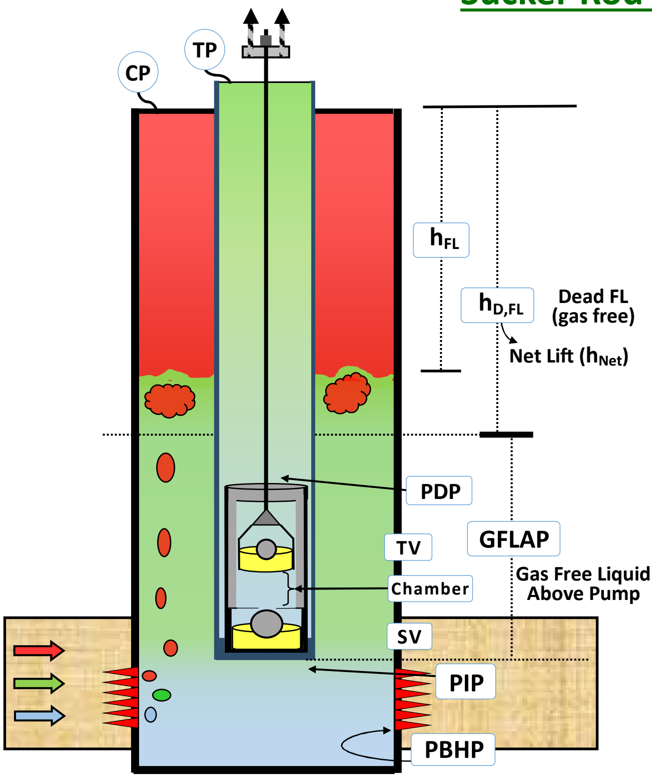
Sucker Rod Pumping Short Course 2.0



Note: Nomenclature table with units for all figures & equations given on the last page.

Calculated Production:

$$BFPD = 0.1166 \times d_p^{\,2} \times SPM \times SL_{DH} \times \varepsilon_p \times \%_{RT}$$

or

$$BFPD = C_p \times SPM \times SL_{DH} \times \varepsilon_p \times \%_{RT}$$

- ε_P: ≈ 0.85 for moderate wear/slippage
- C_P: Pump Constant →

Pump	C_P
1-1/16"	0.132
1-1/4"	0.182
1-1/2"	0.262
1-3/4"	0.357
2"	0.466
2-1/4"	0.590

Downhole Pump Operation:

- Up-Stroke: the SV opens and fluid fills the pump chamber (enters at PIP).
- Down-Stroke: the TV does not open (and thus no net fluid moved) *until* the fluid in the Pump Chamber is compressed to a pressure **>PDP**.
- Due to its compressible nature, free gas in the pump requires the plunger to travel much further into the down-stk before the gas becomes *compressed* enough (>PDP) for the TV to open. Additionally, as the plunger rises at the start of the up-stk the free gas *expands* to fill the new chamber volume created by the vacating plunger. This prevents the pressure in the chamber from rapidly dropping & necessitates the plunger travel further before $\mathbf{P_{CHAMBER} < PIP}$ (so the SV will open to admit new fluid into the pump). → [see *Gas Int*. card next page]

Fluid Load on Pump (F_O) & Pump Intake/Displacement P. (PIP/PDP):

$$F_O = \left(A \times \Delta P\right)_{Pgr} = \frac{\pi}{4} d_P^{\,2} \times (PDP - PIP)$$

$$PIP = CP\left(1 + \frac{h_{D,FL}}{40{,}000}\right) + 0.433 \times SG_O \times GFLAP$$

$$PDP = TP + 0.433 \times SG_{O/W} \times h_{SN}$$

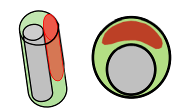
Note:

1) Only use TVD depths with hydrostatic calculations (if well is not vertical).
2) GFLAP = Gas Free Liquid Above the Pump (removes the gas volume).
3) In steady-state production, *only* oil/gas (no wtr) reside above the pump in the annulus.
4) The PIP equation above approximates the pressure due to the gas column (h_D/40,000) and is only applicable for lower CP wells (less than ~300 psi).

Downhole Gas Separator (DHGS):

How to Avoid Gas Interference:

1. Design the DHGS (and its placement) so that gas naturally bypasses the Entry Ports on the body of the gas separator.
   - Best achieved by sumping the pump. If pumping above perfs, it *might* be beneficial to **decentralize** the DHGS (set the TAC 3-10 jts above SN), & since no well is 100% 'vertical': the gas will ride the high side while the DHGS (& liquid) occupy the low side.
2. Design the DHGS so the downward fluid velocity is slower than the **Gas Bubble Rise Velocity** so the gas can escape up and out.
3. If the gas cannot be adequately removed look to install a specialty pump that is better equipped to "pass gas".
   - Managing gas: close pump spacing to maximize the Compression Ratio & longer SL units will help minimize interference.
4. TAC's if set above the perfs (due to their large diam) can create a bottleneck (gas flowing up, liquid trying to fall down) and can lead to "Liquid Hold-Up" that creates gas int: consider putting the TAC below the pump intake or Slimline TAC's.
5. Two general methods for gas separation: gravity driven (standard) or centrifugal/spinning designs.



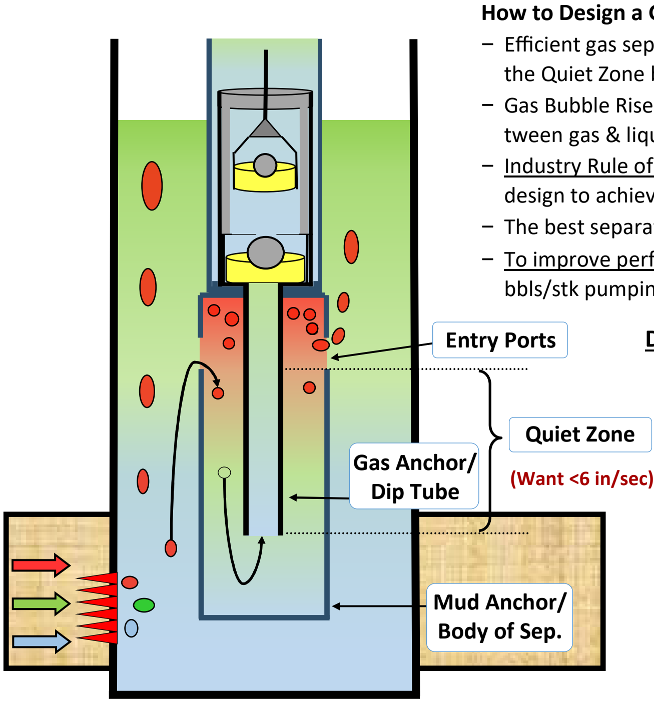
Decentralized DHGS: when a crooked hole has its benefits

How to Design a Gas Separator:

- Efficient gas separation requires that the **downward fluid velocity** in the Quiet Zone be **less** than the **Gas Bubble Rise Velocity**.
- Gas Bubble Rise Velocity occurs due to the density difference between gas & liquid and is proportional to the diameter of the bubble.
- Industry Rule of Thumb: a 1/4" gas bubble rises at 6 inch/sec. Thus, design to achieve a fluid velocity **<6 in/sec** (& the *slower the better*).
- The best separation can be achieved by sumping the pump.
- To improve performance: increase X-Sec Area & reduce the bbls/stk pumping rate (compensate by increasing run-time).

