PRODUCTION OPTIMIZATION UTILIZING THE BALANCE-PORTED VALVE AND PILOT VALVE IN THE PERMIAN BASIN

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INTRODUCTION & BACKGROUND INFO

With the recent increase in production levels created by new drilling and completion techniques, oil and gas production optimization in the Permian Basin has become an increasingly popular subject. The Permian Basin, which has been producing for nearly 100 years, currently accounts for approximately 25% of the United States crude-oil production, with wells that present a wide variety of production challenges. Most of these production challenges relate in some way to the well's rapidly and widely changing production potential. This changing production potential, in a region with so much production activity, lends itself naturally to the economic importance of identifying the most optimal production strategies throughout the life of a well, and even more-so during times of lower oil prices.

Artificial lift plays a significant role in the production optimization strategy for most producing oil wells. There are many current forms of artificial lift that can be used, but in the Permian Basin, the most common forms are Electric Submersible Pumps, Rod Pumps, Gas-Lift, and Plunger Lift. Each form of artificial lift has its advantages and disadvantages, and all provide different techniques aimed at optimizing a well's production during its early, middle, or later production stages. Gas-Lift is quickly becoming a more widely used form of artificial lift because of its versatility to produce at both high and low production levels, and its ability to reduce well-maintenance costs associated with equipment failures seen in other forms of artificial lift. This paper focuses on the production optimization strategy presented by gas-lift, and in particular, gas-lift optimization via the Balance-Ported and Pilot gas-lift valves.

GAS-LIFT OBJECTIVES / INDUSTRY STANDARD DESIGN PRACTICES

The main objective in gas-lift is to take high pressure natural gas and inject it into the well as deep as possible, in an effort to lighten the producing fluid gradient as optimally as possible. By lightening this produced fluid gradient, the formation pressure decreases, and thereby allows more inflow, or production into the well-bore. The injection gas is typically sourced from the producing well itself, separated out from the production stream at surface, and then sent to a local natural gas compressor which increases its pressure and re-directs an appropriate amount of gas back down the well-bore, typically into the casing/tubing annulus, and ultimately back into the well's produced fluid stream.

At the surface, outside of your typical production facilities, the primary equipment items needed for gas-lift are a natural-gas compressor, high pressure injection lines to the well, injection control valves, and metering equipment. Down-hole, however, requires the use of gas-lift valves spaced out along the production tubing string and, typically, a production packer set some relatively short distance above the perforations. The main purpose of the gas-lift valves is to regulate the high pressure gas into the production tubing, at specifically designed depths and injection pressures, and then ultimately close when the production pressures decline enough to allow gas injection at a deeper valve, or depth.

The advantages provided by gas-lift are primarily centered on its ability to function within a broad range of production rates and well pressures. It is capable of handling wells with high gas-oil ratios and can provide a lower, overall operational cost structure than most other forms of artificial lift. Its limitations can be gas availability, handling issues with wet and/or sour gas, and injection depth limitations via the packer depth setting and/or available injection pressure. Other forms of artificial lift can sometimes out-produce gas-lift at the very high and low extremes of a well's production life, but in many operating areas, including the Permian Basin, gas-lift has proven to be a very efficient and cost-effective optimization method for producing oil and gas wells.

In order to gain a better fundamental understanding on the optimization potential provided by the Balance-Ported and Pilot gas-lift valves, it is important to first gain an understanding on the typical gas-lift industry design practices and equipment used. Gas-Lift design is a specialized process that takes design experience, knowledge of the surface facility infrastructure, and base understanding of the well in question and its specific parameters. The purpose of this paper is not to get into the specific design process, but to identify and discuss the key aspects in a typical gas-lift design that affect the wells' ability to produce at its most optimal rate. A typical gas-lift design utilizes an injection-pressure operated, or IPO, valve from top to bottom in a well. Depending upon the well and design rates, etc., a valve port size is selected based on a specific, design gas injection rate, which factors in a number of things such as tubing size, production rates and pressures, GOR, water cut, etc. The port size dictates the valve's spread, or difference between the opening and closing forces.

In Figure 1, the valve mechanics for a typical IPO valve are shown in its closed position. The forces required to over-come the nitrogen dome charge in the valve are primarily controlled by the injection pressure (typically from the casing side) acting on the area of the bellows, plus the production pressure (typically from the tubing side) acting on the valve-seat area, which contacts the valve's ball-stem. When the combination of these two forces exceeds the pressure in the valve's dome, the ball will come off of the seat and the valve will open. In all typical gas-lift valves, the area of the bellows is the larger of these two areas, which makes the injection pressure become the primary acting agent to open and close the valve. This is why the valve is often called an IPO valve, which stands for Injection-Pressure Operated. Once the ball comes off of seat in an IPO valve, the production pressure effect goes away, and the only force keeping the valve in an open position becomes the injection pressure, which is now acting on 100% of the areas (bellows and ball-seat). See Figure 2.

A typical Permian gas-lift installation, utilizing 1" IPO gas-lift valves, will use 3/16" ported gas-lift valves, because of the fact that this port size works well with the required injection rates, also taking into consideration the typical well's production pressures, available gas injection pressure, and valve spread. Standard industry design practices when using a typical 3/16" ported valve, is to drop the design closing pressure of each valve in the design-string by +/- 20 psi, starting at the top. In doing so, this helps to ensure the ability of the upper valve to close when the injection point in the well moves to a deeper valve. At that point, the pressure required to keep the newly operating valve open is +/- 20 psi less than the valve above it. This, in turn, forces the valve above to close. This is one of the most critical elements in a typical IPO gas-lift design, and an important concept to remember when looking at true gas-lift optimization potential. In an ideal scenario, this IPO valve design feature can give the operator a sense of what valve is potentially operating at any point in its injection life, but at the same time, also limits how deep injection can ultimately occur because of this same loss in injection pressure.

BALANCE-PORTED GAS-LIFT VALVE DESIGN STRATEGY

The Balance-Ported Valve is similar to the IPO valve in that it is primarily controlled by injection pressure, the difference is that production pressure plays a larger role in opening and closing the valve. Each Balance-Ported valve contains a uniform and larger valve seat than the typical IPO valve. This larger valve seat allows for a larger production pressure effect to act on the area of the ball in the valve's closed position. See Figure 3. A choke sits upstream of the valve seat, and downstream of the valve inlet ports to the valve. This upstream choke is always sized to be smaller than the valve seat, which in turn puts the injection pressure drop across the choke, instead of across the seat, as in the IPO valve. For this reason, the Balance-Ported valve senses production pressure in both the open and closed positions. See Figure 4.

A typical Permian gas-lift installation, utilizing 1" Balance-Ported valves, will use full available injection operating pressure to set all of the valves in the design-string, with choke size selection for each valve based upon mandrel depth and optimal gas injection rate. Because the Balance-Ported valve senses production pressure in both the open and closed positions, it is not necessary to take design injection pressure drops to close each successive valve in the design-string. As the injection point moves down-hole, the upper valves will close based on a decreased tubing pressure, leaving the injection pressure unchanged.

For this reason, it is not possible to identify which potential valve is operating at any one time in the well's injection life until the injection point reaches the bottom valve. Some operators do not like this feature, but the Balance-Ported valve's primary goal is to inject gas as deeply as possible throughout the well's injection life. Deeper injection equates to higher reservoir draw-down and higher subsequent production rates, which is the goal of production optimization. With all of the different variables that go into any gas-lift valve design, the only true way to identify a potential operating valve from surface, in any design, is to run a systems analysis model, based upon the well's pressures and production rates, or perform a CO2 injection survey. Looking at injection pressure alone for an accurate injection depth, regardless of design, is extremely difficult unless the operator is experienced enough to correct the design for fluid rates, flowing temperatures and pressures, etc.

With that said, the design depths for the Balance-Ported valve are typically spaced-out more conservatively, depending upon the design fluid rate, and anticipated well-head tubing pressure. Because the valve is more sensitive to production pressure, it is important that the mandrels do not get spaced out too far apart, at least within the operating envelope of the design (i.e. operating injection depth vs. design fluid rate). Ultimately, the bottom valve in a Balance-Ported valve design, will be designated as an orifice valve, or an IPO valve at a 50-100 psi lower design injection pressure. This helps to ensure a more crisp injection point for well stability purposes, while also helping to ensure the upper valves do not re-open. More often than not, this valve will be the deepest valve in the design-string, just above the production packer. In many of the Permian designs, regardless of valve type, this bottom valve is often run as a retrievable-type valve in a side-pocket gas-lift mandrel. Setting this valve as a retrievable-type valve allows for design-conversion to intermittent lift via slick-line intervention and the installation of a Pilot valve at a later point in time. The Pilot valve is aimed at optimizing a well's production capability later in its production life, which is also included within this paper.

