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Application of Plungers in Gas Wells Producing Liquids with High Downhole Critical Rates

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Introduction

- The wells discussed here with plunger applications are in the Barnett Shale in N Central Texas. The field has been producing since late 1990’s. The wells have an average true vertical lateral depth of 6700-8500 feet.

- The discussion centers around concerns about how early plunger should be used when looking at the calculated critical velocity, the shape of the tubing performance curve and the production records.

- The performance of 4 wells are discussed.

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Figures 1.a, 1.b and 1.c Production data for Well 1 before/after the plunger launched

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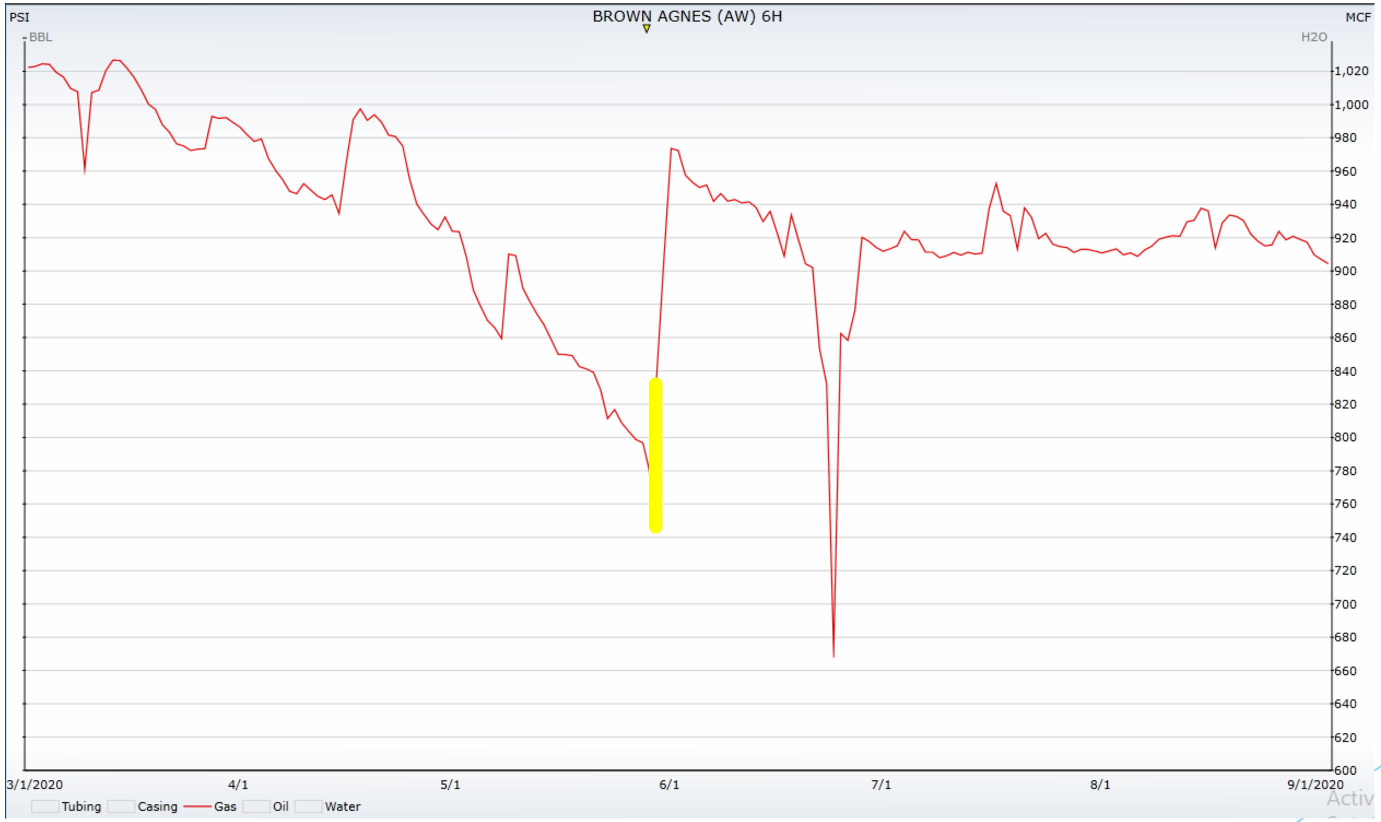
The yellow line marks the date, May 28, 2000, on which a plunger was installed the plunger due to liquid loading. At the time of the install, the well was producing as a rate of 0.78 MMscf/D although production shows loading may have started at 0.9 MMscf/D



1st Well: Calculate Critical When Plunger Installed: Data below:

Well data:
Plunger type:
9” sleeve and tungsten ball
Tungsten ball: 0.5 lbs.
Tubulars:
Bumper spring set at 7612’ @ 54 degrees
EOT 7871’ @ 72 degrees
2 3/8’s tubing
WHT/BHT
70 F/189F
WHP
Tubing 93 psi
Casing 333 psi
BPD/Mscf/D
40.7 bbl/day (37.5 water, 3.2 oil)
~780 Mscf/D before plunger installed from graph
Fluid Gravities
1.06 /55, Water/Oil

MD	TVD	Angle
0	0	1.1
23	23	1.1
105	105	1.1
707.3	705.9	6.8
795.9	793.9	7.1
7015.1	6971.3	2.5
7432.1	7375.1	21.5
7610.9	7511.6	54
7837.9	7613.7	70.5
7871.4	7624.5	71.7

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Must Calculate Critical and compare to actual flow

1. Density:

$$\rho_g = \frac{2.699\gamma_g P}{Tz}$$

2. Critical Velocity:

Turner's Critical Velocity

$$U = 1.92 \frac{\sigma^{1/4}(\rho_L - \rho_g)^{1/4}}{\rho_g^{1/2}}$$

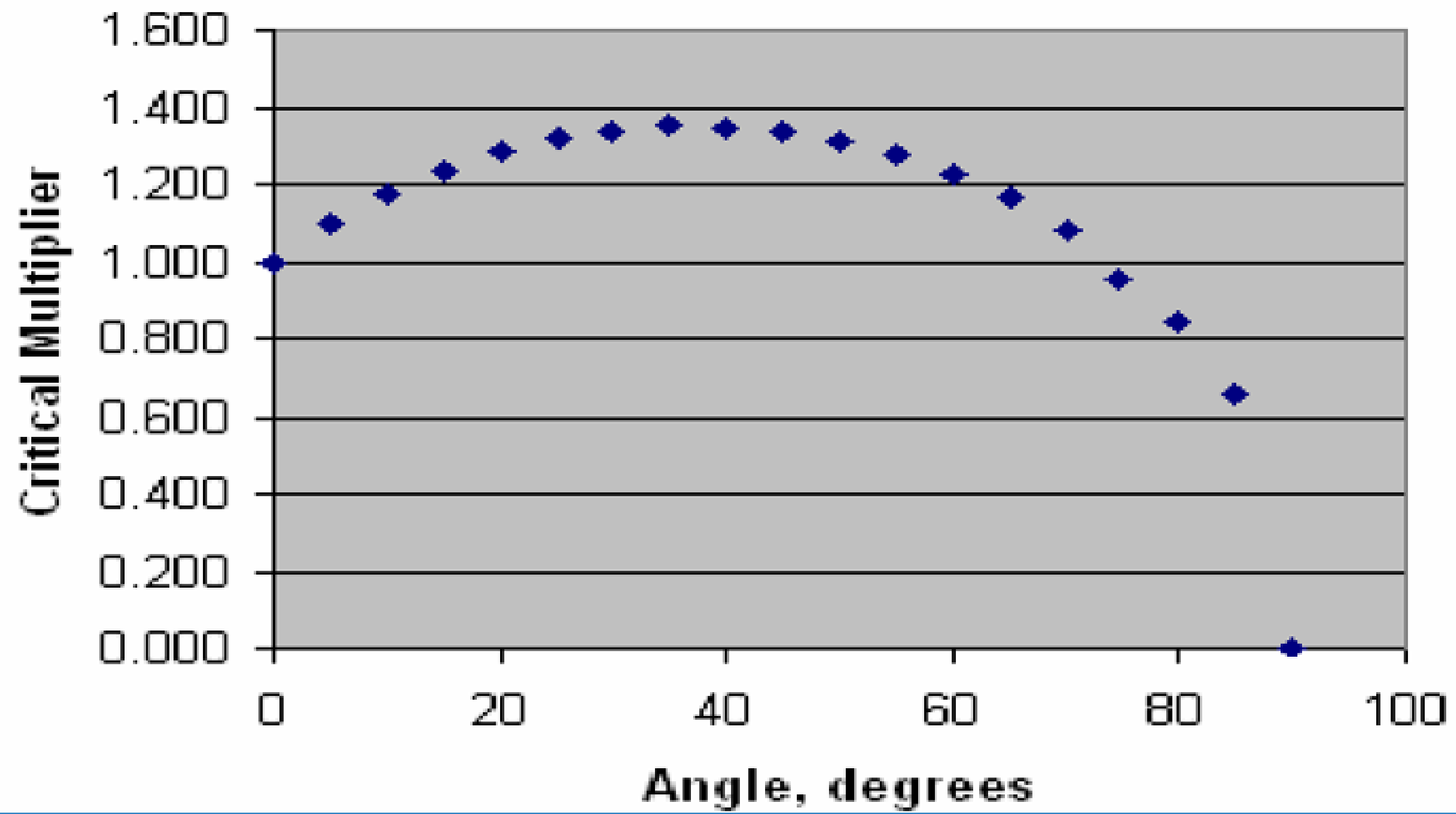
3. Turner's Critical Gas Flowrate:

$$Q = \frac{P T_{sc} A U}{1000 P_{sc} z T} \times 3600 \times 24$$

ρ	Density
P	Pressure
z	Compressibility factor
T	Abs temperature
σ	Surface tension
A	Area
L,g	subscripts for liquid , gas

Figure 3: Adjustment to Critical for Well Deviation. In equation format:

Multiplier=(SIN(1.7*((90-Angle)*2*3.14/360)))^0.38/0.74067



The above relationship is developed and discussed in SPE 115567, “Prediction and Dynamic Behavior of Liquid Loading Gas Wells” by ***Belfroid*** et al.