	OD	ID
GA: Gas Anchor (always listed by ID)		
3/4" GA	1.05	0.82
1" GA	1.315	1.05
1-1/4" GA	1.66	1.38
1-1/2" GA	1.90	1.61
MA: Mud Anchors ("Mother Hubbard")		
2-3/8" 4.7#	2.375	1.995
2-7/8" 6.5#	2.875	2.441
3-1/2" 9.3#	3.5	2.922
Casing as ID of Mud Anchor		
4-1/2" 11.6#	4.5	4.000
5-1/2" 17#	5.5	4.892
7" 26#	7	6.276

(Use grey boxes in EQ for V_{Fluid})

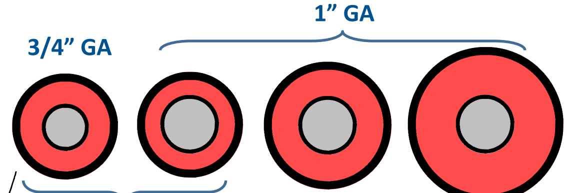


Downward Fluid Velocity in DHGS:

$$\vec{V}_{fluid} = \frac{d_p^{\,2} \times SL_{DH} \times SPM}{60 \times \left(ID_{MA}^{\,2} - OD_{GA}^{\,2}\right)}$$

Comparison of X-Sectional Area

(drawn to proportion)



Area of Quiet Zone, in²: 2.3 1.8 3.3 5.4

Sumped Pump (with 1" GA in Csg), in²: **11.2** (in 4-1/2" Csg); **17.4** (in 5-1/2" Csg)

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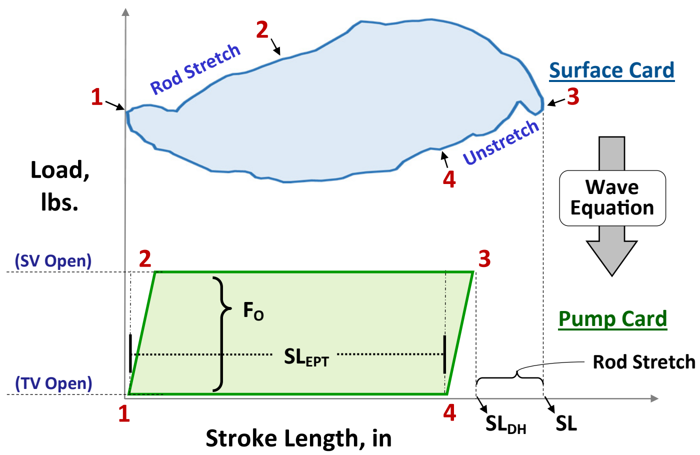
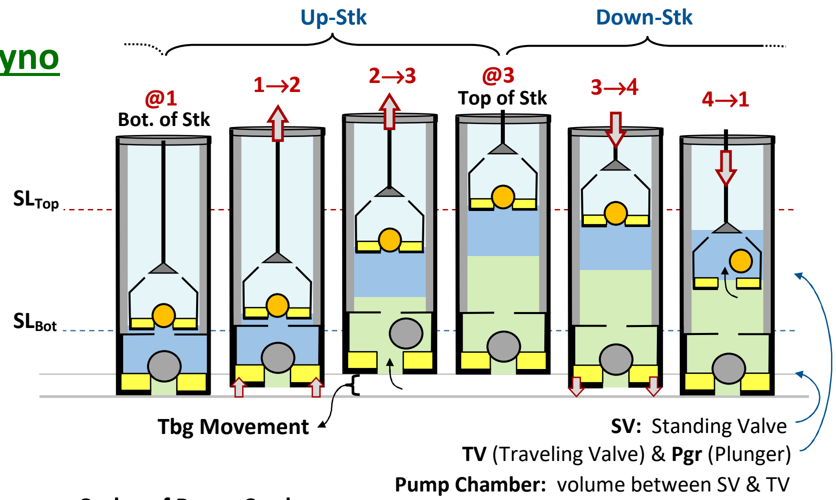
Pump & Dyno



Example Well: 10,000' well w/ 50% FG Rods with 2000' of Un-Anchored Tbg (slants pump card)



Cycles of Pump Card:

@1: **Bottom of Stroke**: Both valves initially closed (plunger not moving).
#1-2: **Expansion:** Pgr moves up picking up the fluid load, F_O. As F_O transfers from tbg to rods, the rods stretch and the tbg un-stretches & moves with the Pgr (delaying F_O pick-up—causing the slant in the pump card).
#2-3: **Intake:** SV opens @ **#2** to admit new fluid. Now: rods carry the full F_O
@3: **Top of Stroke**: SV closes as the plunger stops traveling upward.
#3-4: **Compression:** Pgr begins down. As F_O transfers from rods to tbg the unanchored tbg stretches. TV opens @ **#4** when $P_{Chamber}$ > PDP.
#4-1: **Discharge:** Pgr moves down through the fluid to repeat the cycle.

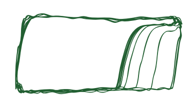
Dynamometer (Dyno) Cards:

- **Surface Card**: displays the load on the top Polished Rod (PR) over a pump cycle. The card shape is a summation of everything (rod string design and length, SPM x SL, fluid load on pump, PPU velocity profile, friction, etc.)
- **Wave Equation**: mathematically models the elastic nature of the rod string and allows us to take the surface recorded measurements and calculate what is happening downhole at the plunger (Pump Card) by removing the buoyant rod weight, acceleration forces and (assumed) frictional forces. There are different mathematical ways of solving this equation (Wave EQ, Everitt-Jennings, etc).
- **Pump Card**: displays the calculated fluid load on the pump plunger (F_O) over a pump cycle. How the fluid load is—picked up, carried and released—indicate the condition of the pump and what conditions it is operating in.
  - SL_{EPT}: **Effective Pgr Travel** (the ***only*** part of the stk that contributes to moving fluid). Depending on the card shape, the limitation will be which valve was open a shorter portion of the stroke: the SV or TV.
  - SL_{DH}: EQ to calculate the downhole plunger travel.

$$SL_{DH} = SL - Stretch_{Rods} + OverTravel$$

The 3 Causes of Incomplete Pump Fillage:

1. **Pumped Off**: Pump Capacity > Reservoir Inflow
2. **Gas Interference**: gas compressibility interfering with the normal actuation of the SV & TV.
3. **Choked Pump**: restricted inflow to pump (plugged intake or excessively high fluid friction in the Dip Tube).



