GAS LIFT SYSTEMS TO MAXIMIZE PRODUCTION THROUGH THE LIFE OF A PERMIAN BASIN HORIZONTAL WELL

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INTRODUCTION & BACKGROUND INFO

Over the past few years, gas lift has become one of the primary artificial lift types used in the Permian Basin. Traditional tubing flow continuous gas lift was the most common method. This paper will describe the different types of gas lift systems available to achieve the highest production through the life of the well.

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 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

The main objective in gas lift is to take high pressure natural gas and inject it into the well as deep as possible, 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.

At the surface, outside of your typical production facilities, the primary equipment items needed for gas lift are a natural-gas compressor, high pressure flowlines 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 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 stream, at specifically designed depths and injection pressures, and then ultimately close when the production pressures decline enough to allow gas injection at a deeper mandrel, or depth.

To gain a better fundamental understanding of the optimization potential provided by the High Pressure, Balance-Ported and Pilot gas lift valves, it is important to first gain an understanding of 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 several 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.

HIGH PRESSURE GAS LIFT

If the initial bottom hole pressure is high enough, it has been common to flow new wells up the production casing. But as the pressure declines it becomes necessary to install some type of artificial lift. The goal with any type of artificial lift is to lower the flowing bottom hole pressure as low as possible to achieve the highest production rates. In the past, electric submersible pumps (ESPs) were the common type of lift used, but recently high-pressure gas lift has grown in popularity. With high-pressure gas lift, it is possible to inject gas through the bottom orifice valve/EOT immediately after the well is put on lift. This allows for a much lower flowing bottom hole pressure compared to the lower, normal gas lift compression pressures used.

Commonly, a booster compressor is installed using the gas lift gas from the current compression system and compressing it to the desired pressure needed to lift. These are typical compressor units that can easily be moved from their current location to a different location to be used on newer wells. Common discharge pressures for these types of compressors have been ~4000 PSI and ~2500 PSI.

With the 4000 PSI booster compressor, only a single orifice valve needs to be placed on bottom. In this case, no unloading valves are needed. Although this can be done with tubing flow gas lift or annular flow gas lift, to achieve the lowest flowing bottom hole pressure possible annular flow would be the preferred method. This is because the annular flow arrangement allows for a much larger production flow area and will vary depending on the production casing and tubing size.

Using the 2500 PSI booster compressor, in most cases, also allows for initially lifting on the bottom orifice valve/EOT. The difference here is that it does require a few 1.5" high-pressure unloading valves. These high-pressure valves can be set with test rack opening pressures as high as 3500 PSI (Following API's recommended practices to ensure the valve can handle the pressure rating is recommended). Typical Permian Basin designs can be set up with the test rack opening pressures usually running between 2100 ~ 2800 PSI. Sizing the port is also important and depends on multiple factors such as Injection Depth, Casing/Tubing Flow, Total BFPD, Etc. Utilizing the 2500 PSI booster compressor allows for similar production as with the 4000 PSI booster compressor but being able to utilize much less horsepower to achieve the production.

As production declines, and the high-pressure booster pressure is not optimum for the amount of fluid being produced, the booster compressor can be removed, and the current gas lift system can be changed. The new gas lift system installed can be designed to allow for producing on the lower pressure permanent gas lift compression system. At this time the system can be designed to operate on annular flow or tubing flow configurations. One thing to consider is the amount of gas injection required. If there are current drilling operations in the same area, the amount of gas needed for lifting the new wells may determine the configuration since annular flow generally requires a higher volume of injection gas compared to tubing flow. Another thing to consider when selecting the configuration is how much production impact there will be when the conversion is completed. This can be determined using Nodal analysis along with historical knowledge in this area.

BALANCE-PORTED GAS-LIFT VALVE DESIGN STRATEGY

In Figure 1, the valve mechanics for a typical IPO valve are shown in its closed position. The forces required to overcome 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 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 seat in an IPO valve, the production pressure 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.

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. 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. In general, as the size of the port increases, the total amount of injection pressure lost increases.