Some surface tension data needed:

(after R Sutton)

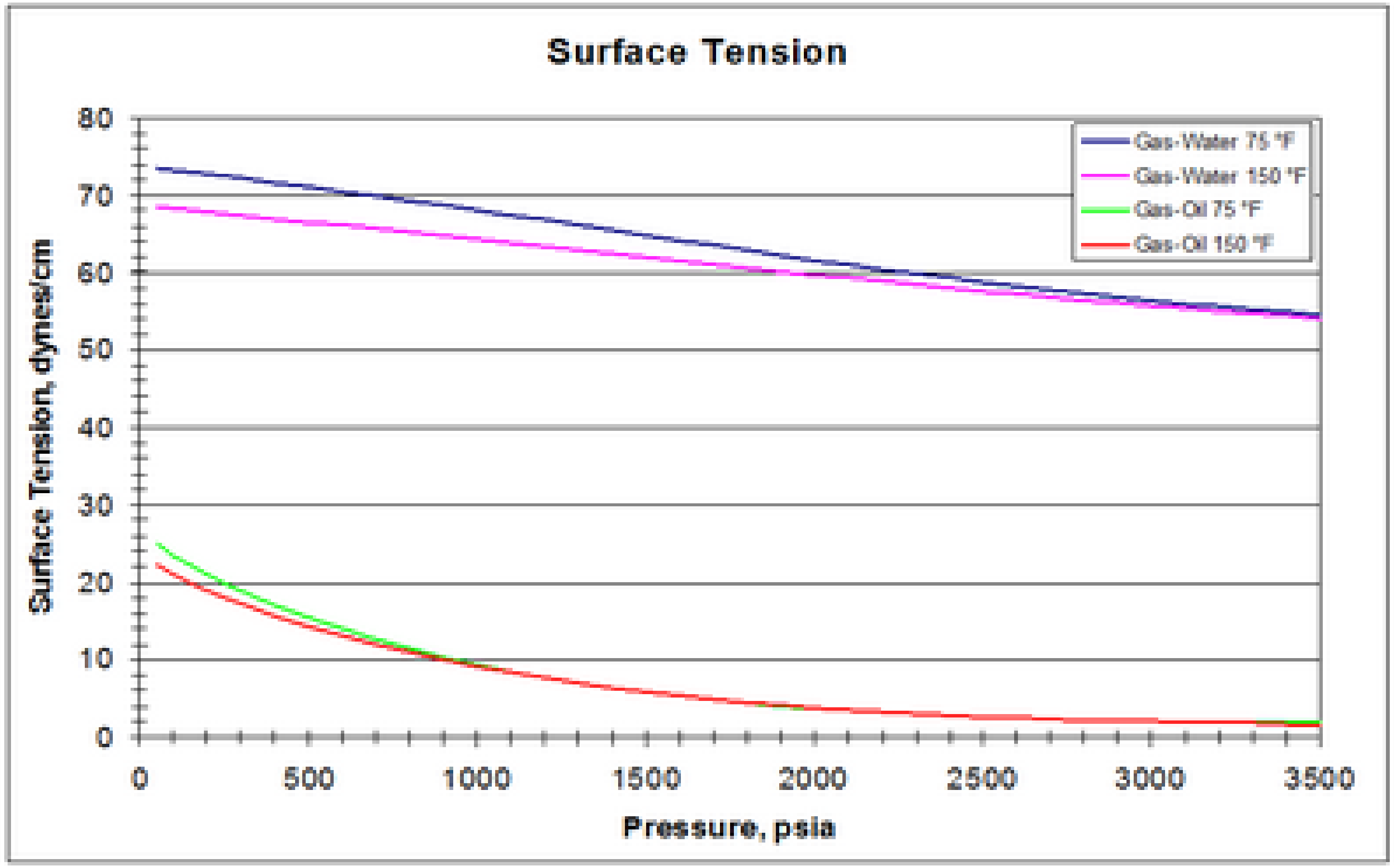


Figure 5: Downhole critical (Coleman and Turner) with Rate vs. Depth

Coleman predicts lower critical than Turner does. Then correct for deviation using Belfroid

Using Turner and correcting for deviation, conditions are very close to loading at depth *(but plunger could have been put in sooner!)*

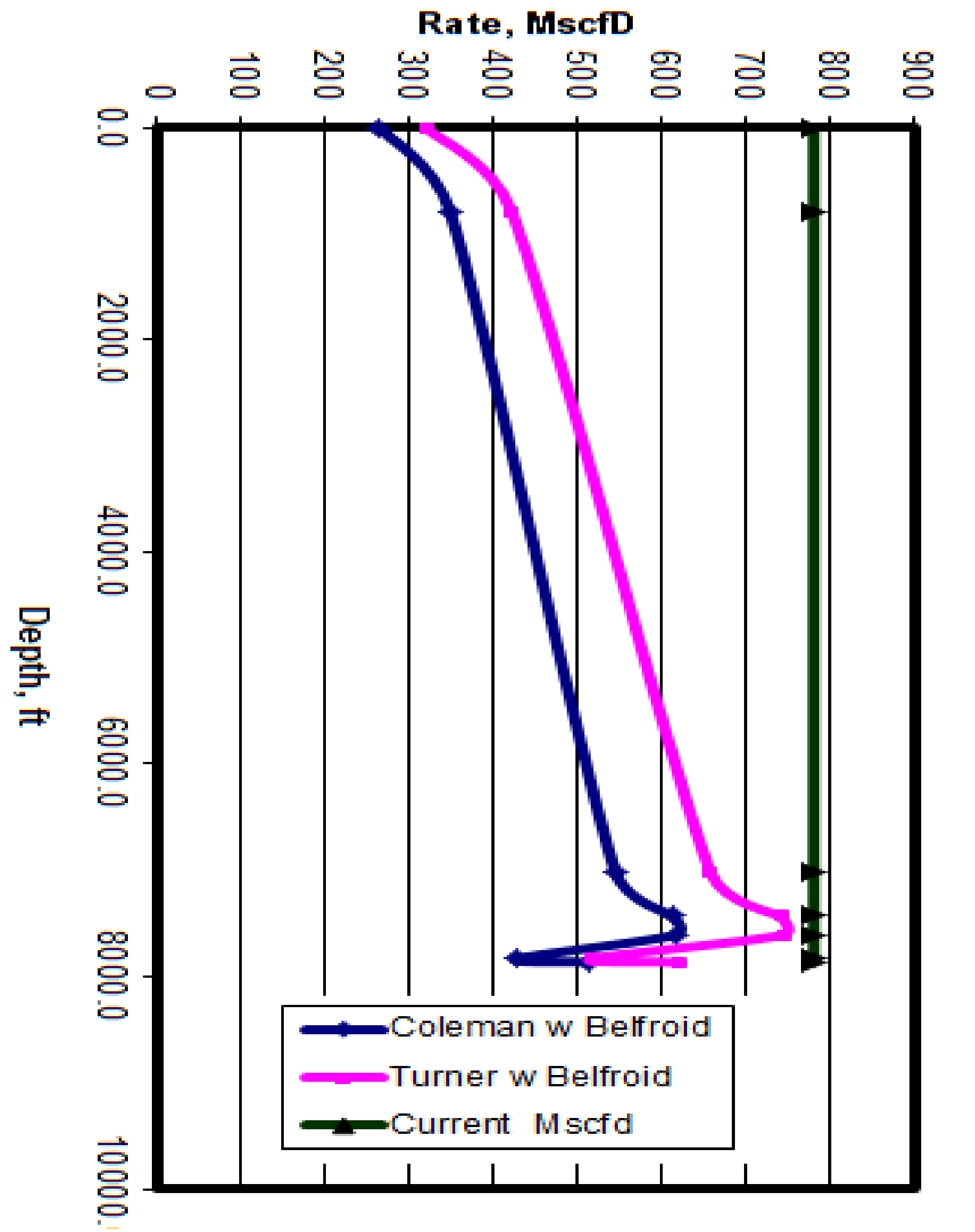


Figure 6: Critical and actual gas velocities: 1st Well

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Shown in Figure 6 is a plot of critical velocity and actual velocity. Shekar is used for the critical calculations. Results are close to previous calculations showing close to or loaded at depth. (Shekar From Snap)

Reference:

Shashank Shekhar, Mohan Kelkar, W.J. Hearn and L.L. Hain; 2017; “Improved prediction of liquid Loading in Gas Wells”; accepted for publication at SPE Production