Compression Ratio of the Pump:

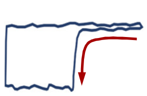
- Anything that increases the compression ratio improves the pump's ability to compress the fluid in the pump chamber & *minimizes* the percentage of the downhole stroke lost due to gas compression.
- Longer SL's dramatically help, but minimizing the Unswept Volume is the most crucial & is achieved by: **close pump spacing** along with good pump design (type of pump, high-compression cages, etc.).

$$Comp\ Ratio = \frac{Swept\ +\ Unswept\ Volume}{Unswept\ Volume} = \frac{Vol\ (@\ Top\ of\ Stk)}{Vol\ (@\ Bot\ of\ Stk)}$$

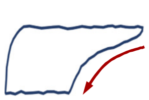
Interpreting Pump Card Shapes:

Ideal Card: fully anchored tbg, 100% liquid fillage, & pump in perfect condition.

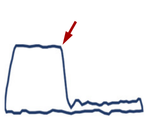
Unanchored Tbg: slant caused by tbg stretching and unstretching; slants at K_{Tbg} (Tubing Spring Constant).



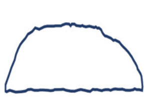
Fluid Pound: sudden impact load due to insufficient liquid to fill the pump chamber. Inefficient and very damaging to pump, rods, and tubing. (Low P gas)



Gas Interference: a more gradual load transfer as the higher P. gas in the pump compresses. Gas Int. greatly reduces the pumping efficiency and indicates the gas separator design could be improved.



Hole In Barrel: as the bottom of the plunger passes the hole (arrow) the hydrostatic pressure is equalized across the plunger causing the F_O to be lost. This shape only applies to bottom hold-down insert pumps.



Worn Pump: slow to pick up & quick to release the fluid load, due to: plunger/barrel wear or TV leaking.

More example cards @ www.DownholeDiagnostic.com www.RodPumpingOptimization.com

Pump Card Interpretation:

1) The Pump Card **only represents** the load on the plunger: so no rod stretch or anything above the plunger should be displayed in it.$^{\psi}$
2) The card shape indicates how the plunger picks up, holds, and releases the fluid load each stroke. Deviation from the ideal rectangle -> problem
3) Keep in Mind: the TV & SV are **one-way check valves** & they only open when the pressure below is greater than the pressure above.
4) *The key to interpretation*:

   The card shape depends only$^{\psi}$ on how the pressure changes inside the pump barrel relative to the plunger movement + tagging forces!

   - At the start of the DOWN-Stk, a non-vertical line indicates F_O not immediately released: due to F#, gas int., tbg movement , or leaking SV.
   - At the start of the UP-Stk, a non-vertical line indicates F_O not immediately picked up: gas expansion, tbg movement , or Delayed TV Seat.
   - $^{\psi}$**Caveat:** things happening higher up hole, if not stripped out by the Wave EQ, plot in the Pump Card even if not happening there—like excessive rod-tbg friction, SBox friction—and will distort the card shape.

Not all dynamometer plots are drawing accurately so be careful before you interpret everything literally. Common distortions can occur depending on the system you are using. The **PRT** (Polished Rod Transducer) measures the change in PR diameter and converts that to the change in load, but PR bending due to a misaligned PPU will distort the cards in various ways. Cards drawn by POC's can exhibit **"Card Rotation"** if the position data does not exactly line up with the load data, so make sure your POC cards are accurately calibrated before interpreting.

Sucker RP Equipment Design: Considerations

Downhole Diagnostic

Equipment Design:

- The pumping system should be designed for the long-haul.
- Don't overdesign. If the well is expected to pump-off in 1-year—at which point the production can be maintained with a slower SPM & downsized pump (decreasing the loadings)—great savings can be incurred by temporarily (fully) taxing a smaller GBox/PPU or temporarily overloading rods (using Grd-D vs HS Rods), for that 1st year instead of upsizing.
- **Longer SL's and slower SPM is preferable**. Advantages include:
  - With a Longer SL: Rod-stretch, gas compression, or unanchored tbg movement will consume a *smaller percentage* of each stroke.
  - Long SL's *increase* the compression ratio & the ability to pump gas, & require *fewer* down-stks **[**rod buckling**]** to achieve the same prod.
  - Slow SPM reduces: acceleration changes, buckling tendencies, rod loadings & the impact force of the plunger if it does #Fluid or tag.

Rod Design:
Sucker Rods are designed to *only* operate in tension (hence heavy sinker-bars commonly installed on bottom). Rods operate in a *pulsating tension* along each stroke as the F_O is picked up & released—and as a result of the stress reversal cycles—they have a limited run life. The **API Modified Goodman Diagram (MGD)** is the industry design guide that that attempts to quantify if a rod design will have a "sufficient" run life based on the Min & Max stress loadings the rods will experience under the operating conditions. In a noncorrosive environment, a **steel rod** operating at 100% MGD Loading is expected to have a run-life *greater than* 10×10^6 cycles [or 10 SPM pumping for ~2 years), while **FG rods** @ 100% loading have an expected >7.5×10^6 cycles @ 160°F. As the MGD loading decreases below 100%, the expected run-life increases *exponentially*. Since the MGD loading value does not take into account corrosion [or buckling, mis-handling damage, etc.] the MGD loading can be de-rated by a Service Factor+ related to the corrosivity/conditions of the downhole environment.

Fiberglass Rods: (AKA, **FRP Rods: F**iber **R**einforced **P**lastic)
- Weigh 70% less & are 4× more elastic than steel, are corrosion resistant (**not** de-rated for corrosive environments), have an undersize pin (allowing 1" FG rods to be used in 2-3/8" tbg, etc.) & have mechanical strengths greater than HS-steel rods. Their expected run-life is temperature dependent.
- FG elasticity is advantageous for fast pumping wells with high fluid levels (leads to plunger Over-Travel). Their elasticity is **dis**advantageous for slower pumping wells with large F_O (SL_{DH} is lost to rod-stretch). This is why on pumped-off FG wells, downsizing the pump might not substantially reduce production: the *downsized* d_P *increases* the DH_{SL} (due to smaller F_O).

Steel Rods:
- Rod Grades (**C**, **K**, **D**, & **HS**): selection should be made based on the mechanical loadings on each taper and the downhole corrosivity.
- Grd D rods: **DC** (carbon), **DA** (alloy), & **DS** (special).
- Different alloys and heat treating processes create different mechanical properties. Generally, as rod strength increases the rod becomes more brittle and less forgiving: i.e. a small *Stress Riser* (pit, imperfection) is more likely to rapidly propagate across the x-section and lead to complete failure.
- Sinker Bars: are designed to absorb the DH compressive forces & keep the higher rods in tension. Their larger OD distributes side-loads from buckling forces over a larger area—so they do not cut as incisively into the tubing.