<u>EXAMPLE WELL DESIGN UTILIZING BALANCE-PORTED VALVE</u>

In an effort to illustrate a typical Permian design utilizing the Balance-Ported valve, the following case-study will be used which chronicles a complete, and ideal, design scenario. This case-study is for an actual well in Glasscock County, Texas. It's a well that was completed in the spring of 2016, with a lateral of about 10,000' MD, producing from a TVD depth of about 8400' from the Wolfcamp B formation. For the sake of discussion, this well is somewhat typical to many other Permian wells in that it is completed with 5-1/2" 20# casing, 2-7/8" 6.5# tubing, and a production packer near the well's kick-out point at +/- 7500' MD.

This well was originally opened to flow with 2-7/8" slick tubing (no gas-lift equipment) for about one month, before the flowing surface pressure fell enough for gas-lift to be considered. Initially, the well came on producing about 2000 BFPD with a water cut of +/- 25%. Before a gas-lift design was generated, the operator decided to obtain some downhole well information to assist in the design process by running a flowing pressure survey with slick-line pressure/temperature gauges, which also included a short build-up period to help estimate the current SBHP. During this survey, the well was producing 1988 BFPD, with a FBHP of 3086 psia and a SBHP of 3245 psia. The approximate Productivity Index (or PI) was calculated at +/- 12.5 BFPD/psia-draw-down. It should be noted that this PI calculation was only used as a current, and rough, approximation of the well's inflow potential because of the age of the well and the fact that build-up period was relatively short. See Figure 5.

With this information, a Balance-Ported design was put together to capitalize on the well's high inflow potential and available injection operating pressure of 1100 psi. The design injection rate was set at 500 MCFPD, with an orifice placed in the deepest mandrel at 7400' MD, just above the production packer. The mandrel spacing in this design was conservatively set at 500' TVD and included 12 gas-lift mandrels for a design fluid rate of 2864 BFPD (75% water cut). See Figures 6 and 7.

The gas-lift equipment was installed shortly after running the survey and generating the gas-lift design. Once the well was unloaded, and kicked off with gas injection, its production rates came in at 2930 BFPD total, with an injection rate of 450 MCFPD, and 1096 psia injection pressure. A surface pressure chart is included to show the kick-off and unloading process, with applicable surface pressures and rates. See Figure 8.

Although gas-lift helped increase the total production rates on this well initially, this well like many other wells in the Permian Basin, slowly fell off in production over the coming months as the reservoir pressures came down and the well followed its natural decline path. See Figure 9. Another flowing survey was performed on this well four months later and showed the well to be producing at a production rate of 1262 BFPD, a FBHP of 1737 psia, and a 50% water cut. Injection points were noted at valve numbers eight and nine in the design-string, at an injection pressure of 1030 psi. This survey can be seen in Figure 10.

Three months later, and after additional decline in production rates, a third and final survey was performed on this same well, showing a production rate of 967 BFPD, a FBHP of 1126 psia, and a 50% water cut. The well was receiving an injection gas rate of 758 MCFPD with an injection point found to be clearly at the bottom orifice valve, and an injection pressure of 965 psia. See Figure 11. It should be noted that the well was heading during this survey, but the heads were more of a combined result of the horizontal flow effects caused by the produced fluids moving through the lateral section, and over injection. The production pressures noted during the survey were clearly less than the required pressures to re-open any of the valves, also taking into consideration the lower injection pressure. This was further verified by the fact that no other gas injection points were seen during the survey at any of the upper gas-lift valves.

Taking all of this information into consideration, the Balance-Ported valve offered the well in this example a chance to operate at its most optimal production rate from the on-set of gas injection, all the way until the injection point reached the bottom gas-lift mandrel. If this well would have utilized a 1" standard IPO gas-lift valve design, the +/- 20 psi design injection pressure drops would have limited the well's injection depth and subsequent production rates, especially when the injection point reached the middle group of gas-lift valves. This design ultimately afforded the well an opportunity to produce at its maximum level for a longer period of time, which is one of the key economic and business metrics used by many operators today.

GAS-LIFT PILOT VALVE DESIGN STRATEGY

When wells get to the latter stages of production, continuous gas-lift, as described in the example above, can only take a well's production so far. The reason for this is directly related to pressure and injection depth. Continuous gas-lift can only lower a well's reservoir pressure to a certain point, before it can no longer produce an economical rate vs. its operating costs. These operating costs are mostly related to surface compression and the required gas injection rate to keep the well producing at some, stable rate.

When a well's pressures and production rates get to this level, some operators choose to switch gears and evaluate production optimization via other forms of artificial lift such as rod-pumps and plunger lift. These forms of artificial lift can help optimize a well's production during its latest stages of production and are probably the two most common forms of artificial lift when a well reaches this stage. Rod-pumping units have dominated the Permian Basin in this capacity for many years, with plunger lift providing an alternative option for some wells, depending upon the well's conditions (i.e. high GOR, paraffin, etc.).

Another alternative form of artificial lift for wells in this stage of production life is intermittent gas-lift. Intermittent gas-lift is a form of gas-lift that intermittently introduces high pressure injection gas into a well, which then displaces a liquid slug to surface. Intermittent gas-lift is characterized by a period of injection, followed by a period with no injection. This period without gas injection, allows the well to feed-into the well-bore, before another cycle of high pressure gas injection enters the tubing aimed at displacing this accumulated liquid column, and subsequent liquid slug, to surface. Intermittent lift is typically a viable gas-lift option for wells with either a lower reservoir pressure and higher Productivity Index, or a higher reservoir pressure and a lower Productivity Index. In the case of Permian wells, the effective reservoir drainage pressure can become quite low at the later stages of its production life, even though the infinite, or true-connected, reservoir pressure can be higher.

Traditional intermittent-lift systems often used larger ported IPO type valves with surface gas injection control valves and timers to intermittently introduce gas injection into a well based upon its inflow potential. The Pilot valve, however, is a gas-lift valve specifically designed for intermittent applications aimed at increasing injection-efficiently, and eliminating the need for surface injection-time controllers. The Pilot valve contains an upper valve section that senses both injection and production pressures, similar to a typical gas-lift valve. However, it also includes a lower power section that shifts and uncovers a very large flow area as soon as the upper valve section opens and the ball comes off of seat. This allows a very large volume of gas to be injected into the well quickly, as the injection pressure quickly falls from the opening pressure of the valve, to the closing pressure of the valve. This change in pressure, also known as the valve spread, is one of the key factors used in properly sizing the valve for the specific well application.

The Pilot valve is typically installed by slick-line in a retrievable-type, side-pocket gas-lift mandrel located just above the production packer. Although there are ways to install this valve and system conventionally if needed, it is generally recommended to install the valve into a side-pocket mandrel whenever possible. Some operators install this side-pocket mandrel on the tubing during the initial completion and load the mandrel with an orifice valve, or flagged-back IPO valve. Others, however, wait until the well reaches this stage in production before pulling the tubing and installing the necessary equipment. Either way, using a retrievable-type mandrel provides the operator with a relatively simple means of converting the continuous-lift design to intermittent-lift, and/or addressing any operational issues with the Pilot valve that might arise after installation.

The design of the Pilot valve can be relatively simple with good well information, but basically involves defining how large of a fluid slug will need to be moved to surface, and what size tubing and casing is in the well. The opening pressure and port size of the valve are set in an effort to ensure that the Pilot valve opens at a pressure lower than the upper gas-lift valves, while also keeping the ability to drain enough casing, or injection, pressure to effectively sweep the liquid slug to surface. Injection operating pressure is a big design key because too low of a system operating pressure will cause the system to act inefficiently. This is one reason why the Balance-Ported valve works well with the Pilot valve, as it keeps the design operating pressure on the upper valves at its maximum level. The Pilot valve can be installed with or without a standing valve, but typically incorporates one in an effort to ensure maximum production efficiency.

EXAMPLE WELL DESIGN UTILIZING PILOT VALVE

The following Permian well is an example of total well optimization utilizing the Pilot valve. The well in this example was completed in the Bone Spring formation in the spring of 2014. It's horizontally drilled and completed with a 5000' lateral and vertical depth of 7400' TVD. The well is completed with 5-1/2" 17# casing, 2-7/8" 6.5# tubing, and a production packer near the well's kick-out point at +/- 6800' MD.

Although the operator in this example was interested in the Pilot valve's ability to potentially increase production on this well, it was primarily interested in its ability to reduce the well's injection gas requirements. For this reason, and since this was its first installation, the operator elected to perform a flowing survey on the well before Pilot valve conversion in an effort to help ensure an appropriate design was selected. The results of the flowing survey can be seen in Figure 12, as the well was flowing at a 228 total BFPD rate with an injection rate of 500 MCFPD at the bottom gas-lift mandrel. The FBHP was recorded at 610 psia and the well showed a very high GOR. From a traditional and continuous gas-lift stand-point, this well showed to be completely optimized.

With this information, a Pilot valve gas-lift design was put together utilizing Balance-Ported unloading valves up-hole, and a 3/8" ported Pilot valve installed in a side-pocket gas-lift mandrel just above the production packer at 6800' MD. Utilizing the Balance-Ported valves up-hole allowed the design to use full available injection operating pressure to set the upper valves, while setting the surface opening pressure of the Pilot valve at 700 psi. The design gas injection rate was 180 MCFPD. See Figures 13 and 14.