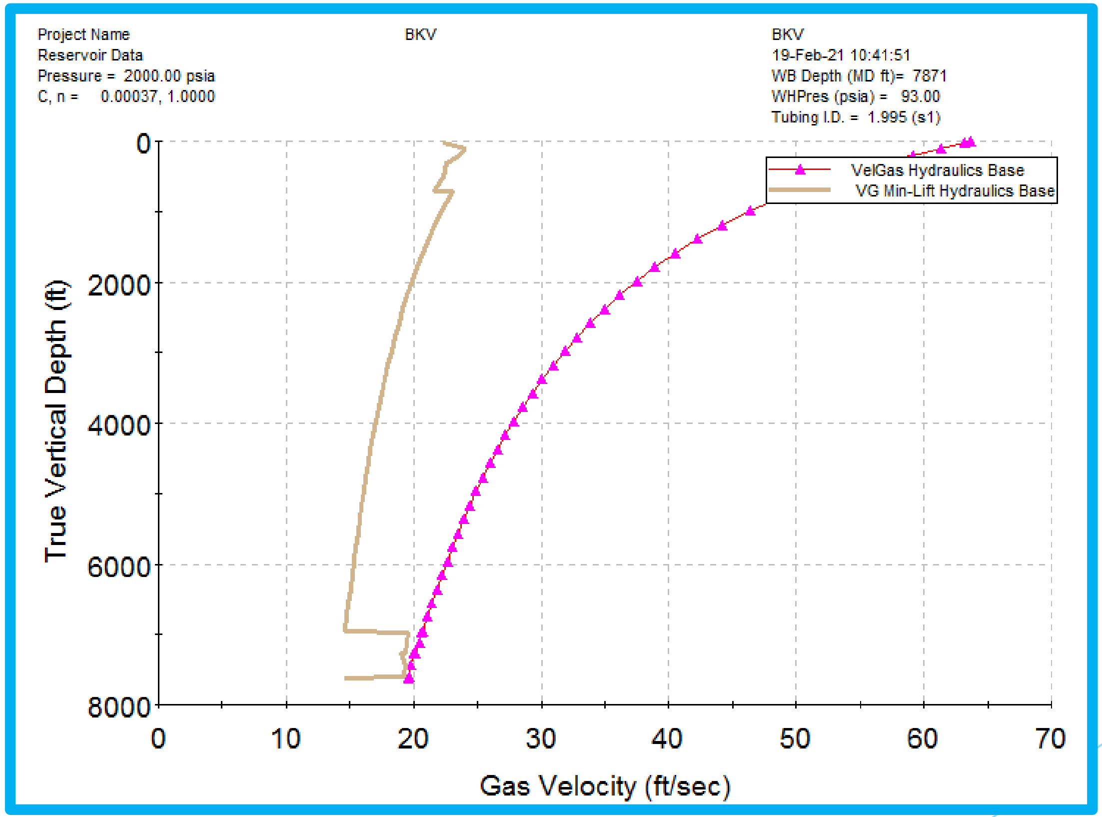
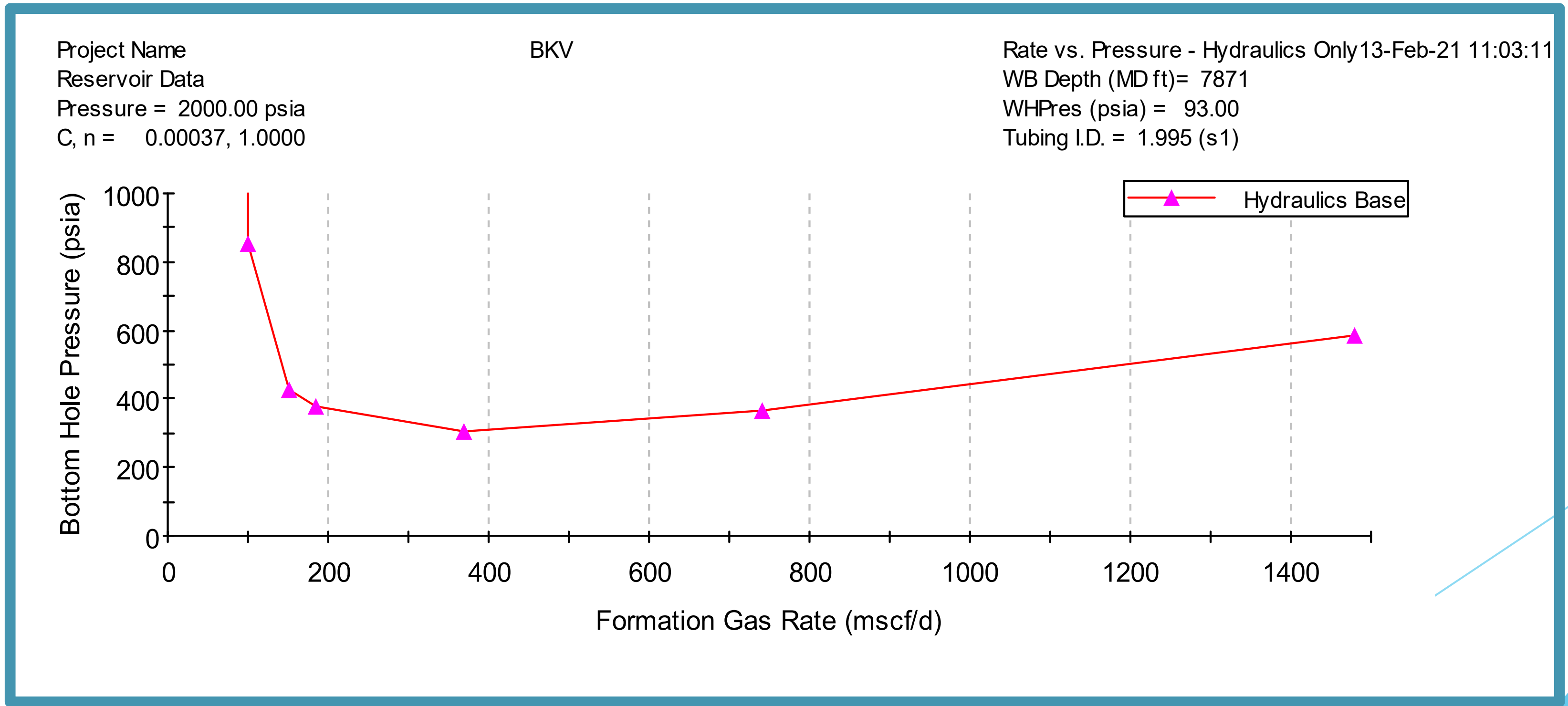


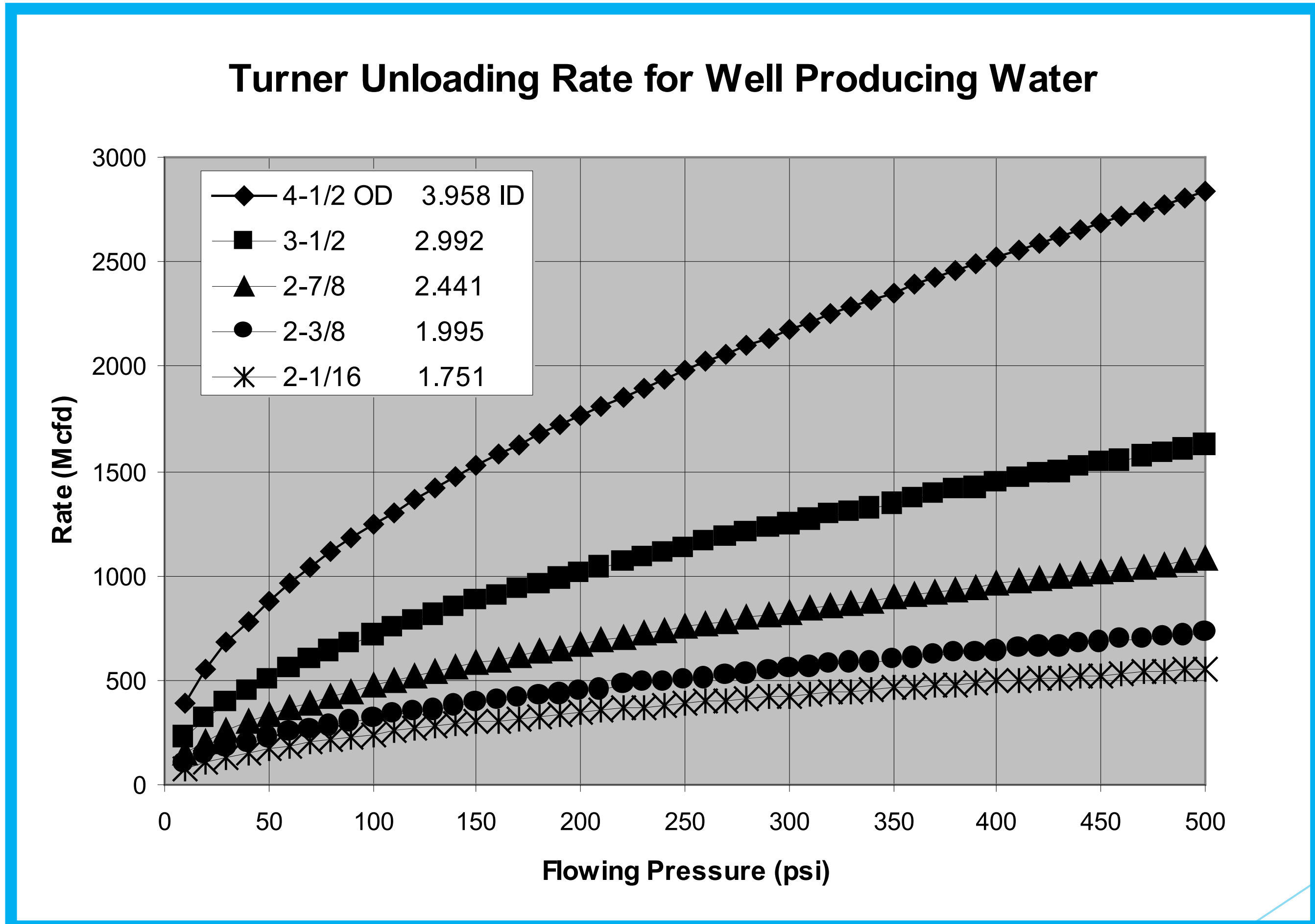
Figure 7: Tubing Performance Curve: 1st Well

The tubing system plot below is somewhat misleading. It shows stability down to About 380 Mscf/D but the critical is closer to 800 Mscf/D. In fact the production data shows the critical may be higher than calculations and be closer to 900 Mscf/D. Looking at only shape of tubing curve may not indicate when loading actually occurs!



Expectations of critical rate?

If you only looked quickly at something like below you might think critical should be only a few hundred Mscf/D



Summary: 1st Well

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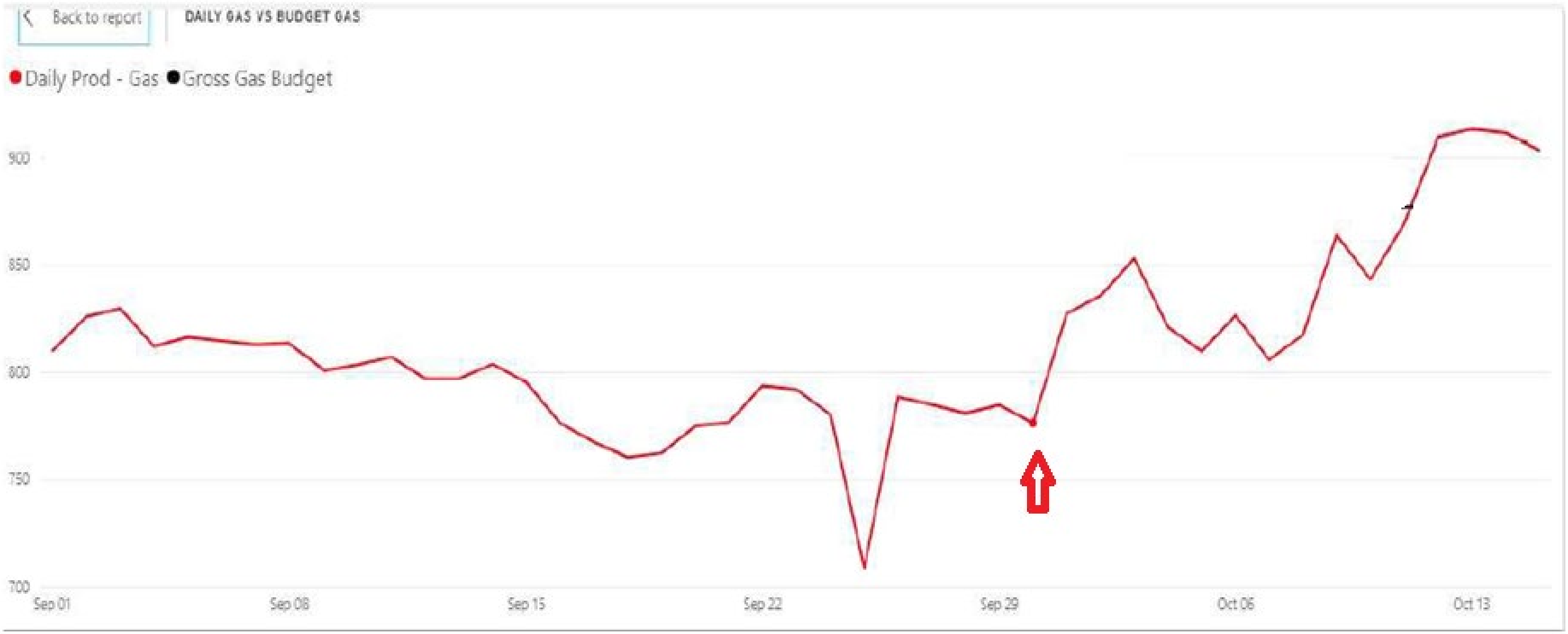
- The well was predicted to be close to loading at the time of installation of the plunger. The Shekar model predicts the same. Both methods may be predicting too low for critical as data indicates loading may be starting at 900 Mscf/D.
- In general it is good practice to install plunger (or other AL) in advance of loading if loading can be predicted. This for conservatism and also because the correlations seem to be predicting not quite critical when actually loading is already occurring.
- Turner compared to Coleman is best for this first well example. Some might say at quick glance critical is ~300 but with gradient calculated and deviation corrections it is much higher.