Rod Boxes: (AKA: Rotary-Connected, Shoulder-Friction-Held Connections)
- The make-up torque (checked by Circumferential Displacement) puts tension in the rod pin and friction-locks the box to the face of the pin shoulder. This pre-stress put into the connection must be greater than the up-stk dynamic rod load which attempts to pull the connection apart.
- Two grades: Grd-T (standard) & SM (Spray Metal; hard surface finish)

Pump:
- Insert (Rod) Pump, 3-types: based on where the Hold-Down is located (top or bottom) & whether the barrel is Stationary or Traveling.
- Tbg Pumps: used in wells needing a larger plunger diameter as the barrel is screwed onto the bottom of the tbg (the d_{PGR} can be up to a 1/4" < ID of tbg). If a larger diameter is needed—> **OTP** (Oversized Tbg Pump)
- First efforts should be made to exclude gas & solids from entering the pump with a good gas/solids separator, but specialty pump designs/components can help in dealing with gas/solids to minimize their impact.

Tubing & TAC: (**T**ubing **A**nchor **C**atcher)
- Unless anchored with pre-tension, the tubing will stretch and contract each stroke as the rods pick up & release the F_O. This "breathing" de-creases the pumping efficiency because *only* the **net relative movement** of the plunger to the pump barrel contributes to fluid displacement.
- With **un**anchored tbg: on the down-stk, as the plunger starts down & begins to release the F_O (onto the SV/tbg) the tbg stretches accordingly. On the up stk, the tbg recoils as the rods/plunger pick up the F_O—causing the pump barrel to initially move upward with the plunger.
- Smaller diam pumps will cause *less* tbg stretch as there is a smaller F_O; also, anchoring a portion of the tbg string will reduce overall tbg stretch.
- Eq. for **Tbg Stretch** or to calculate the **Depth to Free-Point** (stuck pipe):

$$Tbg\ \ Stretch = k_{tbg} \times L_{tbg} \times F_{Pull} \qquad k_{tbg} = 0.4 / A_{tbg,\text{x-sec}}$$

  - **Note**: Stretch (inches); L_{tbg} (in 1000's of ft); F_{Pull} (1000's of #'s).
  - k_{tbg} = Stretch Constant: is *not* affected by the grade of steel, only the x-sec area (k_{tbg} given on *p.5* or use above EQ)
  - L_{tbg} = Length of tbg being stretched by the force, F_{Pull}
- Proper TAC Setting Procedure: after 8 left-hand turns (or until it torques up) continue to hold the torque as the operator alternates 10 pts tension & compression before releasing the pipe wrenches (this works the torque downhole & **fully** engages the TAC slips so it will not turn loose).

+ Possible Service Factors for Sucker Rods: (to derate rods)

Environment	Grd C	Grd K	Grd D	HS Rods
Non-Corrosive	1.00	1.00	1.00	1.00
Salt Water	0.65	0.90	0.90	0.70
H2S	0.45	0.70	0.65	0.50

On deeper wells, using Service Factors will commonly push the designer to use HS Rods to stay below 100% loading, but since HS Rods are more susceptible to corrosion failures, Service Factors are not as commonly used nowadays.

Load on the Polished Rod (PR):

$$F_{PR,Up-Stk} = W_{rf} + F_O + F_{Dynamic/\text{friction}}$$

$$F_{PR,\text{Down}-Stk} = W_{rf} - F_{Dynamic/\text{friction}}$$

- W_{rf} = Weight of rods in fluid (compared to W_r: weight of rods in air)
- In fresh water, **FG rods** weigh 58% of W_r & **steel rods** = 87% of W_r.
- Dynamic Loads: result from acceleration forces
- Friction Loads: due to fluid friction ("viscous friction"), rod-on-tbg side-loads ("drag friction"), SBox friction, paraffin friction, and pump friction ("plunger drag").
- Proper Counter-Weight Balance requires balancing the **average** load on the Polished Rod, thus:

$$CW\ \ Bal = W_{rf} + 0.5 \times F_O$$

Laboratory Measured Loads to Buckle Rods:
- Test conducted with rods in air (Long & Bennett, 1996)
- Notice the large difference even between the 3/4" and 7/8" rods.

Rod Diam.	Force to Buckle
3/4	23#
7/8	162#
1 3/8	641#

Equation for FG Rod Spacing: Inches Off Bottom

$$FG\ \ Spacing = \frac{9 \times h_{FG\_Rod}}{1{,}000} + \frac{2 \times h_{SN}}{1{,}000}$$

- Space 9" for every 1000' of FG Rods & 2" for every 1000' to SN.
- Slow stroking units can space closer than the calculated spacing.
- For proper pump spacing (*especially* w/ FG rods due to their elasticity), load the tbg with fluid *prior* to spacing the pump out.

SRP Optimization

Failure Prevention

Design Considerations:

- Not all rods are the same: lower strength rods are more ductile and forgiving. Rods can have different levels of alloying metals, impurities, and heat treatments: **Q&T** (Quench & Temper) vs **N&T** (Normalize & Temp).
- Consider installing boronized tbg, IPC (Internally Plastic Coated), or Poly-Lined tbg on bottom (or failure prone sections) where tbg leaks occur.
- Spray Metal Boxes: corrosion resistant and made for highly erosive/ corrosive environments. The SM coating is more abrasive on the tbg because the tbg will wear down before the box does (as opposed to softer **T**-boxes). So what is failing most for that well: boxes or tbg?

Pulling the Well:

- Create a Pre-Pull Plan: review location of recent failures, latest well tests, and FL/Dyno reports to see if DH equipment should be modified.
- On 1st tbg failure, scan the tbg out of hole: to get an initial *rod wear profile* on the new tbg & to check chemical program (pitting).
- During a tbg job: rotate ~10 jts of "fresh" tbg from top to bottom.
- During a rod job: rotate a steel pony rod (≥ SL) to bottom. This shifts all the boxes up out of their existing wear tracks to rub on fresh tbg.
- Root-Cause Failure Analysis: *Identify the cause!* Clean corrosion deposits off with a wire brush/diesel, cut failed tbg jts open, discuss with Chemical Co. & take pictures to include in the pull report for future reference.

Operations & Monitoring:

- **Stoke her long & stroke her slow—and match her inflow**.
- Keep the pump barrel full! Ensure proper run-time by calibrating it with a FL Shot/Dyno Test or production well tests, or install a POC.
- As the well pumps off, reduce the SPM: this improves run-life, improves downhole gas separation, & is **insurance** by **reducing the force of impact** generated if (*or* when) the plunger pounds fluid or tags.
- Mix in biocide with any fluids introduced into the well. Bacterial pitting can be the most aggressive in drilling holes in your rods & tbg (…& csg!)