The plot in Figure 15 shows the initial surface pressures and production rates from the initial well kick-off. It should be noted again that this well was on the edge of the Pilot valve's ability to optimize solely based on production level, mainly because of the well's high GOR. The initial post-installation production rates showed a much higher oil-cut (only +/-20% water), and a higher total initial fluid rate of +/- 300 BFPD. These rates have since normalized with time, but the well is still producing its typical +/- 200-250 BFPD rate (with +/- 40% water-cut). The well is receiving a much lower gas injection rate (180 MCFPD), however, which proved to be the biggest win in this specific project since the level of oil production remained about the same. This well was one of two wells in a successful pilot project for the operator.

OTHER DESIGN FACTORS FOR CONSIDERATION

Although the two valve types addressed in this paper present real, fundamentally engineered options geared towards gas-lift optimization, they are still susceptible to other well factors if these factors are not properly taken into consideration, or accounted for. One of these design factors that can greatly affect the functioning ability of any gas-lift valve is temperature. Temperature plays a significant role in the opening pressure of most gas-lift valves because of the nitrogen dome charge that acts as the valve's closing force. An improperly selected design temperature can affect the operating pressure of a gas-lift design quite significantly, and depending upon what direction the error is made in, can cause the design to become very inefficient. In the Permian Basin, geothermal temperature gradients can vary quite largely from one area to the next and should always be properly identified, modeled, and accounted for before finalizing the set pressures on any nitrogen charged gas-lift valve. See Figure 16. Design experience and flowing survey data in each specific field, related to flowing temperatures vs. production flow-rates, helps in optimizing future, additional well-designs. A good understanding on specific field geothermal gradients and flowing temperatures is a vital aspect in allowing especially the Balance-Ported valve to capitalize on its ability to function at full injection operating pressure.

Other factors to consider include injection fluid properties, changing well conditions, horizontal flow effects, and field operational experience. The injection gas composition in many of the Permian fields holds a heavier specific gravity than most traditional injection gas compositions do. Typically, the specific gravity seen in natural gas is around 0.65, however, in the Permian Basin, gas specific gravities can reach as high as 0.75 and 0.8, depending upon the actual gas composition. Understanding the true composition of the injection gas, allows the Balance-Ported valve to operate most efficiently. Injection gas impurities can exist, such as H_2S and water, and if not treated properly, these impurities can cause system malfunctions by way of equipment corrosion, and/or valve leaks. The upstream chokes in the Balance-Ported valve can help prevent seat erosion due to wet injection gas compositions.

Changing well conditions can also create operational issues with the gas-lift equipment because of the extended operating life that each valve can be subjected to. Historically, in other gas-lift fields including offshore fields, gas-lift equipment is primarily slick-line serviceable and tends to be changed-out as the well conditions change. This allows the design to stay optimal while minimizing the life-expectancy of any one valve in the well. In land applications, however, especially in the Permian Basin, gas-lift equipment is run conventionally, or tubing retrievable, and can be expected to operate in a well from its earlier stages of higher production rates all the way down to its lowest production levels. This broad spectrum of operating conditions puts more time and operating stress on each valve in the design string.

In addition to that, the horizontal flow effects can create instability in the well that rivals the gas-lift system's ability to function in a stable manner. Understanding these factors can help in designing the Balance-Ported valve from a mandrel spacing stand-point, and also from a choke-sizing stand-point. The ability to use smaller chokes in a valve can sometimes help to mitigate the effects of the horizontal flow surges coming into the well-bore by attempting to reduce and/or eliminate any valve throttling issues caused by having too large of a port for the required injection rate. The Balance-Ported valve gives the designer this choke-sizing option.

The last well factor to consider when designing Balance-Ported and/or Pilot valves is field operational experience. Both the Balance-Ported and Pilot valves operate differently than the typical, or industry standard IPO gas-lift valve. There is already an overall lack of field experience related to gas-lift operations in general, so the introduction of the Balance-Ported valve and/or Pilot valve can take some time to implement effectively. This process can only be expedited through training and continual field operational schools, aimed at increasing the field operator's knowledge of what goes into a gas-lift design, how to effectively read a gas-lift design worksheet, and what information to be most concerned with when monitoring or trouble-shooting a gas-lift well from surface.

CONCLUSION

In conclusion, gas-lift optimization is not really different than optimization in any other oilfield, or industrial application. It simply requires a basic or fundamental understanding of what the overall objective is, and an identification of what factors can help to achieve that objective most effectively. The Balance-Ported valve offers this advantage for any gas-lift well that is not operating on the bottom valve. It does this by using the full, available injection operating pressure to lift as deep as possible. This is based on the simple production engineering principle that deeper gas injection creates more reservoir drawdown which equates to maximum production rates. The Pilot valve can complement the Balance-Ported valve later in the production life of a well, by providing the operator with a means of maximizing its lower, late-life production potential without the use of a work-over rig, while also reducing the injection gas requirements in the process. Both valves when applied correctly, provide real solutions to consider for ultimate gas-lift and production optimization.

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US Patent No. 4,625,941 – Constant Flow ® Valve