2nd Well

The next graph (Figure 8) shows the daily gas production. The plunger was installed 9/29/2019. With the plunger an increase from 780 Mscf/D to 900 Mscf/D was shown but the well showed loading previously at 720 or less. The critical with angle correction for this case turns out below to be 690 so it shows compared to calculations to not loaded once again but it is close enough that it should warn of impending or in this case actual loading.

The sharp reduction in rate before the plunger installed was due to the well being down due to sand issues.

Figure 8: Production vs time. 2^{nd} Well Analyzed



2nd Well Data

<u>Plunger type</u>
9" Sleeve with Tungsten ball
Ball weight: 0.5 lbs.
<u>Tubular Depth</u>
Bumper spring set at 6607' @ 34 degrees
EOT 6803' @ 63 degrees
2 3/8 tubing
<u>WHT/BHT</u>
70/189 degrees
<u>WHP/CHP</u>
Tubing 76 psi
Casing 277 psi
<u>Bbl/MMcf (when plunger was dropped)</u>
52.5 Bbl/day / 780 MMcf/day 6.5 bopd, 46 bwp
<u>Fluid Gravities</u>
1.11 Water
53.6 Oil

MD	TVD	ANGLE
200	199.5	0.81
2395	2375	8.66
3151	3119	11.9
4094	4060	4.81
5041	4997	1.06
6399	6361	20.64
6678	6682	57.9
6860	6706	71.63
7043	6741	91.4
7135	6736	91.6
7323	6744	92.9

Figure 9: Additional production data: 2nd Well

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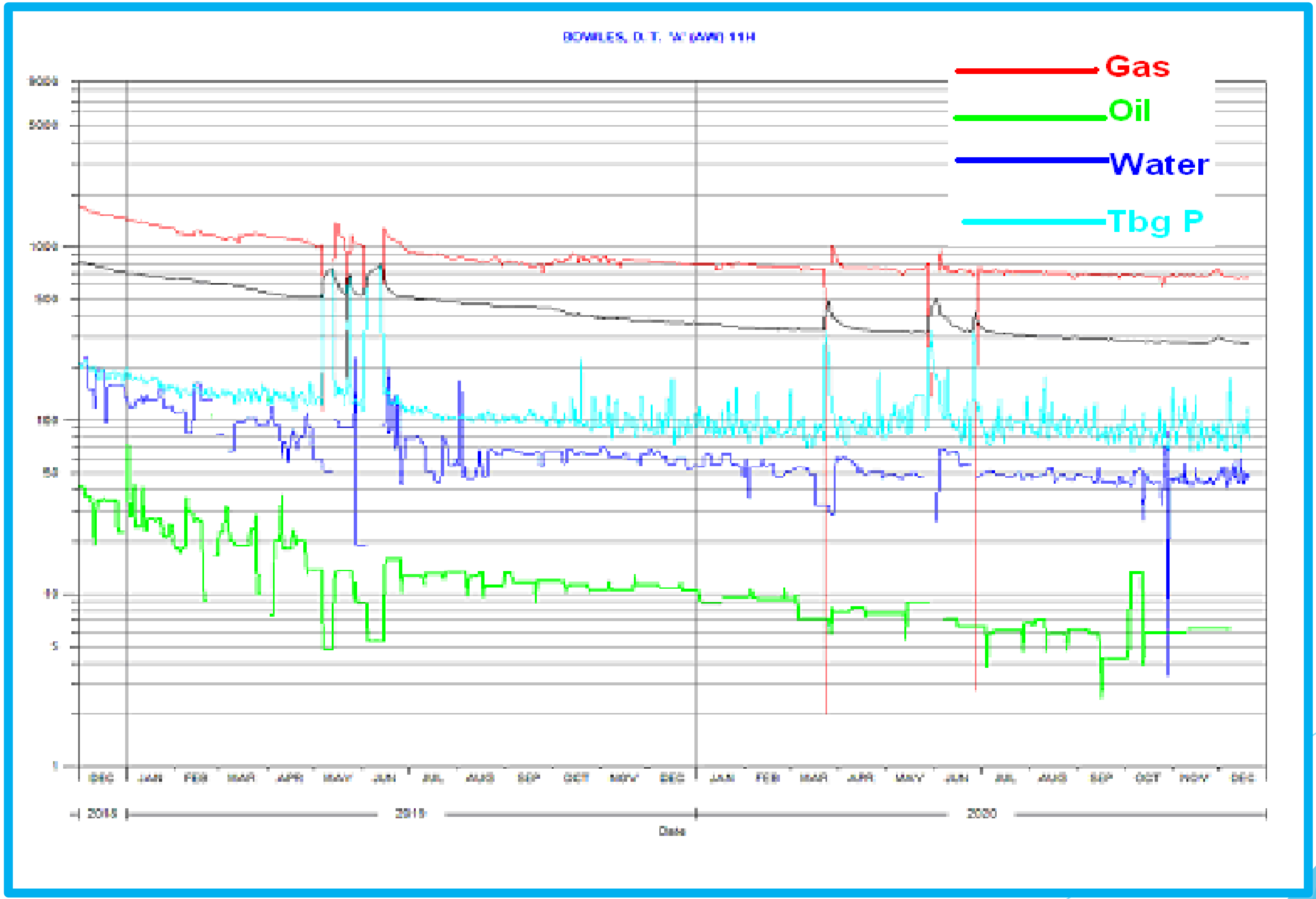

Figure 10: Tubing Performance Curve shown with an IPR: 2nd Well

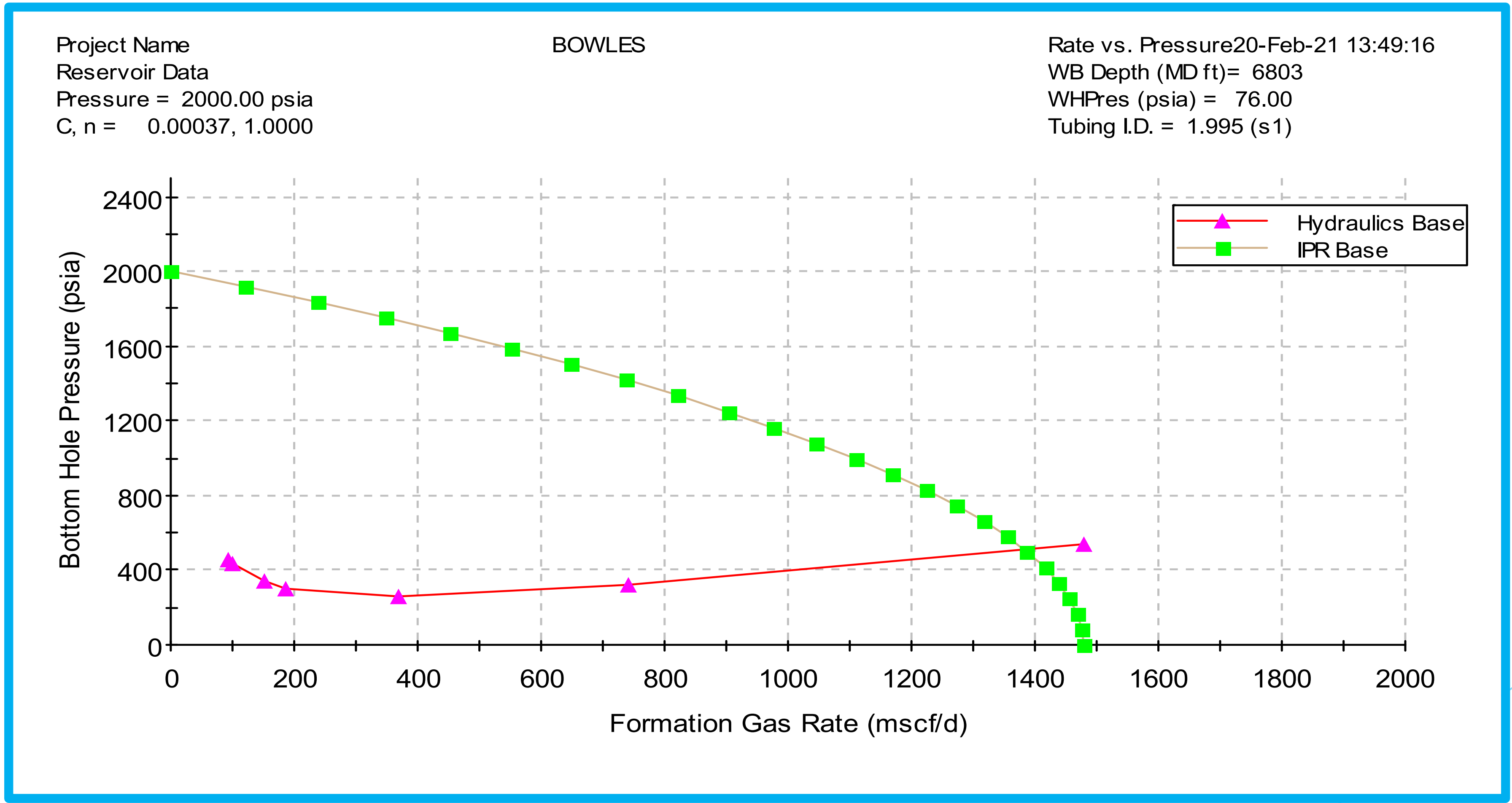

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Figure 11: Critical prediction for 2^{nd} Well When Plunger Installed.

(Snap: Shekar)

Predicts close to but no loading at depth.