Fluid Level Gun & Dyno:

- **Fluid Level** & **Dyno** Surveys are noninvasive diagnostic tools that quantify the well's ***Producing Performance***—in terms of the well's Production Potential (reservoir drawdown) & the Operational Lifting Efficiency of the rod pumping system (how efficiently the fluid is being lifted to surface).
- By interpreting the diagnostic data in context of the well, producing inefficiencies can be detected & corrected. The diagnostic data **lays the foundation** from which **prudent operational decisions** can be made & justified.
- **Dyno's**: measure rod/pump performance (see *Pump & Dyno* page).
- **Fluid Level Gun**: generates an *acoustic wave* (pressure pulse) that travels down the well, reflects off cross-sectional changes in area (collars, perfs, TAC) until the wave encounters the fluid level & completely reflects back.
- The gun's internal microphone records the amplitude and polarity of the reflections on an **Acoustic Trace** (shown below) and allows the depth to the top of the Fluid Level to be determined.
- The subsequent Casing Pressure Build-Up Test allows for the quantification of the MCFPD of gas producing up the casing and, consequentially, allows for the determination of the **GFLAP** (Gas Free Liquid Above Pump) and **BHP's** (Bottom Hole Pressures), like: ***PIP***, ***PBHP***, & ***SBHP***.
- **Polarity of Acoustic Reflections**:
  - ↑**kick**: **Increase** in Cross-Sectional Area (negative reflection) - perf, etc.
  - ↓**kick**: **Reduction** in Cross-Sec Area (positive reflection) - TAC, Liner, FL

Objectives of Rod Pumping Optimization:

Fully achieve the well's maximum producing potential with minimum expenditure (*including* time & attention).

How RP Optimization is Achieved:

1) **Good Equipment Design:** rod/pump/PPU design, gas separation, SPM x SL, metallurgy, SN placement, etc.
2) **Equip. Installation:** properly torque, avoid damaging, etc.
3) **Match:** Pump Capacity ≈ Reservoir Inflow
4) **Operations:** Avoid Fluid#, Gas#, & Pump Tagging
5) **Chemical Program:** Both active and **re**active
6) **Inspiration:** Field hands must buy into the program

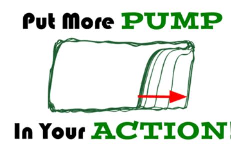
Changing PPU SPM:

$$SPM_{New} = SPM_1 \frac{d_{New}}{d_1}$$

Frame Size	Shaft Diam
143T, 215T	1-3/8"
254T, 256T	1-5/8"
284T, 286T	1-7/8"
324T, 326T	2-1/8"
364T, 365T	2-3/8"
404T, 405T	2-7/8"
444T, 445T	3-3/8"

- To change the SPM the existing motor sheave size (d_1) & the motor shaft diameter (measured or correlated with Frame Size on motor) must be known.
- Drive belts sit ~4/10" within the sheave OD, thus a measured 7.4" sheave OD is really a 7" sheave.
- For an expanded list of frame sizes: **www.downholediagnostic.com**
- The smallest sheave size is 5". If the desired SPM would require a sheave size smaller than 5" look into: upsizing the Bull sheave (on GBox), install a **jack-shaft** or a **VFD** (Variable Frequency Drive), or consider shortening the SL. FYI: "sheave" is pronounced "shiv".

Gas Interference, "Gas Pound" & Fluid Pound (F#):

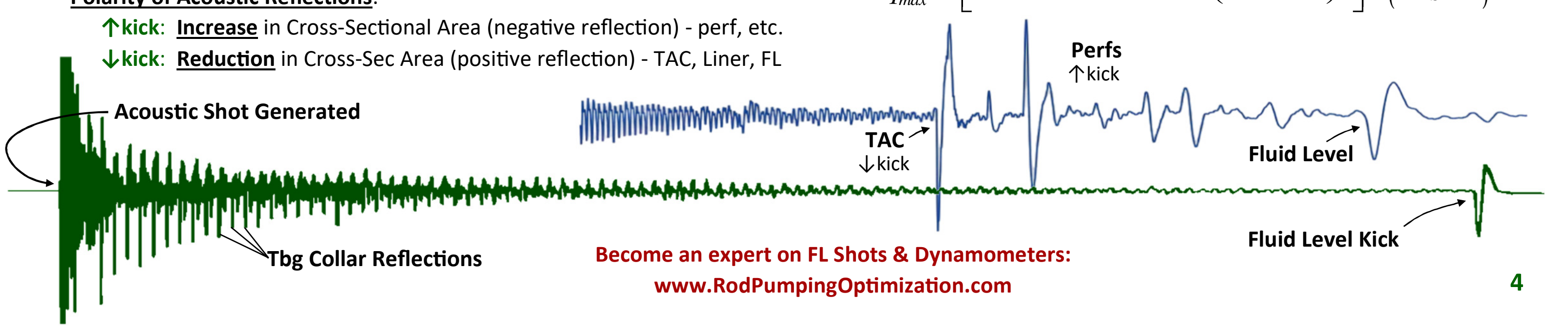


- Gas Pound is essentially Fluid Pound but w/ a higher PIP (~gas int. w/ sudden F_O release).
- Gas Int. is *just as inefficient* as Fluid# but—due the cushioning effect of the gas—it is less destructive to the downhole equipment.
- Although less damaging on a stk-to-stk comparison, gas interference is potentially worse than F#: 1) The well must run more to "pump thru the interference" so it often operates with low fillage, and 2) Gas Int. usually means you cannot pump the well off (so loss of prod). Wells without gas int. do not need to operate w/ low fillage—> down-time.
- Pounding is a shock loading that induces the rods to bend/buckle as they bow out and engage the tbg walls. The **force of the impact** is proportional to: F_O (thus d_P^2), the velocity of the plunger at the time of impact, and the time duration for the load transfer to occur.
- Gas# or Fluid# in the **middle of the down-stk** is more damaging because here the plunger is at *peak* downward velocity.
- Fluid# can often be detected by listening for GBox "thuds," motor speed changes, & watching for the bridle/Polished Rod to twitch on the down-stk . However, for slower SPM, deeper wells or FG rod-strings, it can be more difficult to identify without the aid of Dynamometer cards.

Vogel's IPR (Inflow Performance Relationship):

Well's Producing Efficiency on the Reservoir (ratio); WT: Well Test

$$\frac{q_{WT}}{q_{max}} = \left[1 - 0.2\frac{PBHP_{WT}}{\overline{P}} - 0.8\left(\frac{PBHP_{WT}}{\overline{P}}\right)^2\right] \quad (\overline{P} = SBHP)$$



Become an expert on FL Shots & Dynamometers:
www.RodPumpingOptimization.com

Rod, Tbg & Csg Specs

Downhole Diagnostic

In general, the API minimum standards are listed on this page for the most common grades of pipe used in the **Permian Basin**. Individual products from manufacturers might exceed some of the listed mechanical properties. Consult the manufacturer for specifics & use a **Safety Factor** to de-rate used rods/tbg.