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 role in both opening and closing the valve. 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 smaller than the valve seat, which in turn puts the injection pressure drop across the choke instead of across the seat, dissimilar to 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 Balance-Ported gas lift installation will use full available injection operating pressure to set all 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 easy to identify which potential valve is operating at any one time in the well's injection life unless a flowing PT survey is conducted. 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.

Feedback from pumpers has been very positive in operating the Balance-Ported designs since the injection pressure should be relatively close to the designed operating pressure unless there is a HIT or issue downhole. With all 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 flowing PT survey. Looking at injection pressure alone for an accurate injection depth, regardless of design type, is extremely difficult unless the operator is experienced enough to correct the design for fluid rates, flowing temperatures, pressures, etc.

The design depths for the Balance-Ported valve are typically spaced-out similar to IPO designs. The bottom valve in a Balance-Ported valve design, will be designated as an orifice valve, or an IPO valve set at a 50-100 psi lower design injection pressure. This helps to ensure a crisper injection point for well stability purposes, while also helping to ensure the upper valves do not re-open. Often, this valve will be the deepest valve in the design-string. In many of the Permian Basin designs, regardless of valve type, this bottom valve is often run as a retrievable type of valve in a side pocket gas lift mandrel. Setting this valve as a retrievable type of valve allows for design-conversion to intermittent lift via slickline intervention and the installation of a Pilot valve at a later point in time.

GAS-LIFT PILOT VALVE DESIGN STRATEGY

The Pilot valve is aimed at optimizing a well's production capability later in its production life. 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 economical rates 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 gas lift is typically a viable gas lift option for Permian Basin wells since gas lift is likely to be the artificial lift of choice and the ability to operate below the KOP of the wellbore gives it an advantage when compared to other options.

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 efficiency and eliminating the need for surface injection time controllers. The Pilot valve contains an upper valve section that senses both injection and production pressures, like 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 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 (See Figure 5). 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 later 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 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 in conjunction 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 below, but data has shown the Pilot valve system to be extremely efficient.

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 6). Design experience and flowing survey data in each specific field, related to flowing temperatures vs. production flowrates, helps in optimizing future, additional well-designs. Some aquifers can also cause significant changes in geothermal temperatures across the Permian Basin. A good understanding of 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 0.90, 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 has mostly been conventional style, or tubing retrievable, and is 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 standpoint, and from a choke-sizing standpoint. The ability to use smaller chokes in a valve can sometimes help to mitigate the effects of the horizontal flow surges coming into the wellbore 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 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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ACKNOWLEDGEMENT

Thanks to the engineering management and owners of ALTEC for the permission, technical support, and financing required to print this paper.