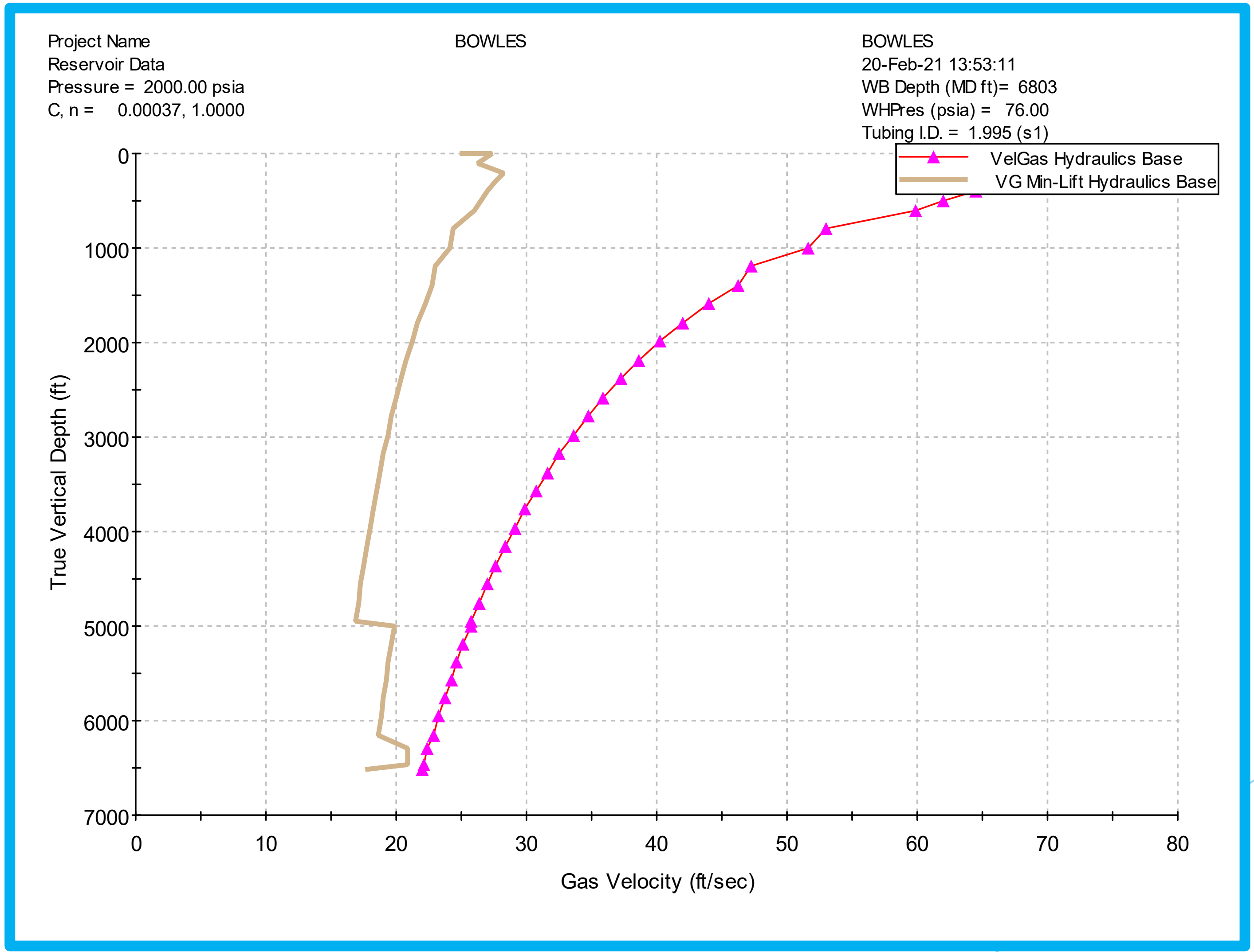

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Figure: 12: Production vs Time: 3rd Well.

The plunger installed 2/7/20, date indicated by the dot in Figure 12. Two days before plunger was installed the well shut in due to well head repairs caused by sand. EOT is 7269'. Figures 12 and 13 show production records vs. time.

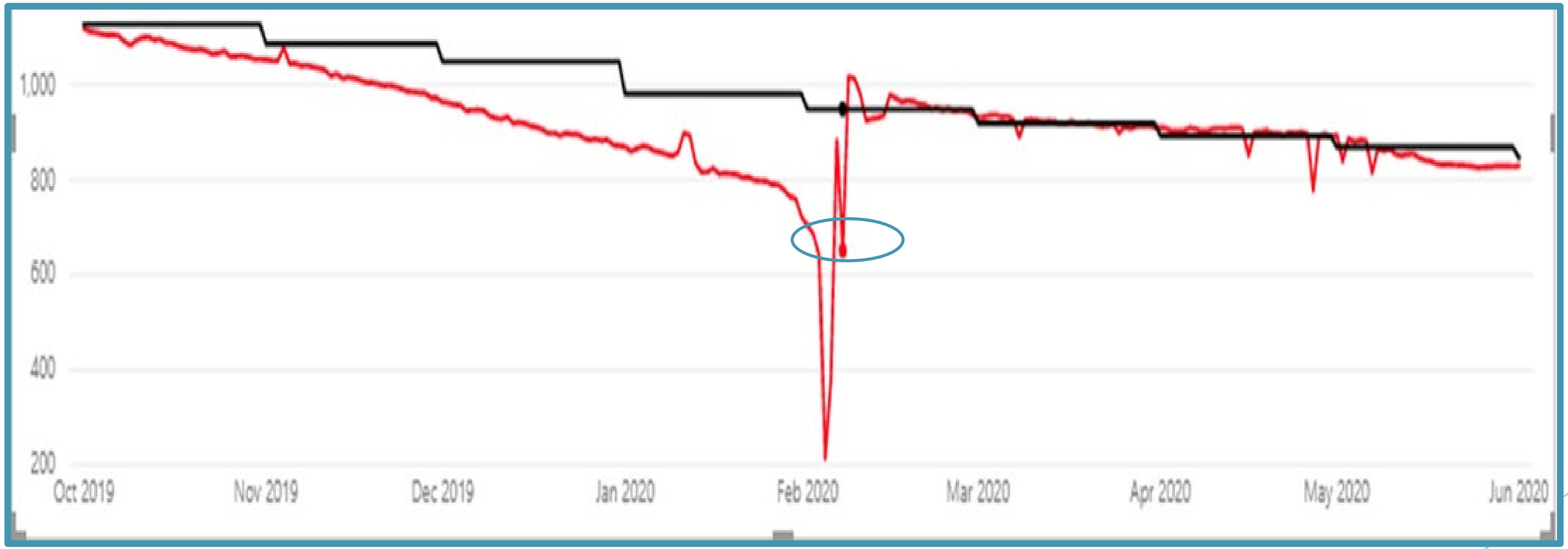

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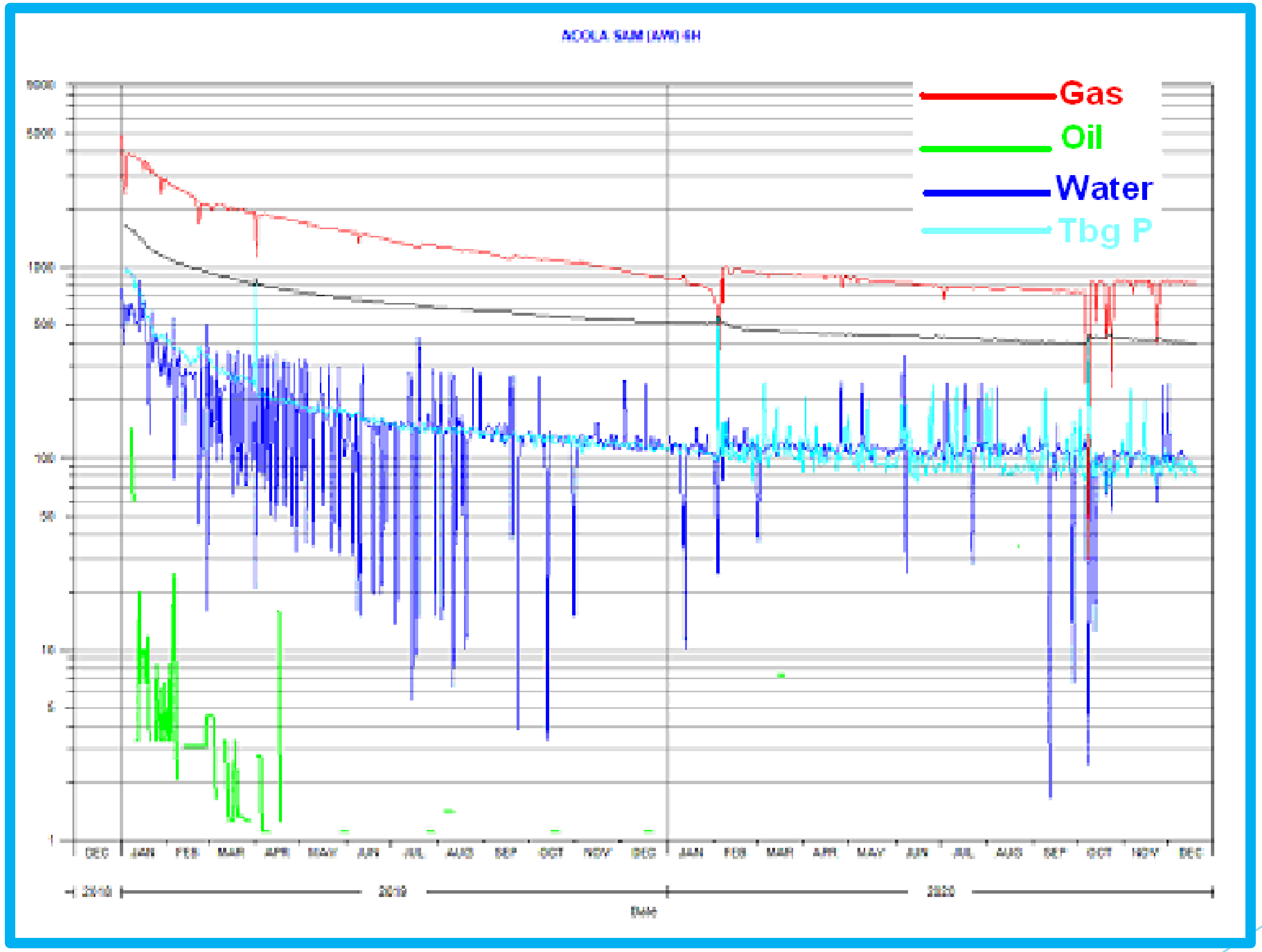
Figure 13: Additional production data: 3rd Well



3rd Well Data

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2 3/8's tubing
Bumper spring set in F nipple @7026'
WHT
70 degrees
BHT
189 degrees
WHP
Tubing 95 psi
Casing 415 psi
BPD/Mscf/D
95 bbl/day (95 water, 0.1 oil)

MD	TVD	ANGLE
6660	6638	7.51
6849	6819	24.09
6994	6904	30.26
7039	6980.6	42
7511	7172	79.63
7889	7195	89.62
7994	7196	90.11