	Diam in	Wt in Air lb/ft[ψ]	X-Sec Area, in^2	Diam of Coupling: Slim Hole OD, in	Diam of Coupling: Full Hole OD, in	(Stuck Pump) Grd D Rods [θ]Max Short Term Pull, lbs
Steel Rods	**5/8”**	1.11	0.307	1 1/4	1 1/2	24,500
	3/4”	1.63	0.442	1 1/2	1 5/8	35,500
	7/8”	2.22	0.601	1 5/8	1 13/16	48,000
	1”	2.90	0.785	2	2 3/16	63,000
	1 1/8”	3.68	0.994	2 1/4	2 3/8	80,500
				Pin Size		
Sinker Bars	**1 1/4”**	4.17	1.227	**5/8 or 3/4**	/	Not usually a concern.
	1 3/8”	5.00	1.485	**5/8 or 3/4**	/	
	1 1/2”	6.00	1.767	**3/4 or 7/8**	/	
	1 5/8”	7.00	2.074	**7/8**	/	
	1 3/4”	8.20	2.405	**7/8**	/	
				Pin Size		*FG Max Short Term Pull[MS], lbs
FG Rods	**3/4”**	0.53[MS]	0.424[MS]	**3/4**	Match Pin Size to steel rod diameter for available box sizes.	**20 - 21**,000
	7/8”	0.65[MS]	0.578[MS]	**3/4**		**25 - 29**,000
	1”	0.88[MS]	0.760[MS]	**7/8**		**35 - 50**,000
	1 1/4”	1.38[MS]	1.200[MS]	**1**		**50 - 70**,000

[ψ]Weight of couplings not included. The **lb./box** (Full Hole) goes from: **1.3#** (5/8”) → **3.1#** (1-1/8”).
[θ]Max Pull for new rods based on a smooth pull (**not** herky-jerky). The load pulled at the top of each taper must be computed and the pull should not exceed the lowest limit. De-rate w/ a S.F.
[MS] **Manufacturer Specific**: **average values given** (except the FG Max Pull shows the range between the 3-primary manufacturers). Max Pull on **FG Rods** is limited by the end-fitting connection.

Rod Grade	Min Yield Strength, psi	Min Tensile Strength, psi	AISI Designation
Grd C	60,000	90,000	C-1536-M
Grd K	60,000	90,000	A-4621-M
Grd D	85,000	115,000	A-4630-M
HS Rods	115,000	140,000	A-4330-MI
FG Rods	90,000	115,000	/

Min. *Yield* Strength: the max stress the rod can bear before yielding (i.e. before the stress crosses over from **elastic stretch** to **plastic deformation**). Beyond this stress the material is permanently elongated! (use for max stress calcs.)

Min. *Tensile* Strength, T_{Min}: the stress that will cause the material to pull into 2-pieces. Depending on the Max & Min stress fluctuation experienced by a rod during the pumping cycle the **100% MGD Loading** resides between 36-57% of T_{Min}. As the min. stress on the down-stk *approaches* buckling (zero load), 100% MGD = 36% of T_{Min}

$$Stress = \frac{Force}{Area} \qquad Strain = \frac{\Delta L}{L} = \%\,Elongation$$

	Diam in	Weight #/ft	Metal X-Sec Area, in^2	ID in.	Drift in.	OD of EUE Collar, in.	Capacity: bbls/ft	Capacity: [+]ft/bbl	Displacement *bbls/ft	k_{tbg}, Stretch Constant
Tbg (EUE)	**2 1/16”**	**3.25#**	0.933	1.751	1.657	na	**0.00298**	336	0.00116	0.42781
	2 3/8”	**4.7#**	1.304	1.995	1.901	3.063	**0.00387**	258	0.00167	0.30675
	2 7/8”	**6.5#**	1.812	2.441	2.347	3.668	**0.00579**	173	0.00232	0.22075
	3 1/2”	**9.3#**	2.590	2.992	2.867	4.500	**0.00870**	115	0.00334	0.15444
Csg	**4 1/2”**	**10.5#**	3.009	4.052	3.927	5.00	**0.0159**	63	/	0.13294
		11.6#	3.338	4.000	3.875	"	**0.0155**	64	/	0.11983
	5 1/2”	**15.5#**	4.514	4.950	4.825	6.05	**0.0238**	42	/	0.08861
		17#	4.962	4.892	4.767	"	**0.0232**	43	/	0.08061
		20#	5.828	4.778	4.653	"	**0.0222**	45	/	0.06863
	7”	**26#**	7.549	6.276	6.151	7.656	**0.0383**	26	/	0.05299
		29#	8.449	6.184	6.059	"	**0.0371**	27	/	0.04734

[+]Note: ft/bbl has been rounded. *Displacement (bbls/ft) for EUE open-ended tbg (includes the disp. volume of upsets & couplings).

Tbg Joint Yield Strength Calc:

Ex: 2-3/8” 4.7# N-80

X-Sec Area = 1.304 in^2

Min Yield = **80**,000 lb/in^2

$$80,000 = \frac{Force}{1.304}$$

Thus, the min. force to yield new tbg = 104,320#.

Used Tbg, API Bands

Color Band	Body Wall Loss
White	Brand New
Yellow	0-15%
Blue	16-30%
Green	31-50%
Red	51-100%

Mechanical Properties of EUE (External Upset End) Tbg:

Tbg Size	Weight #/ft	Grade	Collapse Pressure, psi	Burst Pressure, psi	Max Pull to Yield, Lbs.	MakeUp Torq. (optim.), ft-lb
2 3/8”	**4.7#**	**J-55**	8,100	7,700	71,730	1290
		L/N-80	11,780	11,200	104,340	1800
		P-110	13,800	15,400	143,470	2380
2 7/8”	**6.5#**	**J-55**	7,680	7,260	99,660	1650
		L/N-80	11,160	10,570	144,960	2300
		P-110	13,080	14,530	199,320	3040

Tubing API Grade: “Letter Grade”—“Min. Yield Strength (in 1000’s of psi)”
(Different heat treating processes & alloys combine to create the higher strength grades)

Buoyancy Force: is equal to the weight of the fluid displaced by the immersed object.