TABLES & FIGURES

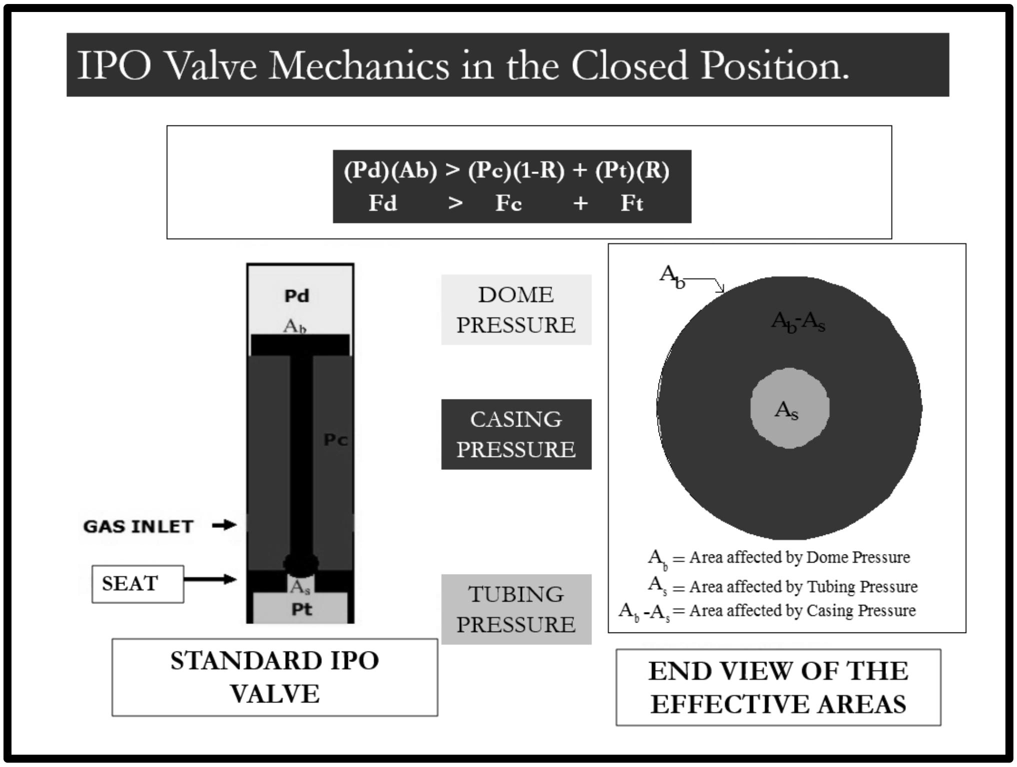

Figure 1 – Standard IPO Valve Mechanics Closed

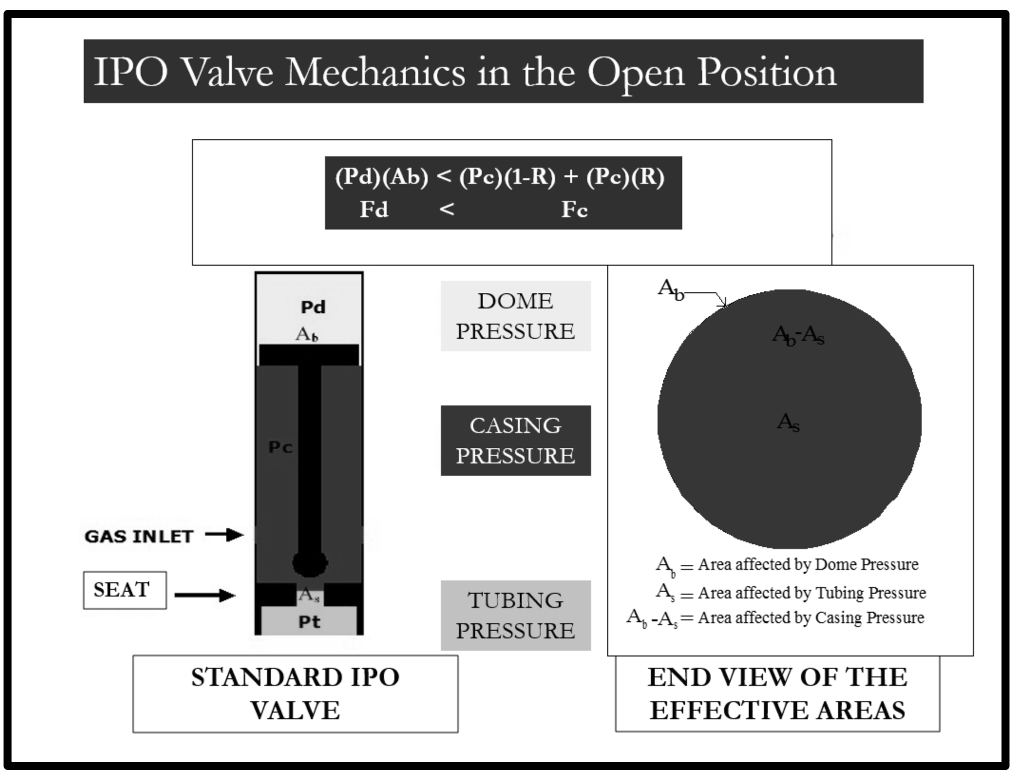

Figure 2 - Standard IPO Valve Mechanics Open

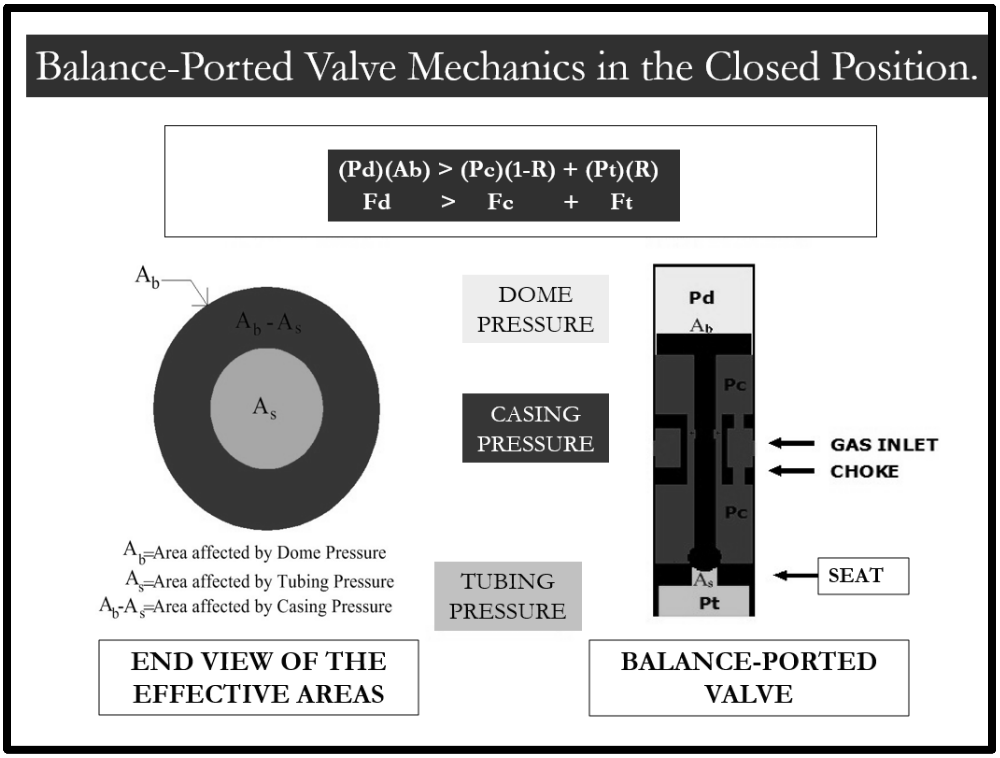

Figure 3 – Balance-Ported Valve Mechanics Closed

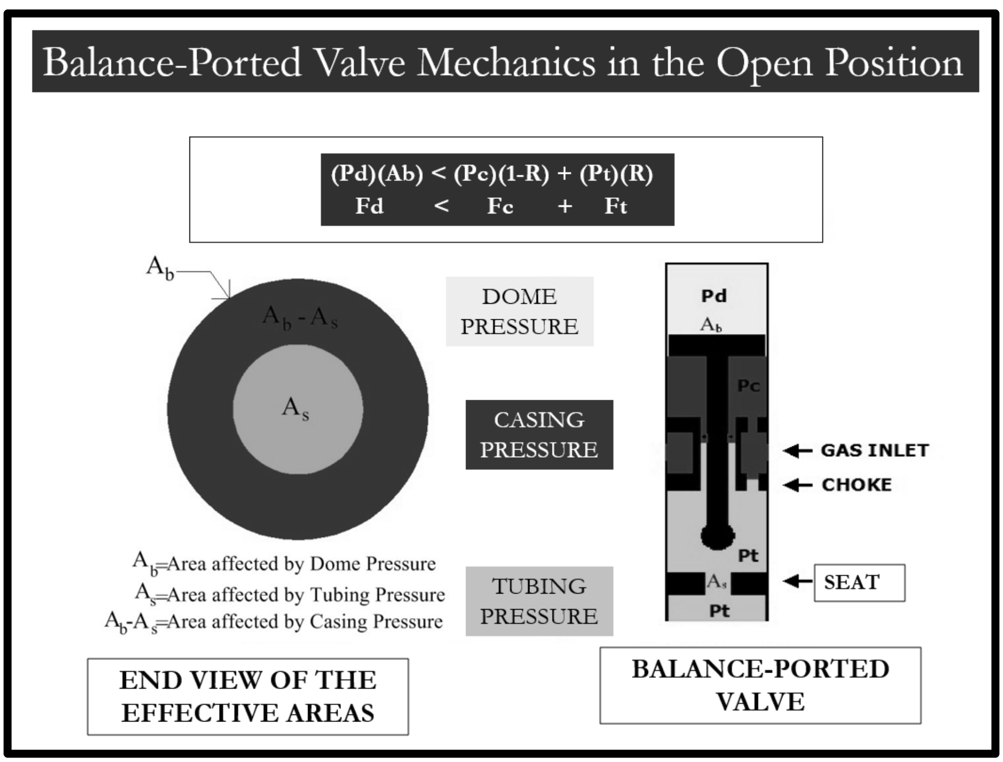

Figure 4 - Balance-Ported Valve Mechanics Open

Flowing Gradient Profile - RIH

Company:		API #
Lease:		
Well No:		
Field:		

WLM (feet)	MD (feet)	TVD (feet)	Pres. (psia)	Temp (o F)	Pres. (psi/ft)	Temp (o F/ft)	Mandrels MD	Mandrels TVD	Port Choke	Ptro
0	22	22	214.62	117.06						
978	1,000	1,000	435.63	123.15	0.226	0.006				
1,978	2,000	2,000	707.65	128.91	0.272	0.006				
2,978	3,000	3,000	1,041.17	134.33	0.334	0.005				
3,978	4,000	4,000	1,417.71	139.50	0.377	0.005				
4,978	5,000	5,000	1,804.64	143.63	0.387	0.004				
5,978	6,000	6,000	2,211.07	147.08	0.406	0.003				
6,978	7,000	7,000	2,622.29	148.97	0.411	0.002				
7,379	7,401	7,401	2,786.14	149.47	0.409	0.001	Test Depth			
7,558	7,580	7,580	2,859.28	149.70	0.409	0.001				
8,034	8,056	7,992	3,027.62	150.21	0.409	0.001				
8,320	8,342	8,135	3,086.05	150.39	0.409	0.001				
8,610	8,632	8,136	3,086.46	150.39	0.409	0.001	Extrapolated Mid-Perfs			

Well Test & Fluid Parameters				Tubulars			Reservoir
Qo =	522	Tot. bbls	1,988	KB to THF	22	ft	
Qw =	1466	GOR =	816	Tubing Size	2 7/8"	6.5#	Perforations
Qtg =	426	GLRi =	214	Casing Size	5 1/2"	20#	8,632' - 18,197' MD
Qinj =	0	GLRf =	214	Packer	7,480' MD		8,136' TVD
% Cut =	73.7	γ w =	1.074	Time and Gauge Data			
FTP =	215	γ o=	0.793	Gauge S.N.	5338		
Pcsg =	158	γ g =	0.650	Calibration Date	9/15/2016		
Choke =	42	Mixed Grd.	0.433	Build up Hours	4.0 hrs.		
API =	47.0	Fluid Level	2,239	Total Shut Hours	5.0 hrs.		
Psep =	43	FBHP	3,086	Gauge Start Time	05/09/16 9:37:30		
Tsep =	111	SBHP	3,245	Shut in well	05/09/16 11:47:50		
Tfluid =	117	ΔP@perfs	158	Gauge Stop Time	05/09/16 17:21:48		
SITP =	656	PI =	12.577	Comments:			
Altec Rep On Sight:							
DATE:							