Figure 14. Tubing Performance Curve for 3rd Well

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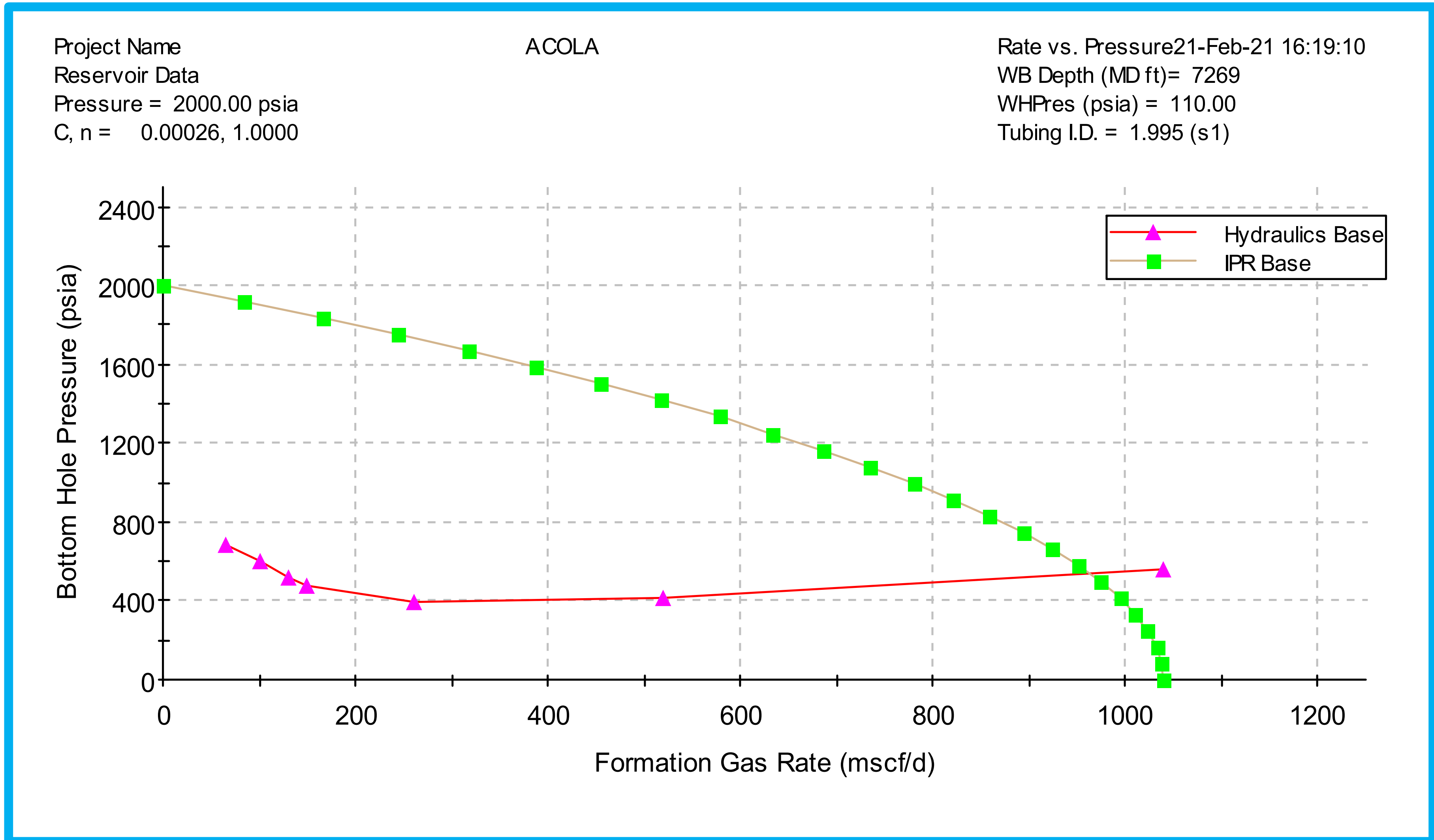
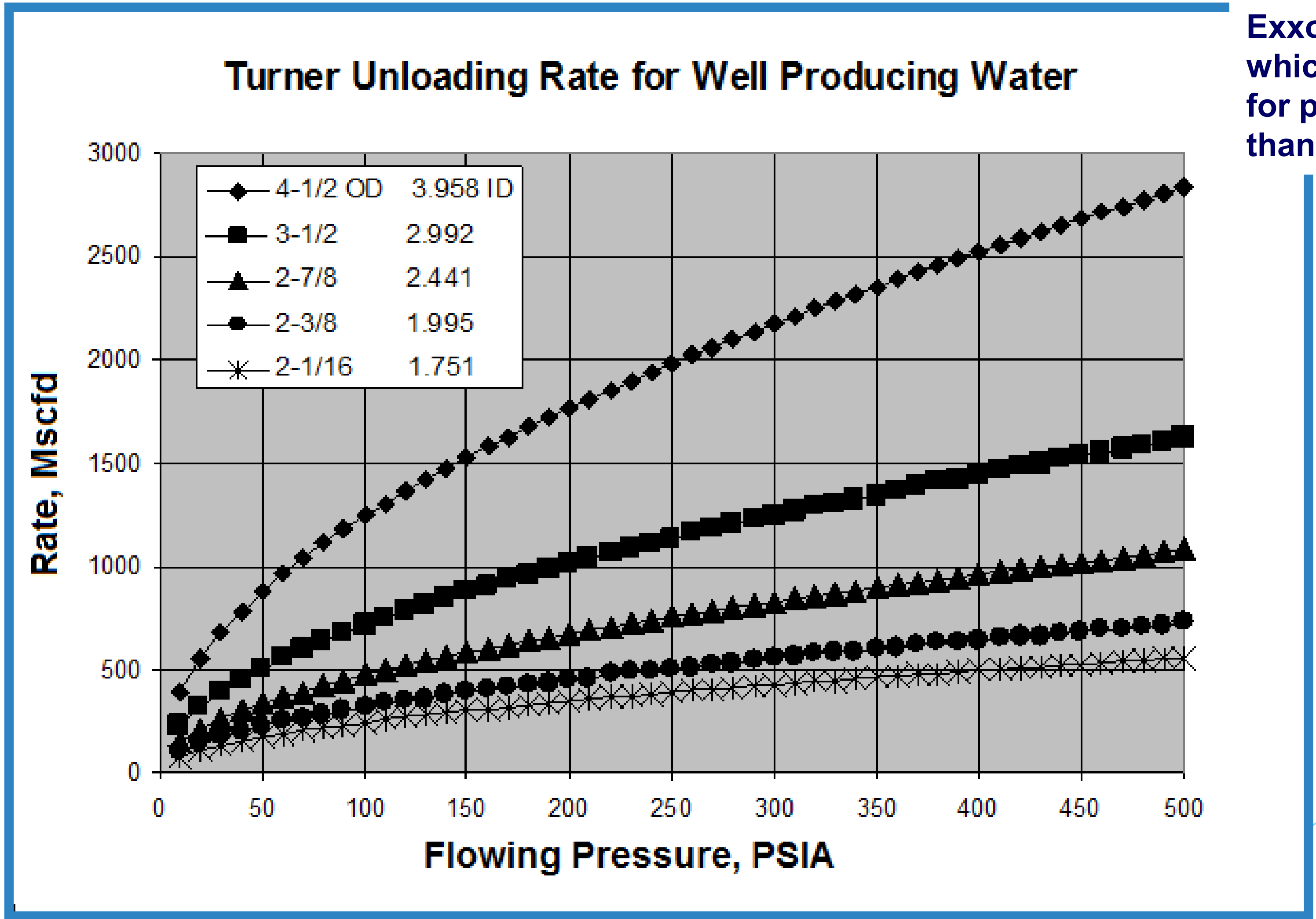


Turner Critical Rate: Water

A quick glance at this would say critical is ~ 300 Mscf/D without depth/deviation corrections



Divide rate by 1.2 for Exxon correlation which is really better for pressures lower than 1000 psi

Figure 15: Shekar results for Acola Well

Loading is predicted when plunger installed.