- ρ_{steel} = 489 lb/ft^3 & $\rho_{Fiberglass}$ = 150 lb/ft^3.
- In Fresh Wtr (SG=1.0): FG weighs 58% & Steel 87% the W_{Air}

$$\frac{W_{Buoyant}}{W_{Air}} = \left(1 - \frac{62.4 \times SG_{O/W}}{\rho_{Material}}\right) \quad \text{(weight ratio)}$$

Capacity Factor (CF): for *any* size hole *or* annulus (in bbls/ft)

- Set OD = 0” if no concentric string is inside the pipe
- Ex: ignoring upsets/boxes, the C.F. between 2-3/8” tbg (ID=1.995”) & a string of 3/4” rods (OD=.75”) is 0.00332 bbls/ft

$$CF = \frac{ID^2 - OD^2}{1029}$$

Capacity:	Tbg Size	4-1/2" 10.5# bbls/ft	4-1/2" 10.5# ft/bbl	4-1/2" 11.6# bbls/ft	4-1/2" 11.6# ft/bbl	5-1/2" 15.5# bbls/ft	5-1/2" 15.5# ft/bbl	5-1/2" 17# bbls/ft	5-1/2" 17# ft/bbl	5-1/2" 20# bbls/ft	5-1/2" 20# ft/bbl	7" 26# bbls/ft	7" 26# ft/bbl	7" 29# bbls/ft	7" 29# ft/bbl
Tbg/Csg Annulus	**2-3/8"**	0.0105	96	0.0101	99	0.0183	55	0.0178	56	0.0167	60	0.0328	31	0.0317	32
	2-7/8"	0.0079	126	0.0075	133	0.0158	63	0.0152	66	0.0141	71	0.0302	33	0.0291	34
Tbg/Csg Annulus + Tbg Capacity	**2-3/8" 4.7#**	0.0144	70	0.0140	72	0.0222	45	0.0217	46	0.0206	49	0.0367	27	0.0355	28
	2-7/8" 5.6#	0.0137	73	0.0133	75	0.0216	46	0.0210	48	0.0199	50	0.0360	28	0.0349	29

*Note: ft/bbl has been rounded to aid memory

Nomenclature, API, & EQ's

API Pumping Unit (PPU) Description:

C 320 D — 305 — 100

a #1 b

Max SL, in.

a: PPU Type:

- **C**: Crank Balanced
- **B**: Beam Balanced
- **RM**: Reverse Mark
- **A**: Air Balanced
- **M**: Mark II (grasshoppa)

PPU Structure Rating, 100's of lbs.

#1: GBox Torque, 1000's of in-lbs

b: D - Double Reduction GBox

Note: PPU's that have the Equalizer Bearing residing directly over the GBox Crankshaft will use equal degrees of crank rotation for both the up & down-stroke. The equalizer bearing is shifted forward towards the horse head on the Reverse Mark & Mark II making their **up-stk 12% (RM) & 18% (MII) slower than their down-stk**.

API Pump Designation:

20—125 R H B C 20—5—4—0

#1 #2 a b c d #3 #4 #5 #6

- #1: Tubing Size, ID - 20 = 2.0" (2-3/8"); 25 (2-7/8"); 30 (3.5")
- #2: Pump Bore, ID - 125 = 1.25", etc.
- a: Pump Type: **R**: Rod, **T**: Tbg
- b: Plunger Type & Barrel Thickness: → Metal Pgr: **H**: Heavy, **W**: Thin; Soft Pgr: **P**: Heavy, **S**: Thin
- c: Seating Assembly Location: **A**: Top, **B**: Bottom, **T**: Bot. (Traveling-Barrel)
- d: Seating Assembly Type: **C**: Cup, **M**: Mechanical
- #3: Barrel Length, ft.
- #4: Plunger Length, ft.
- #5: Length of Upper Extension, ft.
- #6: Length of Lower Extension, ft.

Also important to know:
Plunger & Barrel Metallurgy, Plunger Clearance ("Fit"), & Cage Designs

Nomenclature:

< *or* >	Less than *or* Greater than. Ex: 1 < 1.01; **A&M** > **UT**
Δ	Delta, represents the *change* in a quantity
%	Percentage (25% = 0.25)
ε	Efficiency, fraction (85% = 0.85)
ρ	Density, lb./ft^3 (wtr = 62.4 lb/ft^3)
μ	Viscosity of Fluid, cp ↑ *Math & Greek*
A	Area, in^2
API	American Petroleum Institute, industry guidelines
d	Diameter, in.
BFPD	Bbls Fluid Per Day (i.e. Oil+Wtr: BOPD + BWPD)
BHP	Bottom Hole Pressure, psi
CP	Csg Pressure (usually Flowline P.), psi
DH	Downhole (abbrev.)
DHGS	Downhole Gas Separator/Separation
F	Force, lb.
F_O	Fluid Load on Pump, lb.
GA	Gas Anchor (inner tube of DHGS); AKA 'Dip Tube'
GFLAP	Gas Free Liquid Above Pump, ft.
h	Height, ft
ID	Internal Diameter, in.
k	Spring Constant, units: in./1000 lb./1000 ft
L	Length, ft.
MGD	Modified Goodman Diagram (rod loading guide)
OD	Outer Diameter, in.
P	Pressure, psi
PBHP	Producing BHP (@ bottom perf), psi
Pgr	Plunger
PIP	Pump Intake Pressure, psi
PDP	Pump Displacement Pressure, psi
ppg	Pounds per Gallon, Lb./gal (FW = 8.33 ppg)
PPU	Pumping Unit (AKA Pumpjack, Nodding Donkey)
PPM	Parts Per Million
PR	Polished Rod (top connecting rod)
SBHP	Static BHP (local avg. Reservoir P.), psi
SG	Specific Gravity (FW = 1.0 SG = 8.33 ppg)
SL	Stroke Length, in
SPM	Strokes Per Minute, stk/min
SV	Standing Valve (pump's non-moving valve)
tbg	Tubing (abbrev.)
TAC	Tubing Anchor Catcher (for tbg tension)
TV	Traveling Valve (moving/stroking valve of pump)
TVD	True Vertical Depth (vs Measured Depth), ft
TP	Tubing Pressure, psi
W	Weight, lb.

Subscripts:

D,FL	Dead Fluid Level (FL when gas volume subtracted)
DH	Downhole (e.g. @ the pump)
DT	Dip Tube: inner barrel of DHGS
EPT	Effective Pgr Travel ("pumping" part of DH SL)
FG_Rods	Length of Fiberglass Rods, ft.
FL	Fluid Level (the "kick" on the Acoustic FL Trace)
MA	Mud Anchor: outer barrel of DHGS
p	Pump
O *or* W	Oil *or* Water; O/W = Oil & Wtr (mixture)
rf	Rods in Fluid (considering buoyancy force)
RT	Run Time, fraction of the day the well pumps
SN	Seating Nipple (i.e. pump depth)
tbg,x-sec	Cross sectional area of tbg metal, in^2

Helpful Reference EQ's:

°API	S.G.
30	0.88
35	0.85
40	0.83
45	0.80
50	0.78

Chlorides ppm	Density ppg	Specific Gravity
0	8.34	1.00
50,000	8.62	1.03
100,000	8.96	1.07
150,000	9.26	1.11
200,000	9.60	1.15
250,000	9.96	1.19
258,000	10.00	1.20

S.G. of Oil:

$$SG_O = \frac{141.5}{API + 131.5}$$

S.G. of Produced Water:

The **S**pecific **G**ravity of produced water is a function of the **TDS** (Total Dissolved Solids), not just Chlorides. So a Wolfberry well producing 100K Cl probably has a S.G. closer to ~1.09.

