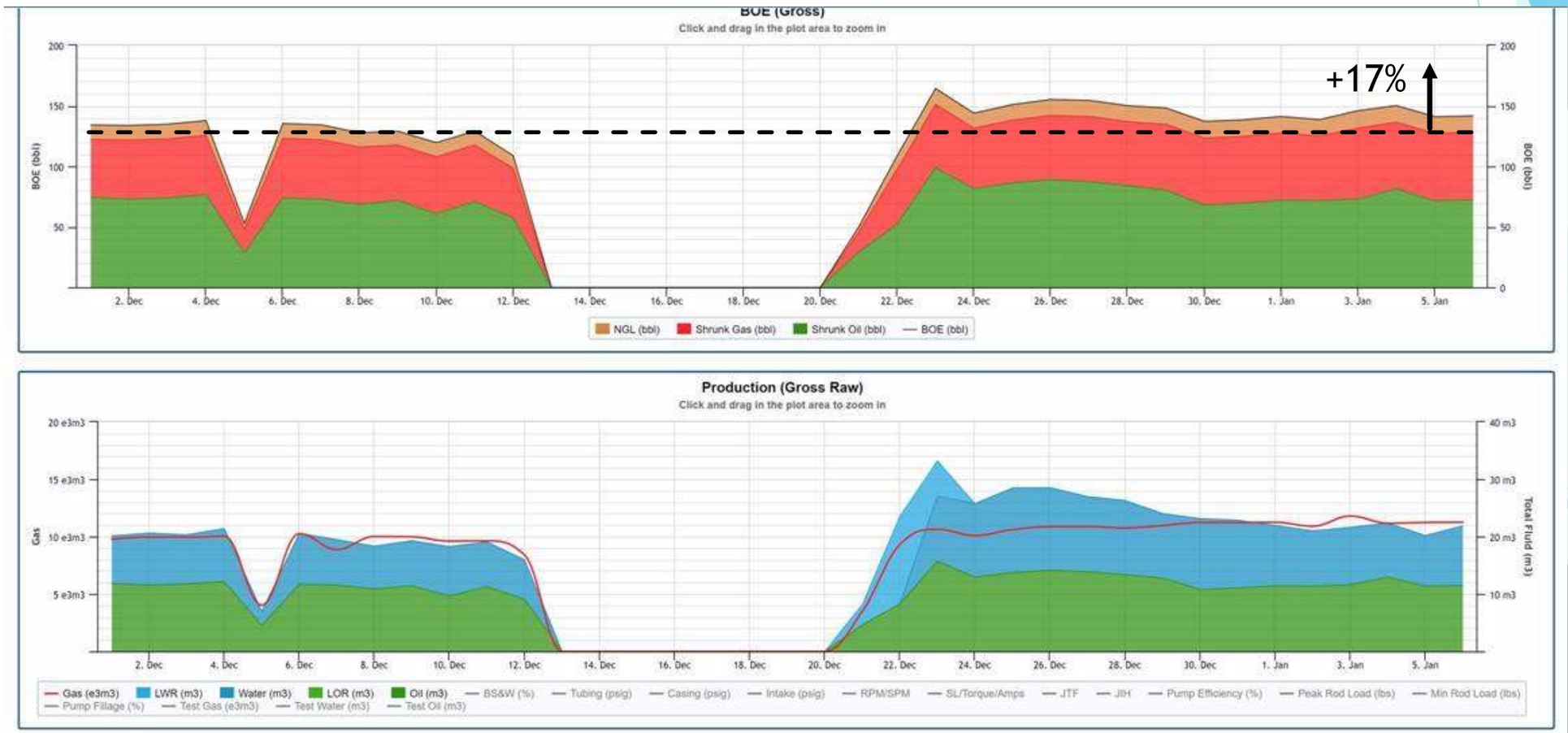


AFTER



Case Study: Canada, Charlie Lake

- Gassy foamy oil/water
- Replaced poor-boy weighted intake separator @ 60º inclination
- Successfully improved separation, reduced gas slugging and increased production (same SPM)



Thank You & Questions

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