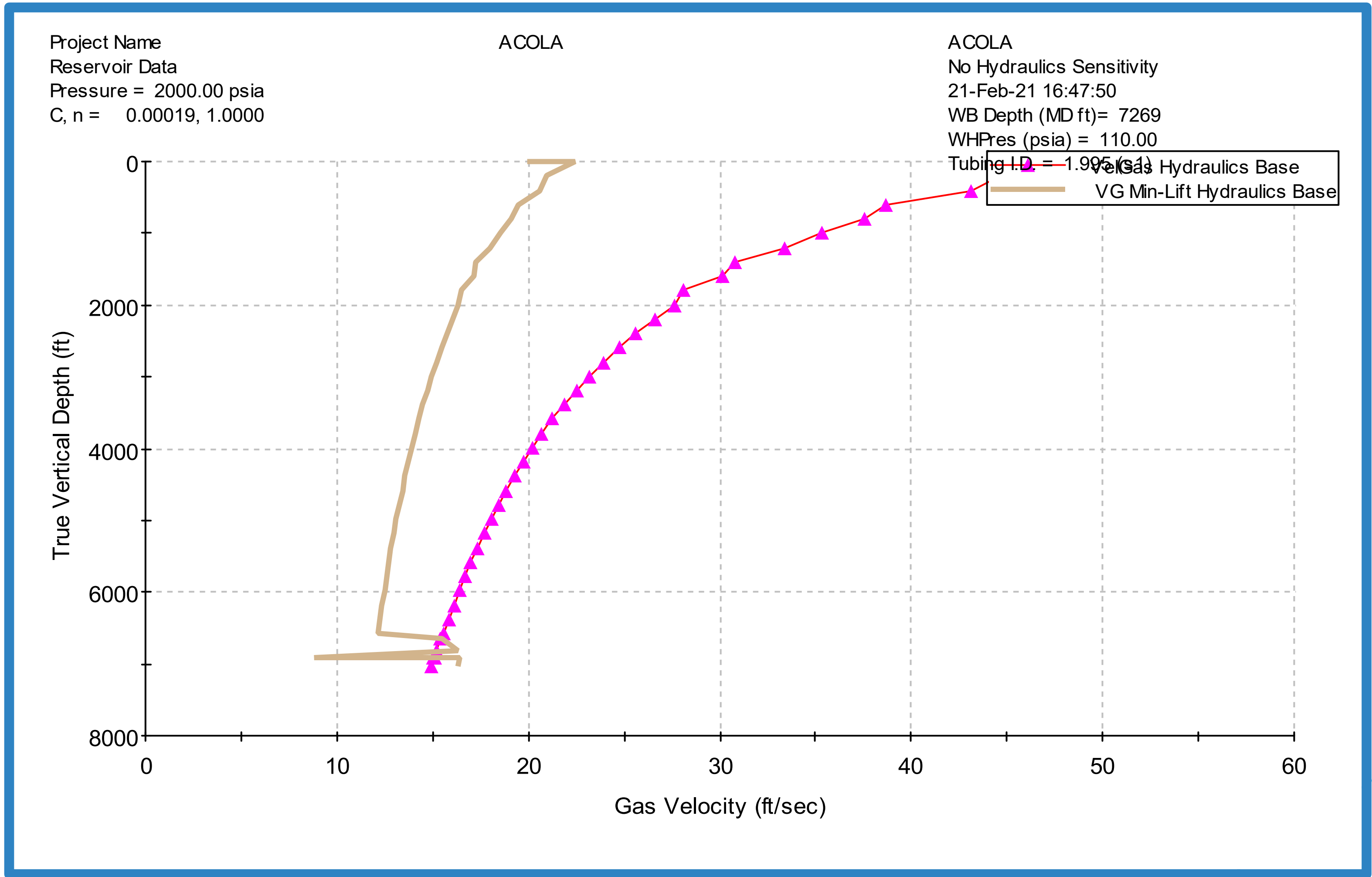


Figure 16: Production data: 4th Well

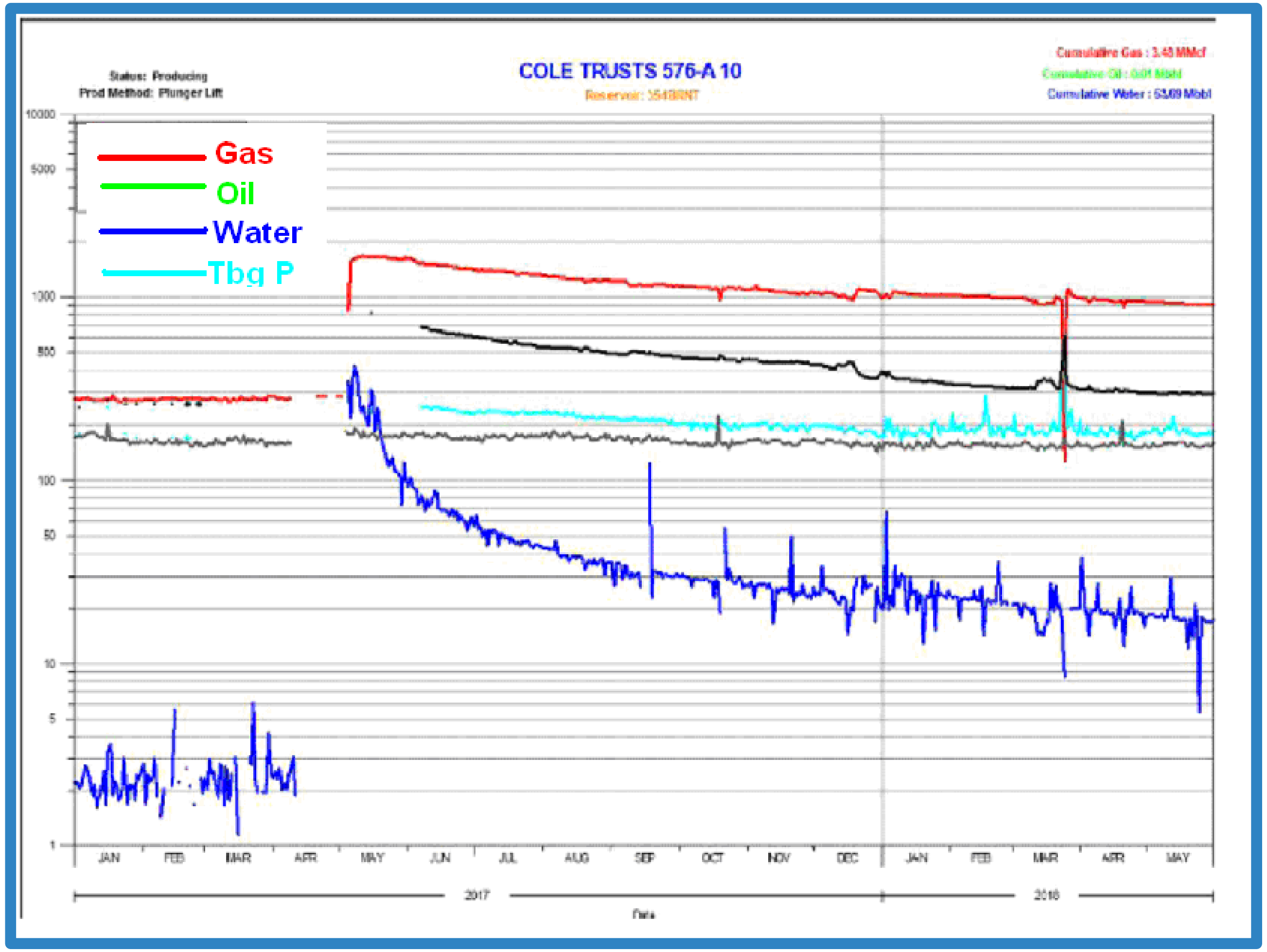


Figure 17: Gas Production: Fourth Well.

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The plunger was installed 12/19/17, date indicated by dot shown below.. Daily production was 973mcf/day before then up to 1107mcf/day after install.

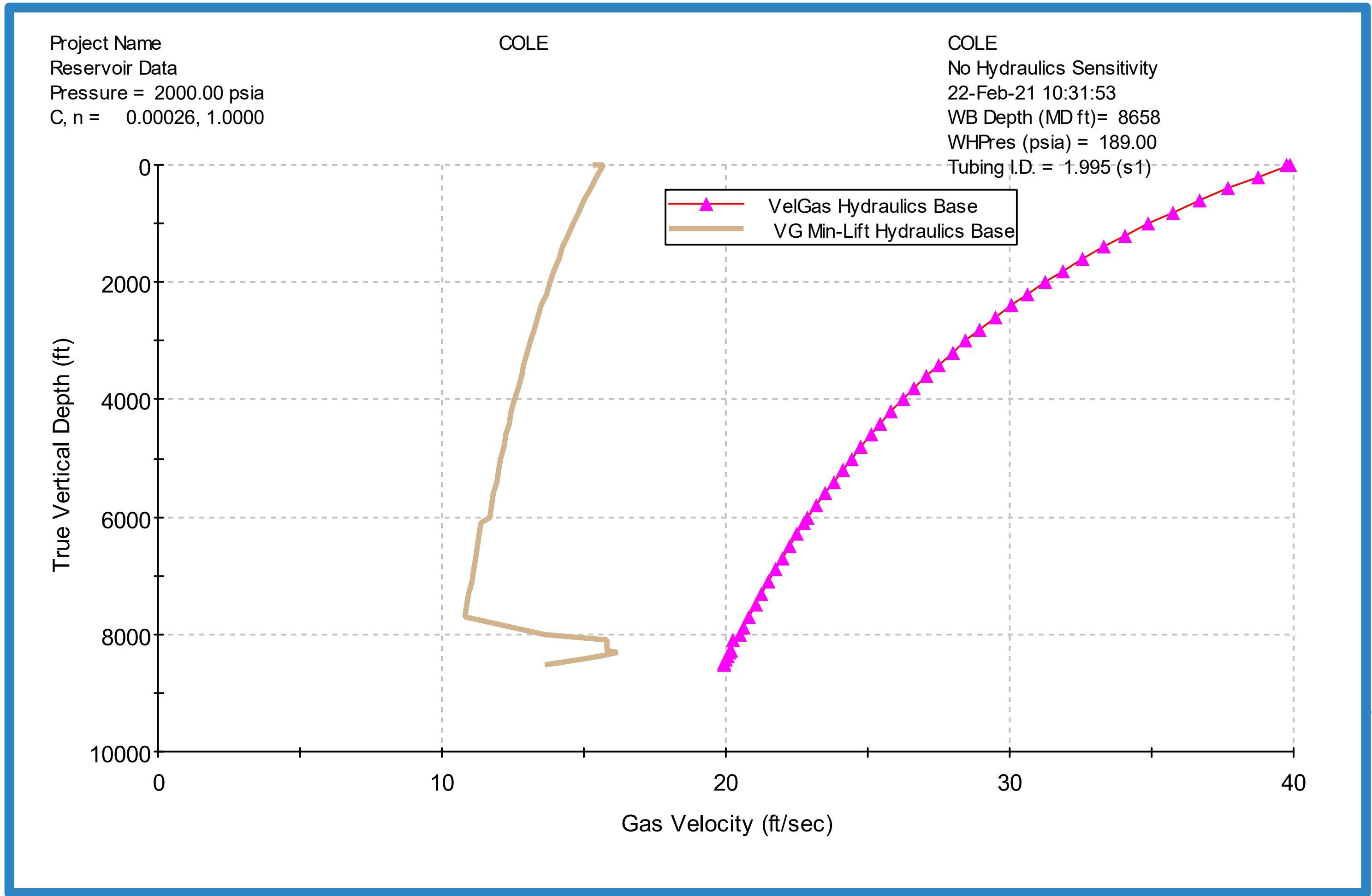
4th Well: Data

- Plunger: 9" sleeve with a Tungsten ball
- Tubing: 2 3/8
- Bumper spring is set in the X nipple at 8502 MD 8431 TVD at 51 degrees
- EOT is 8658 MD 8513 TVD At 65.8 degrees.
- WHT: 65 F. BHT is 189 F
- Production data vs. time in shown in Figure 16.

MD	TVD	ANGLE
6100	6099	0.76
7700	7699	1
7889	7888	4.8
8014	8012	8.4
8108	8104	15.6
8328	8303	36.1
8422	8376	43
8517	8439	52.4
8612	8492	61.4
8644	8507	64

Figure 18: Shekar results for Cole Well

At 973 Mscf/D the FBHP is calculated to be about 412 psia. The Turner corrected critical is calculated to be 716 but the flow is 937 Mscf/D. The Shekar model (below) shows also no liquid loading so again predictions of critical are low compared to apparent actual conditions. From production one could argue that the actual critical occurs closer to 1050 Mscf/D.



Summary:
Loading vs Predictions of Loading

- Well 1: loading at .78-.9 mmscfd but predicted at .77
- Well 2: Loading at .72 but predicted at .77
- Well 3: Loading at .62 and predicted at .62
- Well 4: Loading at .973-1.05 but predicted at .716
- Turner Predicts higher critical rate than Coleman
- Shekar uses Turner and Belfroid Correction

Figure 19: When J curve deviates from Friction dominated portion (After Green, Wellmaster)

In a presentation by D Green, Wellmaster, the following concept was introduced. Green shows a straight Line extension of the friction dominated portion of the J curve (below). He indicates that this is the point where a plunger can begin to work as the rate declines.