S.G. of O/G Mixture:

$$SG_{O/W} = \frac{BOPD \times SG_O + BWPD \times SG_W}{BOPD + BWPD} = \%_O \times SG_O + \%_W \times SG_W$$

Assuming gas-free

Bottom Hole Pressure:

$$BHP = P_{Surface} + 0.433 \times SG \times h_{TVD} = P_{Surface} + 0.052 \times ppg \times h_{TVD}$$

Avg Polished Rod Velocity:

For comparing pumping speeds (velocity) of wells w/ different SL's

$$\vec{V}_{PR} = \frac{2 \times SL \times SPM}{12} \quad (\text{ft/min})$$

Fluid Slippage:

$$Slippage = [1 + 0.14 \cdot SPM] \times 453 \frac{d_{pgr} \times \Delta P_{pgr} \times C_{pgr}^{1.52}}{L_{pgr} \times \mu} \quad (\text{BFPD})$$

(2006, Patterson Equation)

C_{Pgr}: Total Plunger/Barrel Clearance (inches; "5 Fit" = 0.005")

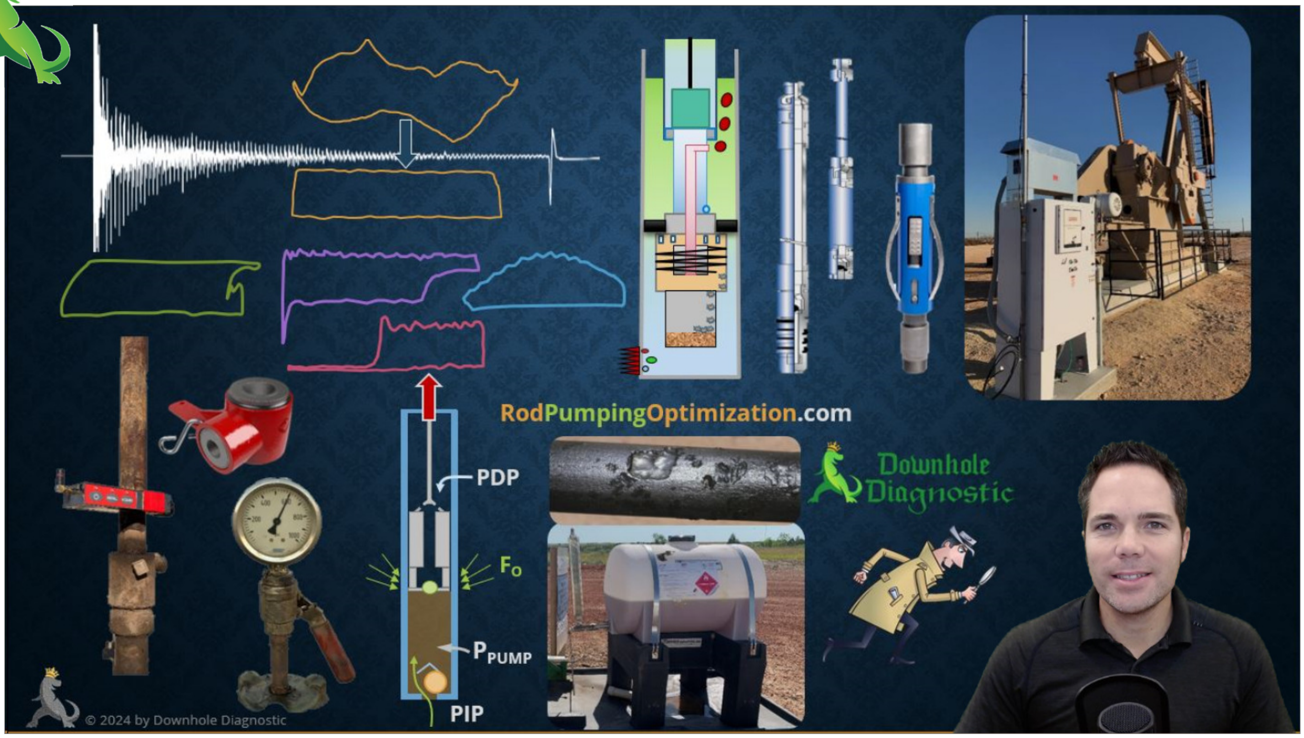
L_{Pgr}: Pgr Length (inches). μ: fluid viscosity (cp)

Failure Frequency:

$$Failure\ Frequency = \frac{\#\ of\ Failures / Year}{\sum Producing\ Wells}$$

(A F.F. of 0.25 = 4-yr avg Run Life per well)

50-hr Online Course: Rod Pumping Diagnosis & Optimization



Let me introduce to you a 50-hr online course on Rod Pumping systems that can 10x the value of your engineers and field operators when it comes to designing, troubleshooting and optimizing Rod Pumping wells.

I am a Petroleum Engineer with a passion for Rod Pumping optimization. I worked as an engineer for an oil company for 5-years and I have spent the last 10-years working independently for hundreds of companies to help them understand and optimize their wells.

The course blends theory with field practice and hands-on troubleshooting (with tons of real world pictures and interesting examples). There is a strong focus on applying and interpreting FL Shots & Dynamometer tests—our two diagnostic tools that let us see downhole.

The course will make your employees expert on:

- **Components & Theory of Rod Pump Operation**
- **Fluid Level Shots: application & interpretation**
- **Dynamometer Card Interpretation & POC's**
- **Downhole Gas & Solids Separation**
- **Specialty Equipment (pump, rods, & tbg) to Minimize Failures & Extend Run Life**
- **Troubleshooting & Optimizing Wells**

The course is broken into 1-hr segments and fully available after purchase: $1776 (6-month access period). Group discounts available.

Shawn Dawsey, PE
(432) 230-8700 (cell)

(the course looks like this: I am floating in the bottom corner of the slide with lots of images/diagrams to illustrate the points)

Section Outline:

1. **Introduction** (1-hr)
2. **Rod Pumping Overview** (2-hr)
3. **Intro to Optimization & Fluid Level/Dyno Tests** (1-hr)
4. **Fluid Level Shots (pt. 1) – Basics** (6-hr)
5. **Downhole Pumps & Pump/Rod Operation** (2-hr)
6. **Dynamometers (pt. 1) – Card Interpretation** (7-hr)
7. **Fluid Level Shots (pt. 2) – Over-Time** (5-hr)
8. **Dynamometers (pt. 2) – Over-Time** (9-hr)
9. **Echometer Equipment & Software** (3-hr)
10. **Gas & Solids – Separation & Handling** (6-hr)
11. **Run Time Control – Timers, POC & VSD** (6-hr)
12. **Other Topics (Chemical, Pump Action)** (2-hr)
13. **Optimization & Troubleshooting Wells** (4-hr)
14. **Final Quiz** (5-hr)

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Downhole Diagnostic

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