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TABLES & FIGURES

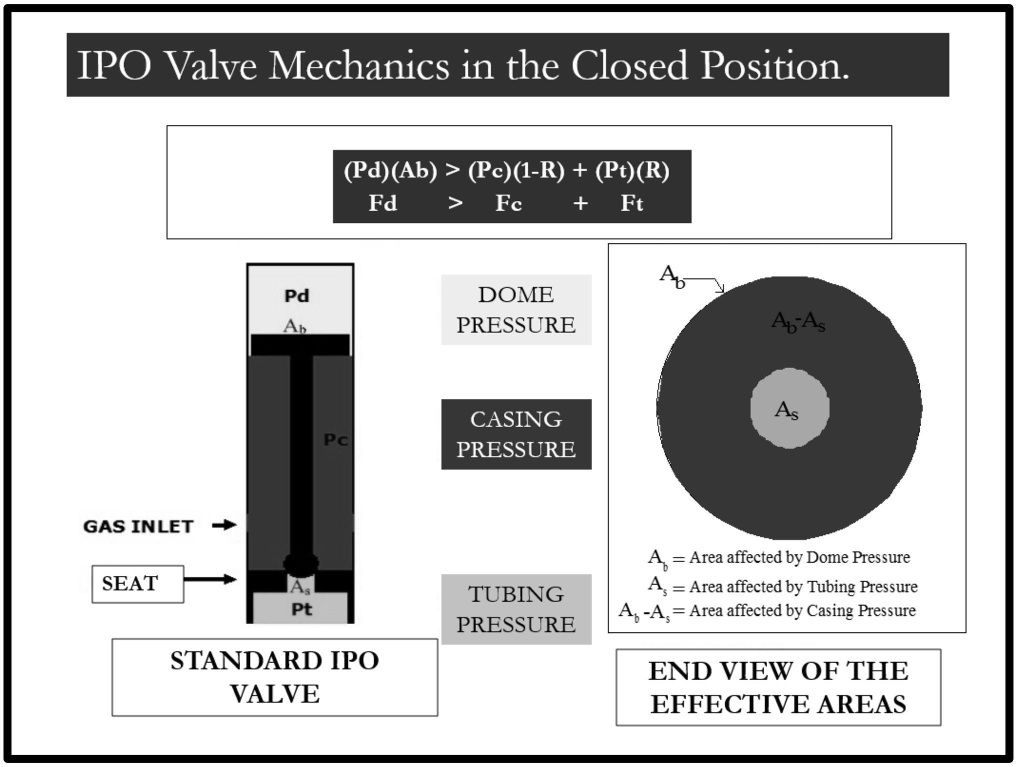

Figure 1 – Standard IPO Valve Mechanics Closed

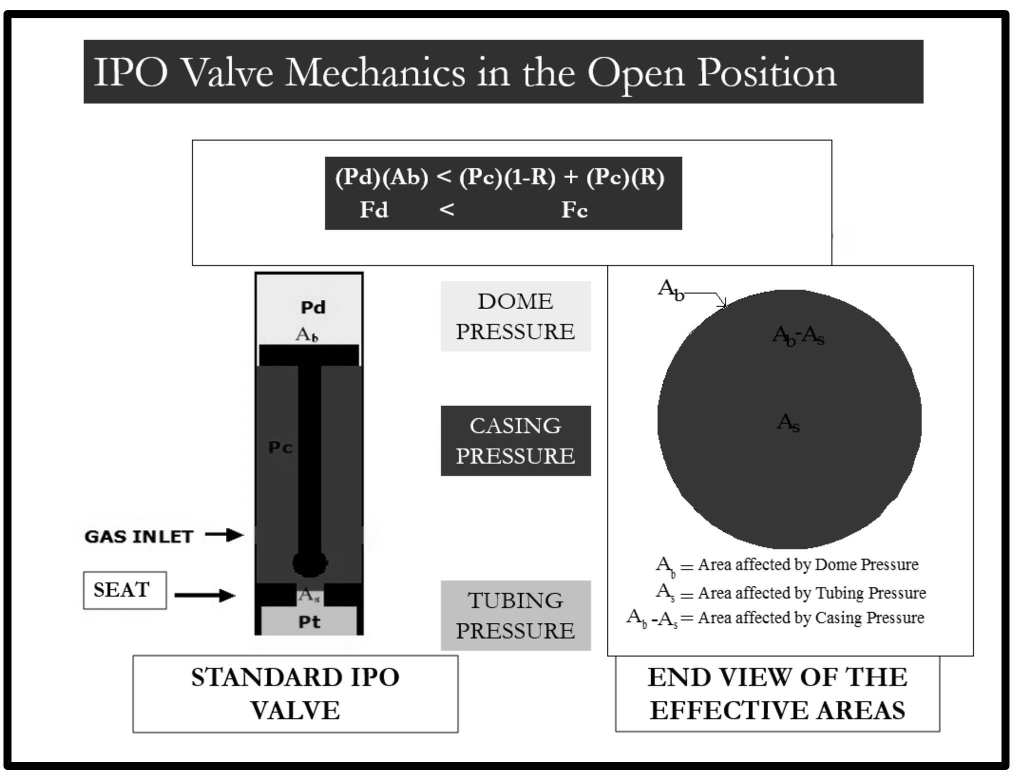