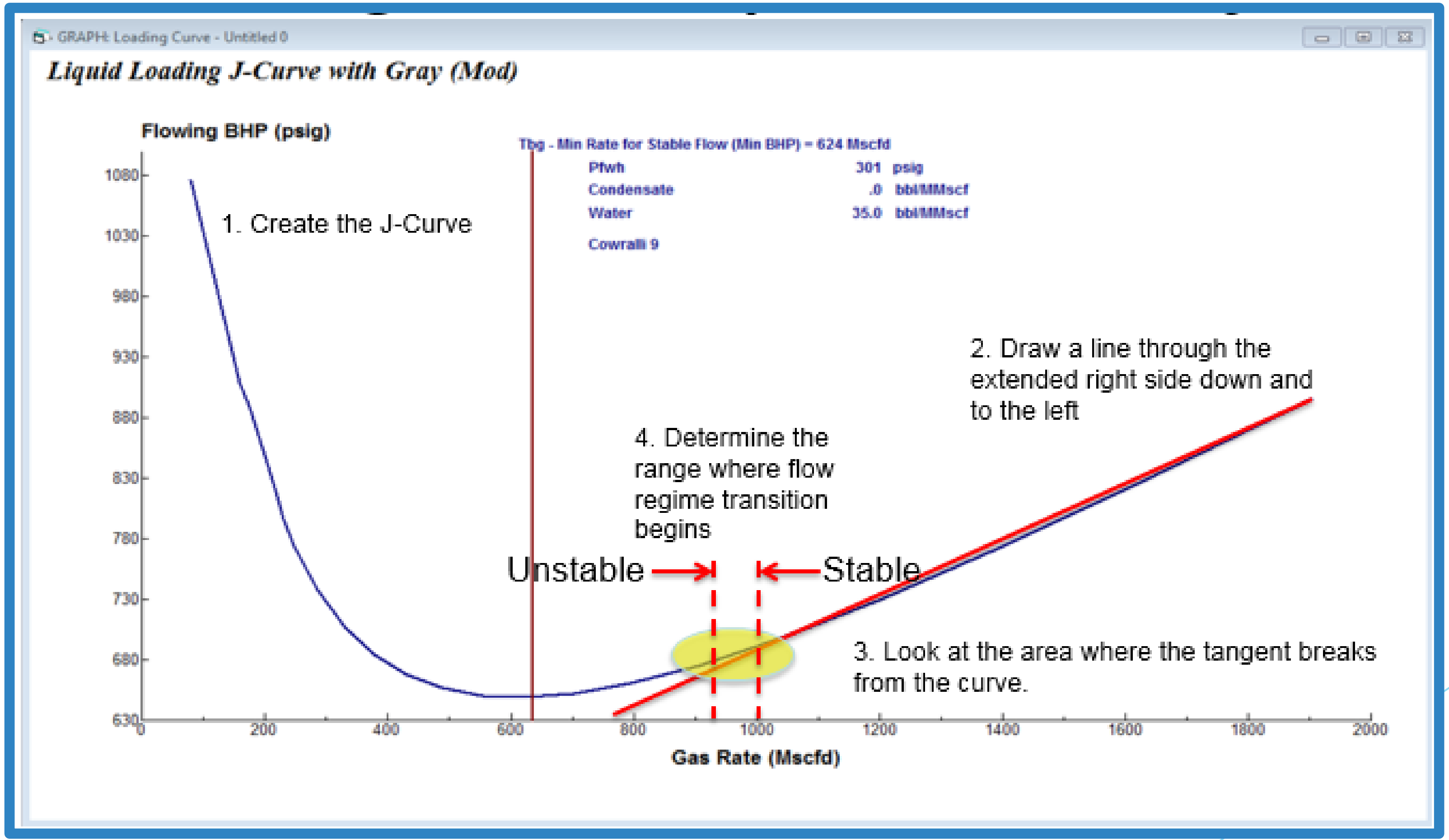
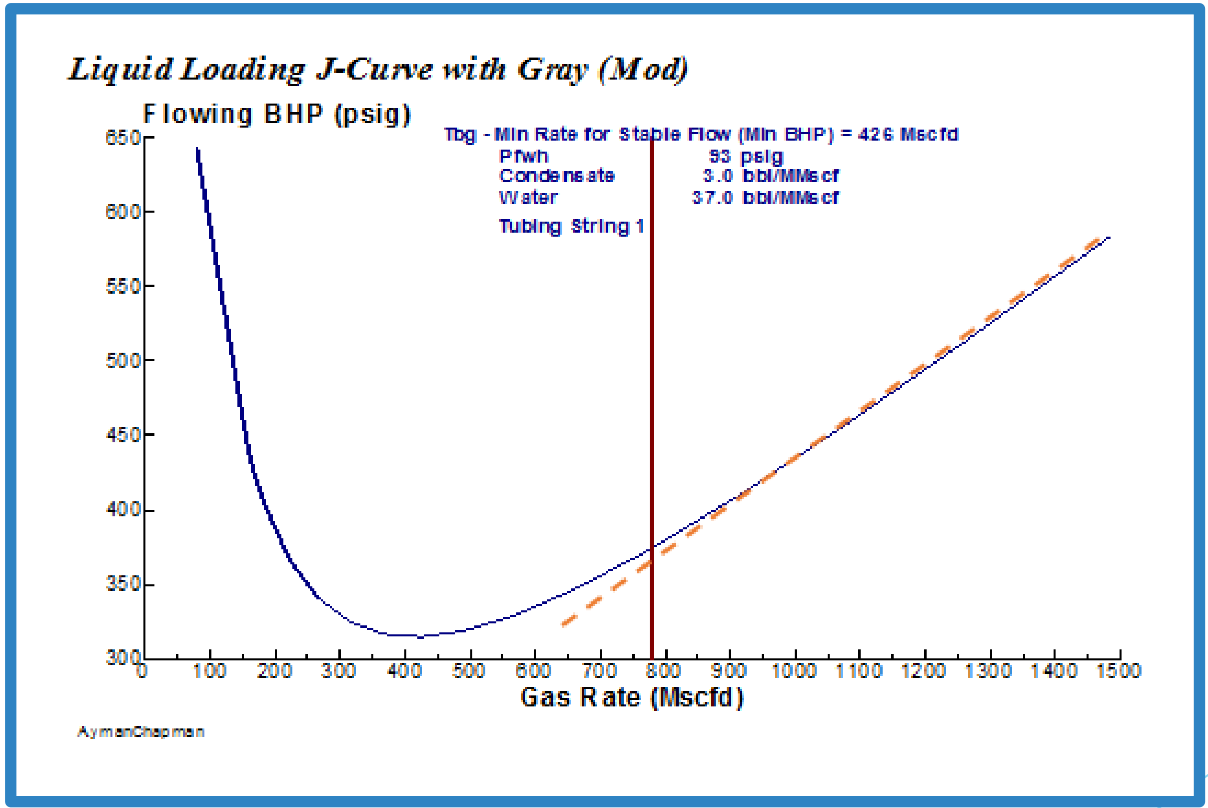
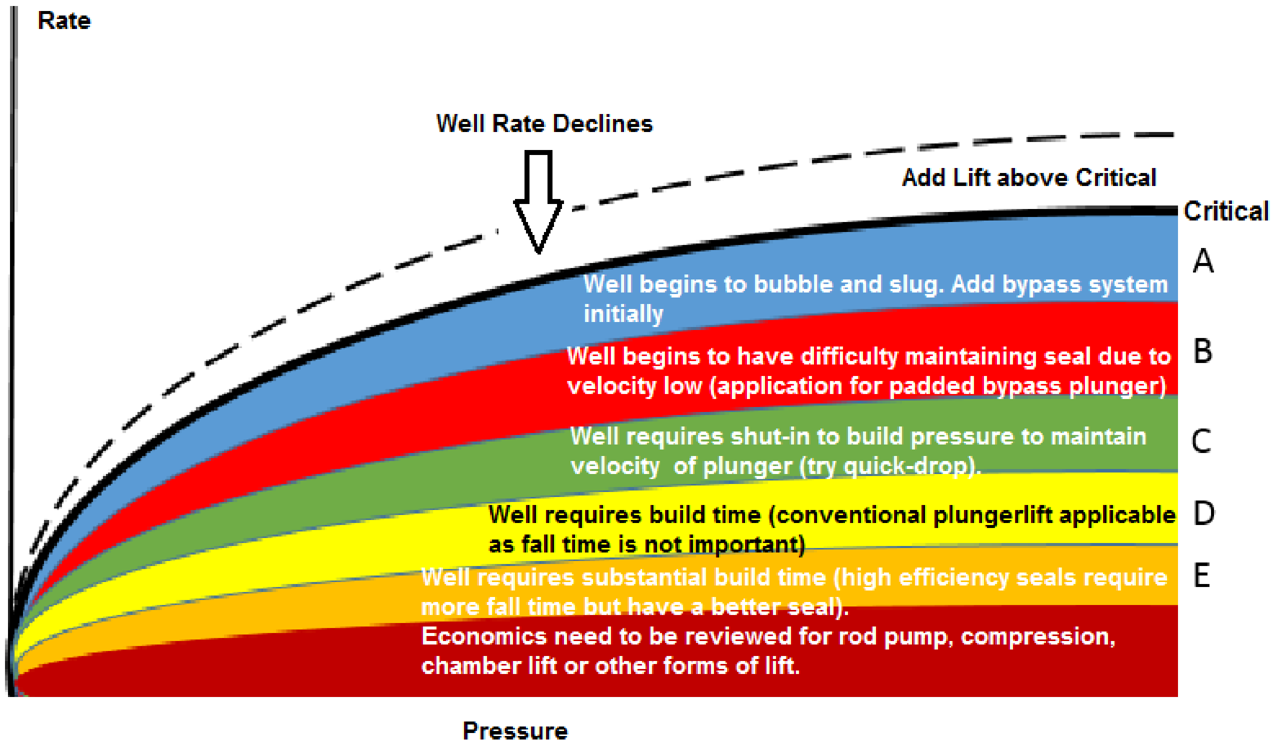


Figure 20: Applying the concept in Figure 20 to Well One

Although above critical, using Green's concept, the plunger could be dropped where the J curve starts deviating from the fully turbulent approximate straight line according to Green's concept (below) . This coincidently when the plunger was actually dropped. However stability is normally thought to be if you are to the left of the minimum of the tubing curve so some questions remain.

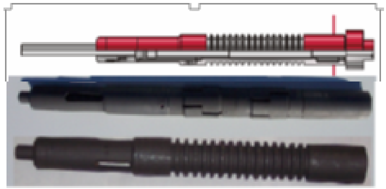


Plunger Type with Well Life

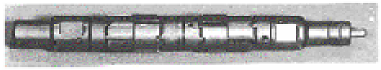


A

B

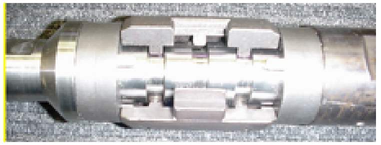


C



D

E



Summary

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- The results in the discussion show that predictions for critical are, in general, low compared to what is apparently actually happening.
- The data shows the possibility of launching the plunger above the calculated critical. This is becoming industry practice but the calculation of critical is more complex than first used. The Green model or concept seems close to the rate where plunger was shown to be effective. Operators should put in plunger a little before the rate drops to or below the calculated predicted critical as good results and increased production can result as shown here.

Summary: Continued

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- The critical calculations are not 100% accurate (for example the Turner predicts 20% higher than the Coleman). Based on these results conclusions about calculated critical is that loading apparently starts above the calculated critical. Perhaps as much as 10% higher compared to calculation results.. Further correlations of critical calculations compared to actual results should allow a workable rule to be established.

- In general one should always put in AL somewhat early but these cases are more extreme. Based on this data even if calculations indicate above critical flow if data shows what appears to be loading one should test the use of plungers. Or in other words paying attention to recorded data seems more important than commonly used calculations concerning if the well is loaded or not but calculations are very convenient to use as a planning tool to anticipate when critical will occur.

Acknowledgements/Thanks & Questions

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- Thanks for your attendance

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