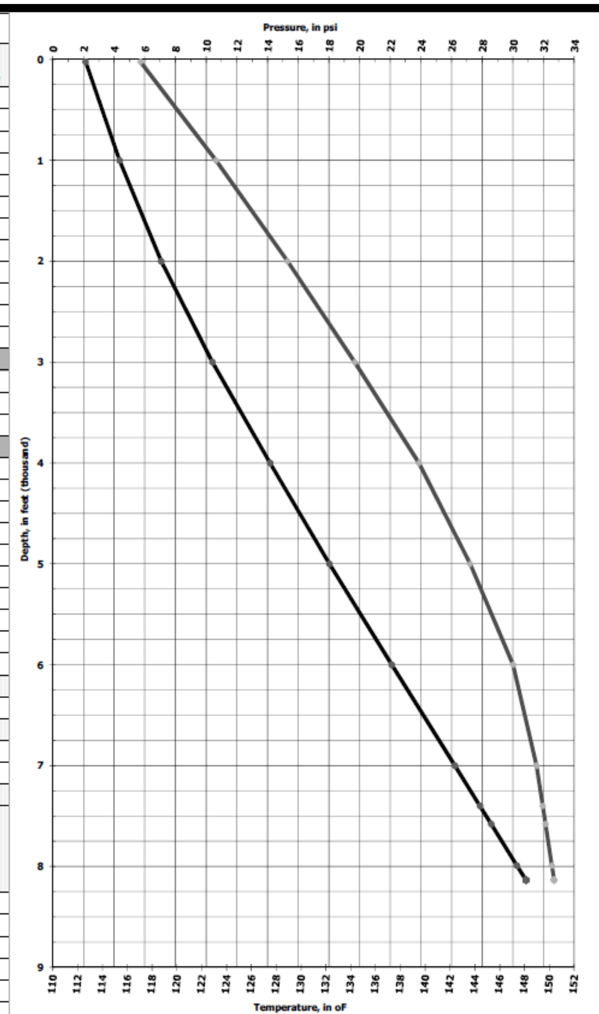

Figure 5 – Pre Balance-Ported Valve Design Example Flowing Survey

Valve no.	DEPTH MD	DEPTH TVD	TEMP	CKE	Estimated Max Port	Estimated Max mscf	Estimated Max R	1-R	Δ Pc	Pt	Pt*R	Pso Psc	Pvo Pvc	Pd	TCF	Pd @ 60 deg	calc. Ptro	use Ptro
1	**1600**	**1600**	128	10	5/16	426	0.2463	0.7537	55	814	201	**1100**	1155	1072	0.825	884	1173	**1180**
2	**2300**	**2300**	135	10	5/16	414	0.2463	0.7537	80	881	217	**1100**	1180	1106	0.810	896	1189	**1195**
3	**2900**	**2900**	139	12	5/16	573	0.2463	0.7537	100	945	233	**1100**	1200	1138	0.803	914	1213	**1210**
4	**3400**	**3400**	140	12	5/16	578	0.2463	0.7537	118	962	237	**1100**	1218	1155	0.799	923	1225	**1225**
5	**3900**	**3900**	142	12	5/16	582	0.2463	0.7537	135	980	241	**1100**	1235	1172	0.795	932	1237	**1240**
6	**4400**	**4400**	144	12	5/16	587	0.2463	0.7537	152	997	246	**1100**	1252	1190	0.792	943	1251	**1255**
7	**4900**	**4900**	145	12	5/16	591	0.2463	0.7537	170	1014	250	**1100**	1270	1207	0.789	953	1264	**1270**
8	**5400**	**5400**	147	12	5/16	596	0.2463	0.7537	187	1032	254	**1100**	1287	1224	0.787	963	1278	**1285**
9	**5900**	**5900**	148	12	5/16	601	0.2463	0.7537	204	1049	258	**1100**	1304	1241	0.785	974	1292	**1295**
10	**6400**	**6400**	149	12	5/16	605	0.2463	0.7537	221	1066	263	**1100**	1321	1259	0.783	986	1308	**1305**
11	**6900**	**6900**	149	12	5/16	610	0.2463	0.7537	239	1083	267	**1100**	1339	1276	0.782	998	1324	**1315**
12	**7400**	**7400**	150		3/16	622			233	1000		**1000**	1233		0.781			**Orifice**
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		
21																		
22																		