Figure 2 - Standard IPO Valve Mechanics Open

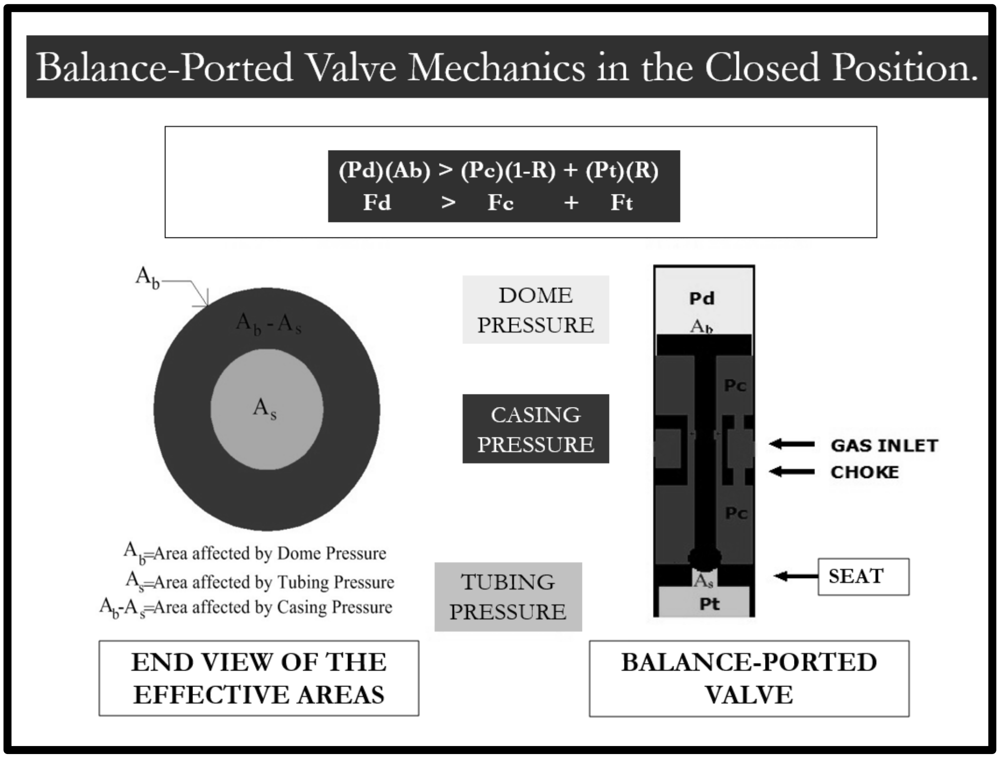

Figure 3 – Balance-Ported Valve Mechanics Closed

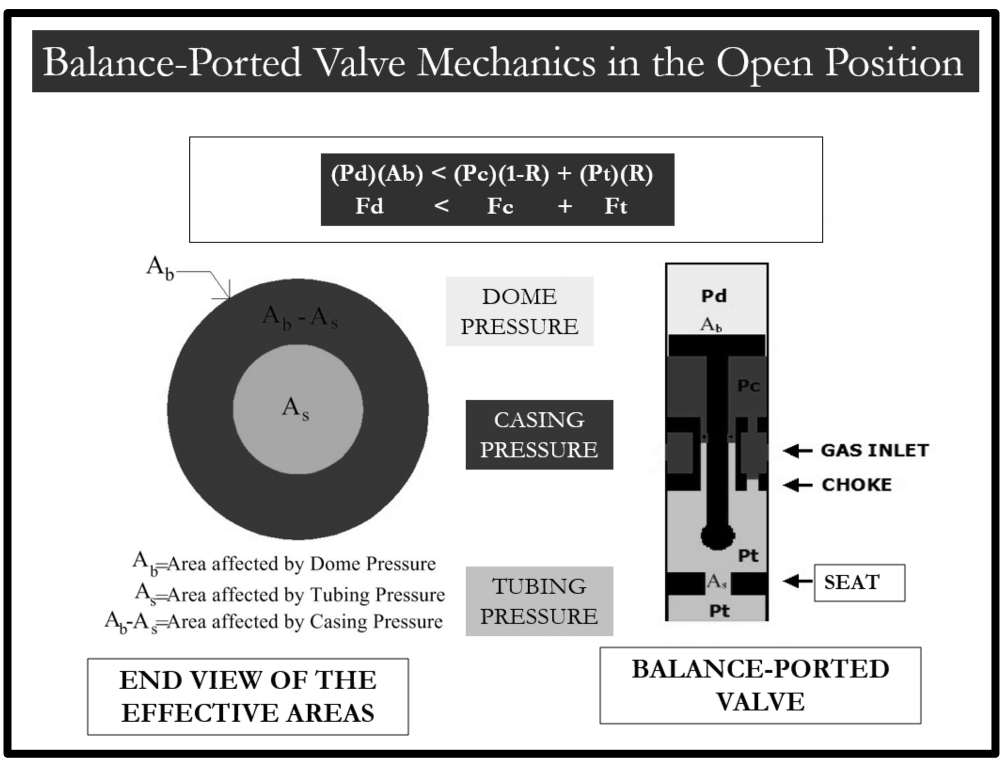

Figure 4 - Balance-Ported Valve Mechanics Open