Figure 6 – Recommended Balance-Ported Valve Design Example Worksheet

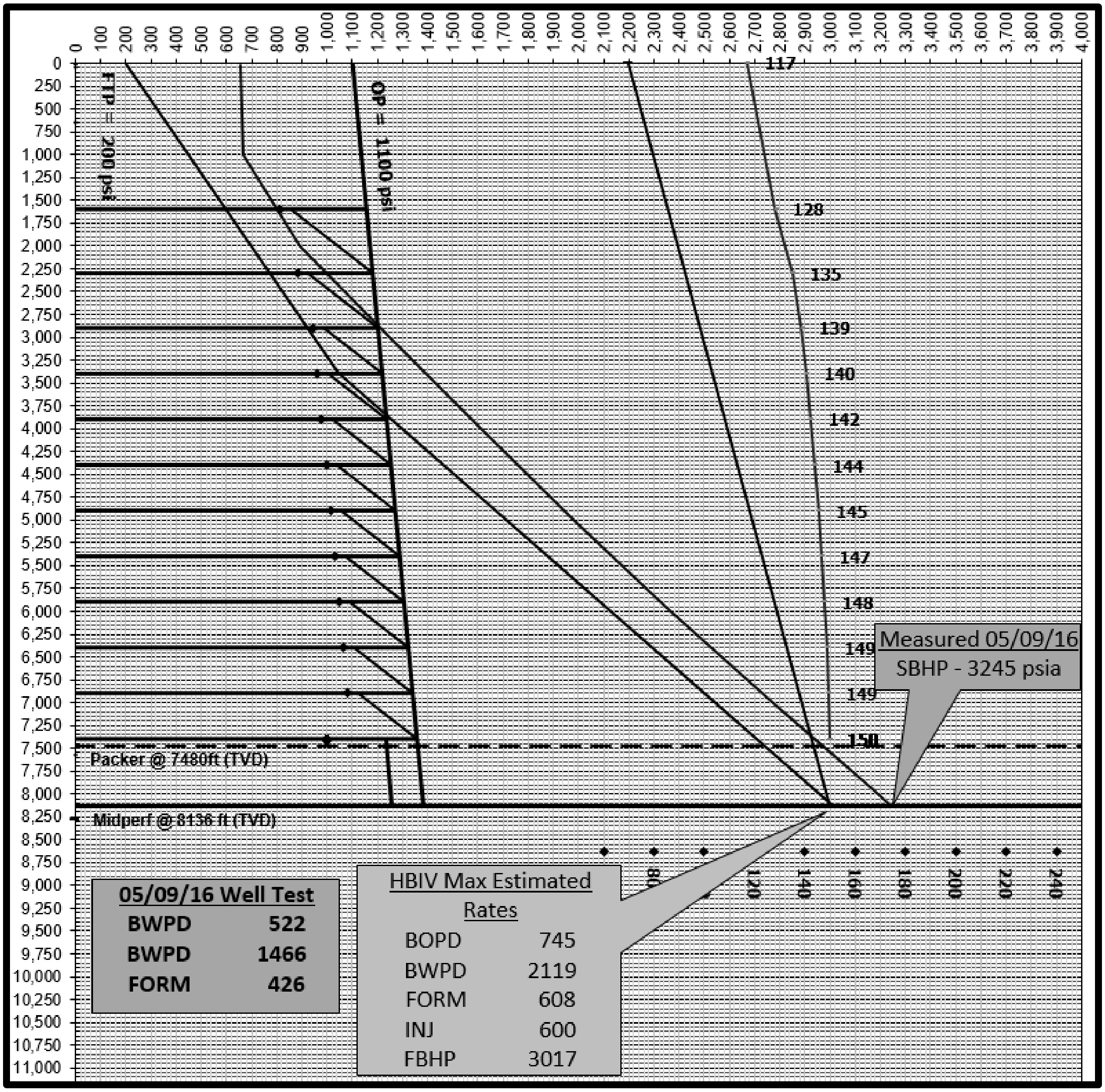

Figure 7 - Recommended Balance-Ported Valve Design Example Graph

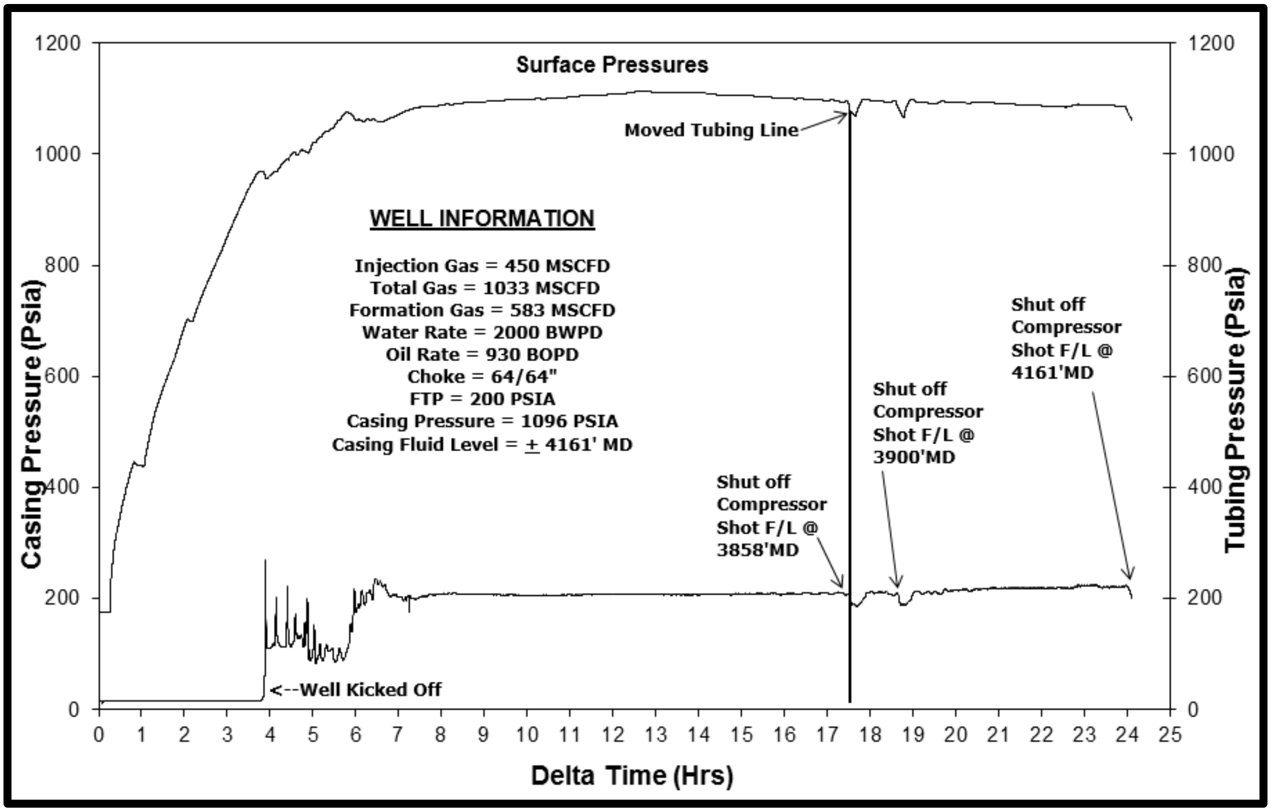

Figure 8 – Post Balance-Ported Valve Design Example Kick-Off (Surface Pressures & Rates)

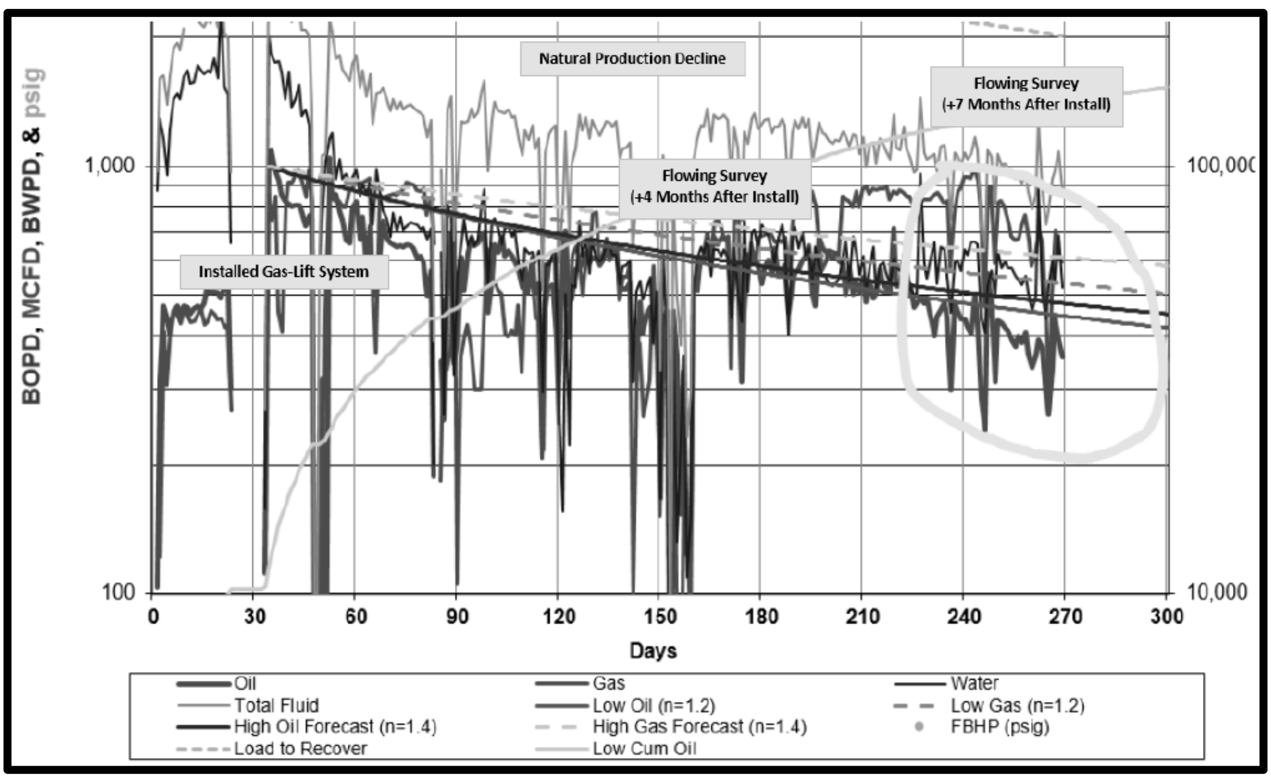

Figure 9 - Balance-Ported Valve Design Example Production Decline Graph

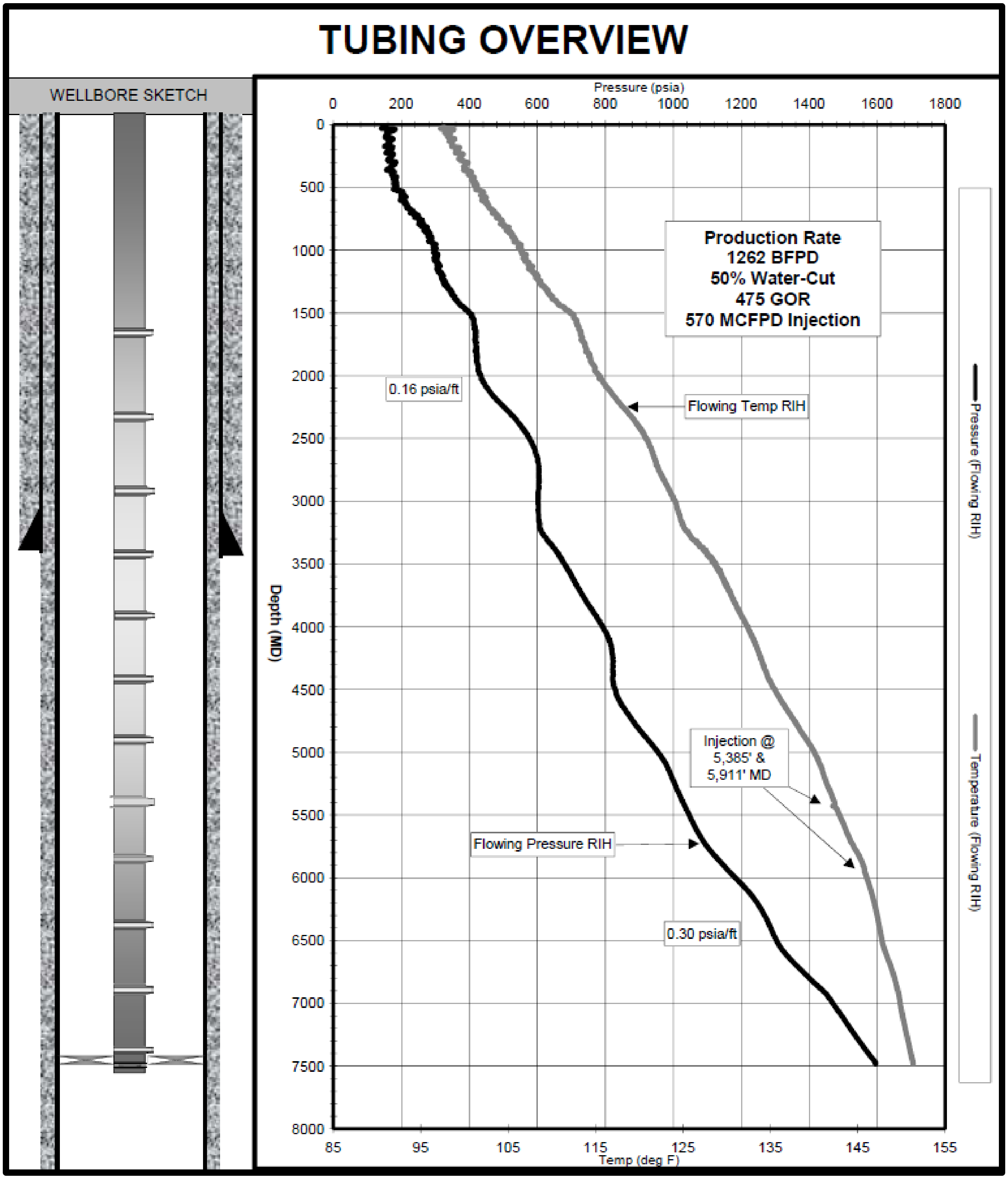

Figure 10 - Post-Balance-Ported Valve Design Example Flowing Survey (4 Months Later)

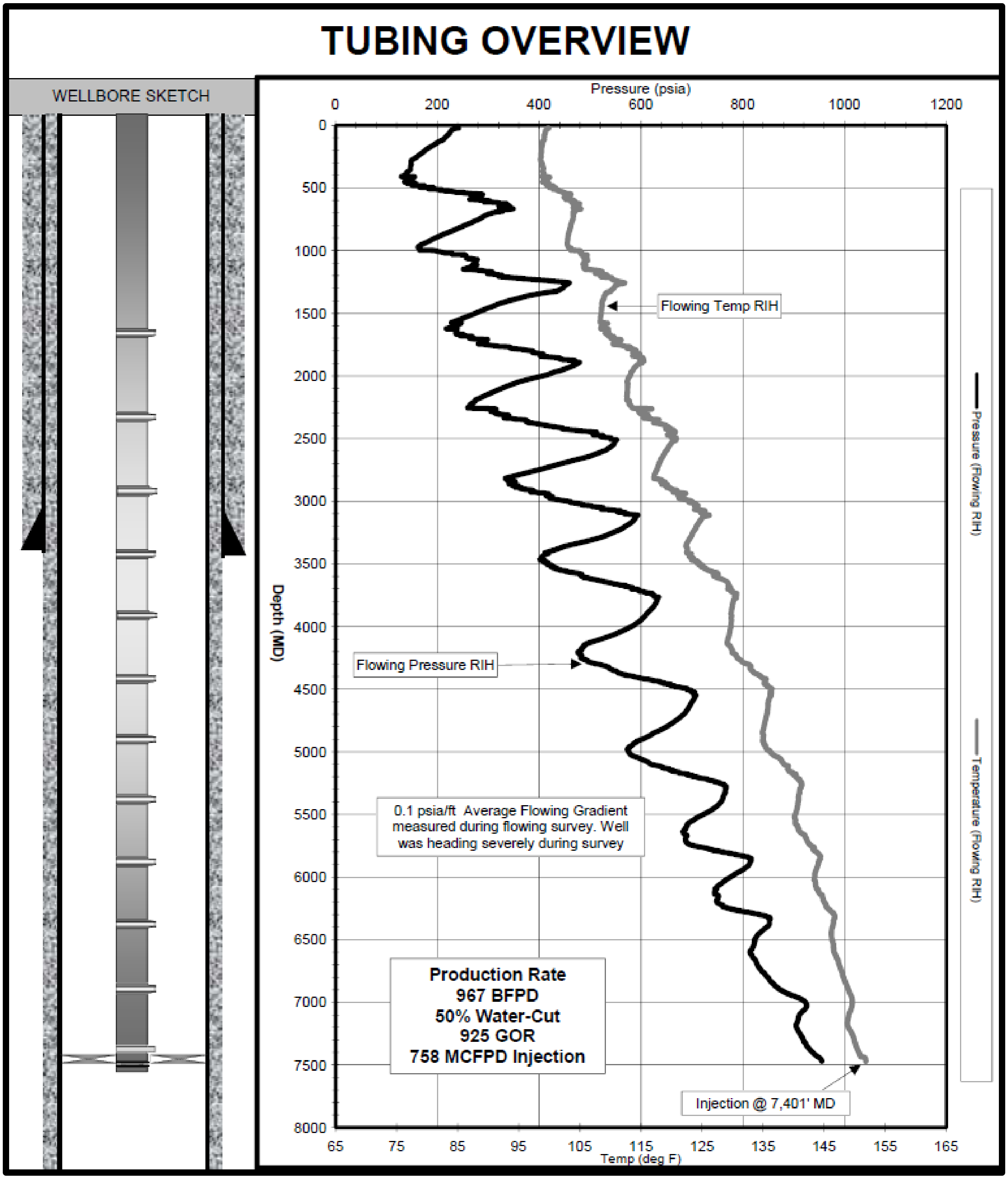

Figure 11 – Post Balance-Ported Valve Design Example Flowing Survey (7 Months Later)

Flowing Gradient Profile - POOH

API #	
Company:	
Lease:	
Well No:	
Field:	

Mandrels MD	Mandrels TVD	Port Choke	Ptro
4,798	4,797	N/A	N/A
5,502	5,501	N/A	N/A
6,207	6,206	N/A	N/A
6,783	6,782	N/A	N/A

WLM (feet)	MD (feet)	TVD (feet)	Pres. (psia)	Temp (o F)	Pres. (psi/ft)	Temp (o F/ft)	
0	31	31	210.84	70.94			
469	500	500	259.61	76.46	0.104	0.012	
969	1,000	1,000	248.38	80.18	-0.022	0.007	
1,969	2,000	2,000	184.46	84.30	-0.064	0.004	
2,969	3,000	3,000	325.89	94.97	0.141	0.011	
3,969	4,000	4,000	468.90	104.88	0.143	0.010	
4,767	4,798	4,797	485.04	113.41	0.020	0.011	
5,471	5,502	5,501	418.86	117.36	-0.094	0.006	
6,176	6,207	6,206	549.29	121.93	0.185	0.006	
6,752	6,783	6,782	584.80	126.25	0.062	0.008	
6,790	6,821	6,820	589.31	129.93	0.119	0.097	Test Depth
9,784	9,815	7,412	624.83	134.66	0.060	0.008	Mid-Perfs Extrapolated

Well Test & Fluid Parameters			
Qo =	130	Tot. bbls	228
Qw =	98	GOR =	4,115
Qtg =	1026	GLRi =	4,500
Qinj =	491	GLRf =	2,346
% Cut =	43.0	γ w =	1.074
FTP =	158	γ o=	0.814
Pcsg =	749	γ g =	0.650
Choke =	48	Mixed Grd.	0.401
API =	42.3	Fluid Level	N/A
Psep =	94	FBHP	610
Tsep =	75	SBHP	N/A
Tfluid =	68	ΔP@perfs	N/A
SITP =	N/A	PI =	N/A
Altec Rep On Sight:			
DATE:			

Tubulars			Reservoir
KB to THF	31	ft	"Bone Spring"
Tubing Size	2 7/8"	6.5#	**Perforations**
Casing Size	5 1/2"	17#	7,772' - 11,858' MD
Packer	6,815' MD		7,401' - 7,406' TVD

Time and Gauge Data	
Gauge S.N.	5534
Calibration Date	November-15
Build up Hours	N/A hrs.
Total Shut Hours	N/A hrs.
Gauge Start Time	08/29/16 10:08:25
Shut in well	N/A
Gauge Stop Time	08/29/16 13:46:10
Comments:	

Note: Used avg flowing press/temp gradients to extrapolate press/temps at mid-perfs

Figure 12 – Pre Pilot Valve Design Example Flowing Survey

Valve no.	DEPTH MD	DEPTH TVD	TEMP	CKE	Estimated Max Port	Estimated Max mscf	R	1-R	ΔPc	Pt	Pt*R	Pso Psc	Pvo Pvc	Pd	TCF	Pd @ 60 deg	calc. Ptro	use Ptro
1	**1700**	**1700**	77	8	5/16	272	0.2463	0.7537	44	330	81	**940**	984	823	0.950	781	1036	**1040**
2	**3100**	**3099**	91	8	5/16	279	0.2463	0.7537	81	455	112	**940**	1021	882	0.912	804	1067	**1070**
3	**4300**	**4299**	103	8	5/16	285	0.2463	0.7537	113	574	141	**940**	1053	934	0.881	823	1092	**1090**
4	**5300**	**5299**	113	10	5/16	436	0.2463	0.7537	136	664	164	**920**	1056	960	0.858	824	1093	**1090**
5	**6100**	**6099**	121	10	5/16	422	0.2463	0.7537	153	712	175	**900**	1053	969	0.840	814	1080	**1090**
6	**6783**	**6782**	128		3/8	179						**700**						**Pilot Valve**
7												**Pso**						
8																		
9																		
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Figure 13 – Recommended Pilot Valve Design Example Worksheet