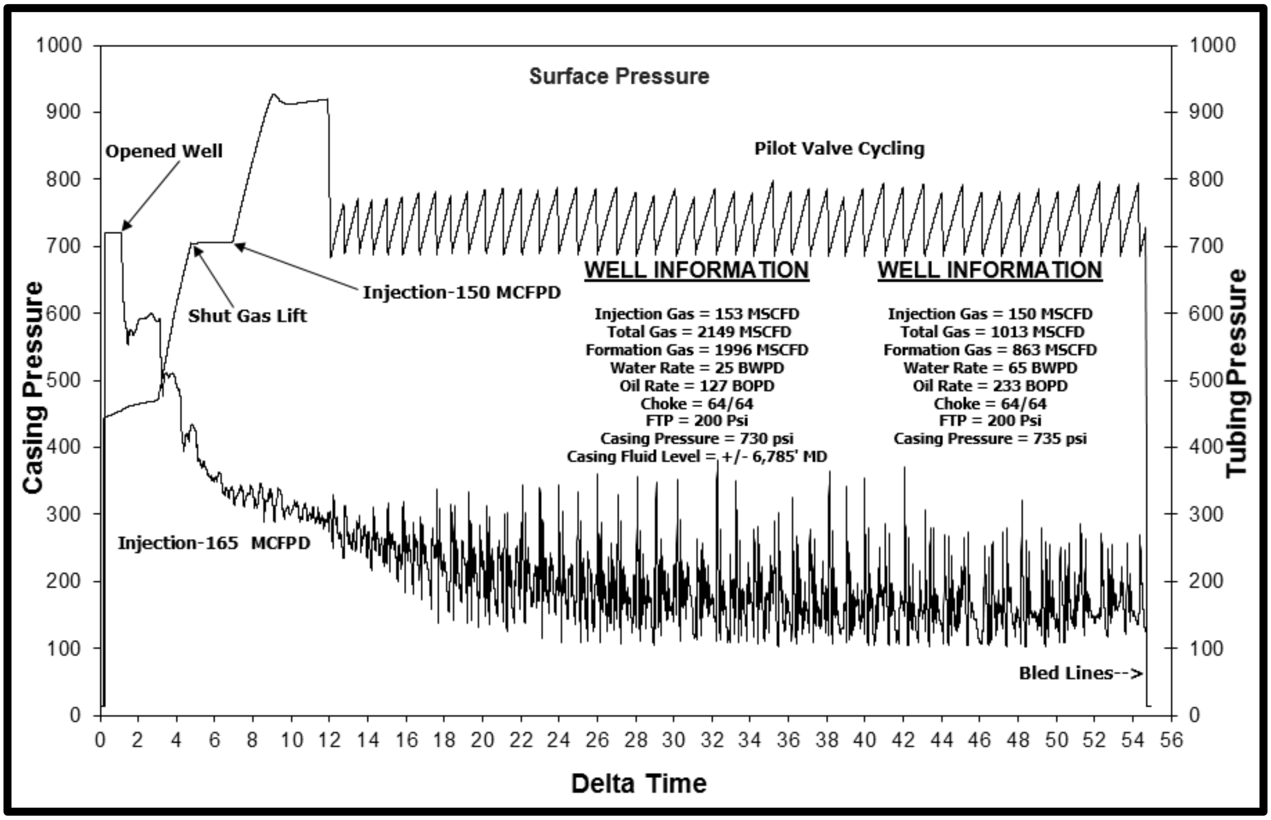

Figure 5 - Post Pilot Valve Design Example Kick-Off (Surface Pressures & Rates)

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 6 – Permian Basin Geothermal Gradients by County