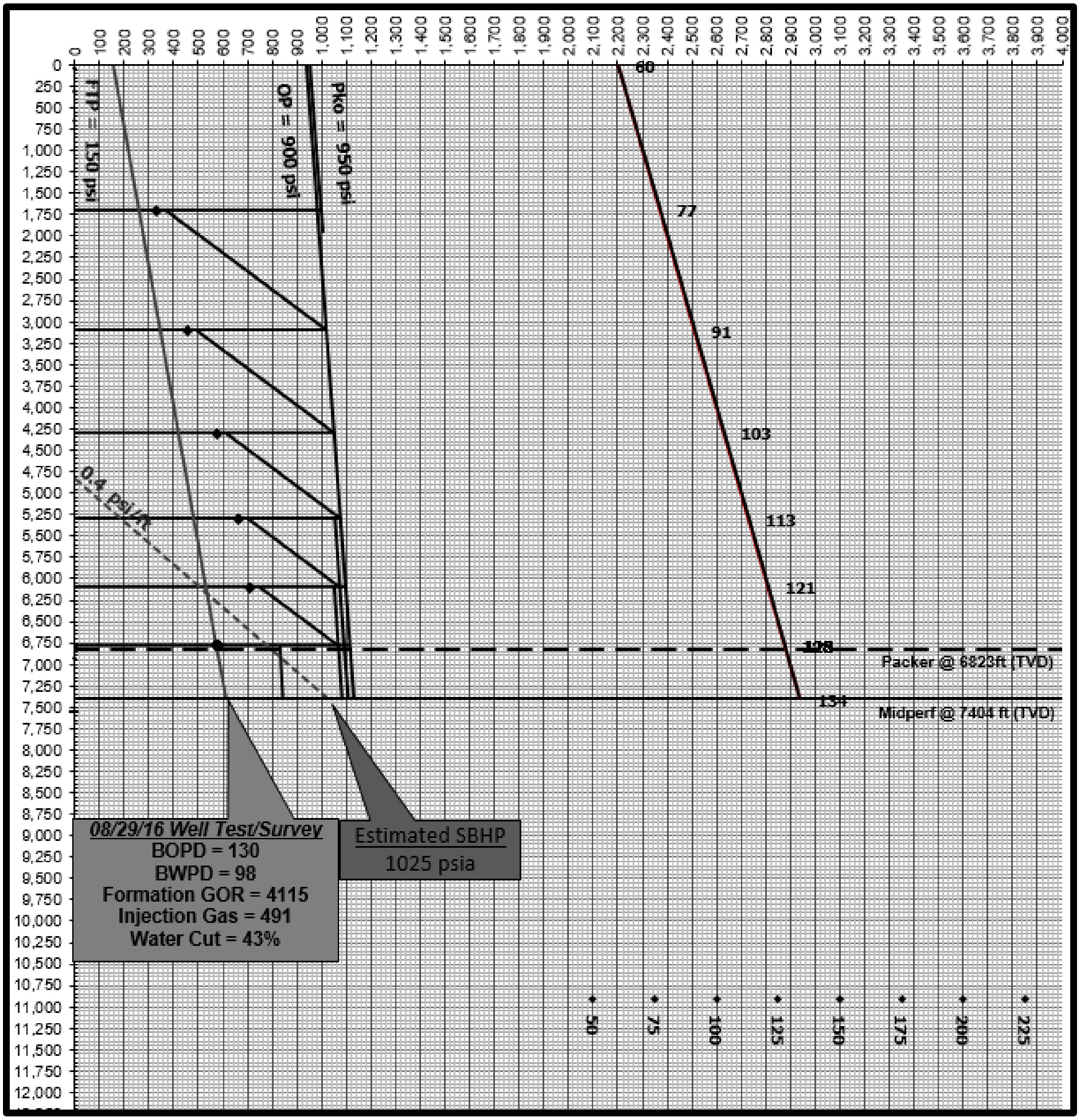

Figure 14 – Recommended Pilot Valve Design Example Graph

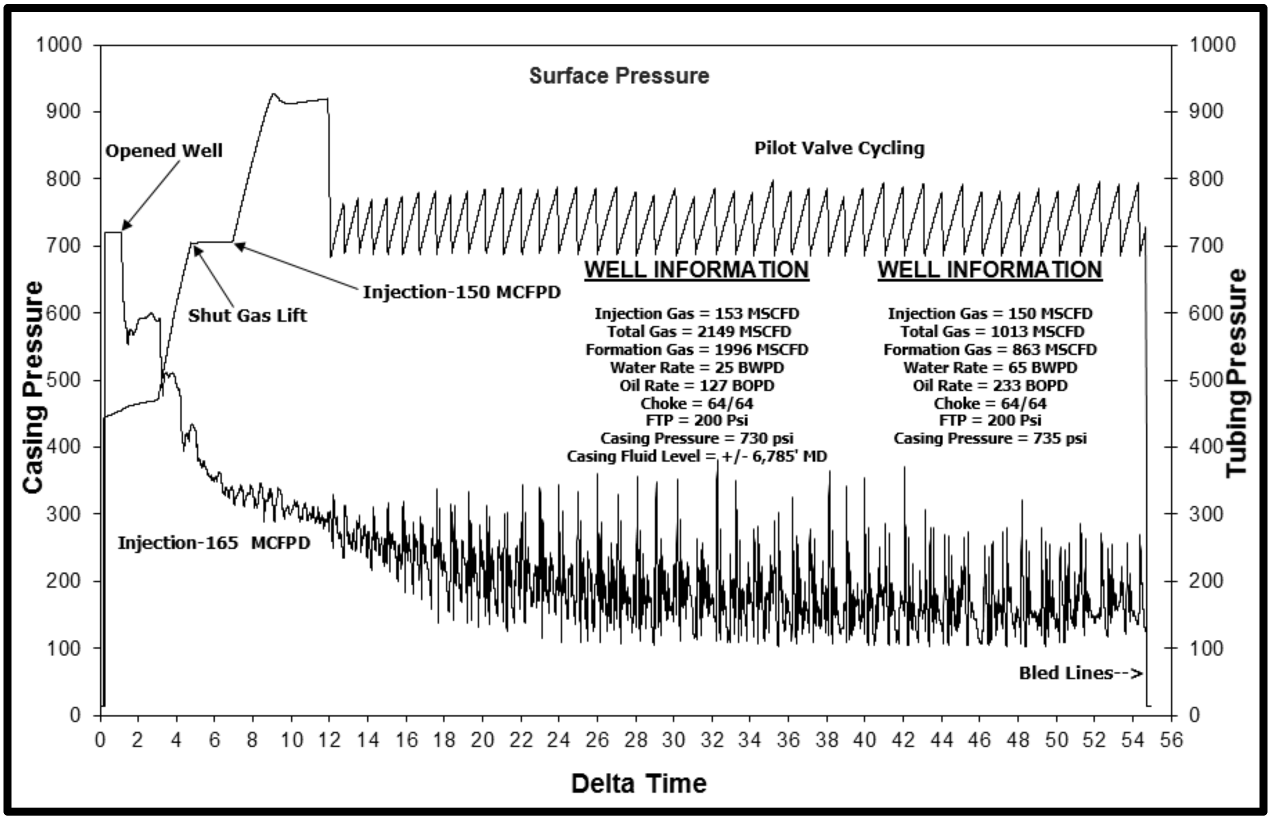

Figure 15 - Post Pilot Valve Design Example Kick-Off (Surface Pressures & Rates)

Permian Basin

Temperature Gradients by County

County	BHST	County	BHST
		Nolan	1.30
Andrews	0.75	Pecos North	0.89 to 1.30
Borden	0.90	Pecos Central	1.1
Coke	1.30	Pecos South	1.3
Cottle	0.95	Reagan	0.9
Crane	0.77	Reeves North	0.75 to 1.00
Crockett	1.47	Reeves Middle	0.85
Dawson	0.80	Reeves South	1.02
Ector	0.77	Runnels	1.70
Eddy	0.73	Schleicher North	1.4 to 1.80
Edwards	1.80	Schleicher Middle	1.60
Fisher	1.20	Schleicher South	1.80
Gaines	0.78	Scurry	1.00
Garza	0.95	Sterling	1.10
Glasscock	0.90	Stonewall	1.20
Howard	0.93	Sutton	1.80
Irion	1.20	Terrel	1.20
Kent	1.00	Terry	0.77
King	1.10	Tom Green North	1.2 to 1.80
Lamb	0.78	Tom Green Middle	1.40
Lea	0.74	Tom Green South	1.80
Loving	0.77	Upton	0.90
Martin	0.77	ValVerde	1.51
Midland	0.77	Ward	0.80
Mitchell	1.10	Winkler	0.75
		Yoakum	0.75

Figure 16 – Permian Basin Geothermal Gradients by County