A CASE STUDY: OPTIMIZED VALVE SPACING IN GAS LIFT TO ACCOMMODATE MATURING RESERVOIR CONDITIONS IN PERMIAN BASIN WELLS

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ABSTRACT

In unconventional wells, unstable dynamic behavior ensuing from an exchange of energy in the casing and tubing is the biggest challenge in gas lift wells. As reservoir and tubing pressures decline from early conditions, wells show erratic behavior in decreasing fluid levels and hence unload and operate at variable depths. This case study presents the full workflow of creating an effective gas-lift design from concept initiation to execution and field installation.

With spacing in gas lift valves as a function of gas injection pressure, we can assure unloading from the deepest point of the tubing string (i.e., packer depth). A successful spacing design can be constructed to give the number of valves for the available kickoff pressure and also accommodate future reservoir decline. There are two equations solving this versatile spacing, one for the first gas lift valve (from surface) and another for all deeper unloading valves.

After performing a well delivery simulation with a nodal analysis program, a production rate versus injection gas curve is generated at each of the several potential depths of injection. We select a rate and corresponding injection gas rate at each depth. The rate from each depth is validated with measured data for outflow and reservoir inflow.

Normally several designs will be done until the spacing criteria, and available kickoff pressure to reach the desired injection depth will match the desired production rate. This iterative methodology enables us to develop the gas lift spacing design where a valve at a shallower depth is designed to ensure unloading efficiency and a valve just a joint above the packer is placed to make production achievable at the lowest possible reservoir pressure.

INTRODUCTION

Unconventional wells typically follow a hyperbolic decline production curve pattern, with a high decline rate between 40% and 80% in the first year. Continuous gas lift is the answer to the crucial phase of producing and lifting mature and depleted reservoirs, which can no longer produce under their natural energy (Ali A. Garrouch, 2019). Finding the depths of the unloading valves and the operating point of injection employing an iterative procedure is a key factor in any gaslift design.

IPO valve is by far the most widely used type of valve to unload gaslift wells. This is due to:

(1) The availability of comprehensive testing data of gas passage through different port sizes in a gaslift valve.
(2) Ease to calculate valve operating pressure at any depth from the injection pressure at the surface, making it easy to design and troubleshoot the well.

This paper explains how valve spacing procedure by sequentially dropping the closing pressures of the unloading valves can be synced with reservoir pressure decline in WOLFCAMP A.

This type of method assures that each unloading valve will close as the unloading proceeds and will emphasize the need to match spacing to well's productivity.

The heart of valve spacing is to find the depths of the unloading valves and to determine, at each of these valves, the following parameters:

I. The unloading liquid flow rate.
II. The required unloading injection gas flow rate.
III. The valve seat diameter to be able to pass the required injection gasflow rate.
IV. The test-rack calibration opening pressure~~,~~ that will allow the unloading valves to close in a sequential manner as the unloading of the well proceeds, leaving only the operating valve open when the unloading of the well is completed.

Figure 1 (Hernandez, Ali. Fundamentals of Gaslift Engineering) shows how the production pressure decline as a function of reservoir pressure decline changed the operating point from valve 4 to valve 6'. Thus, There are only three unloading valves in the early stages of the reservoir, and in matured conditions, there are five unloading valves numbered as 1' to 5'. And it explains how within the same well, distance between the valves can be modeled with their respective closing and opening pressures.

METHODOLOGY

Spacing is constructed within the boundaries formed by the tubing pressure gradient (from nodal analysis), the kickoff gas pressure gradient (from gas specific gravity and surface pressure), and the kill fluid gradient (from the workover fluid in the casing annulus and the tubing). We will simplify these fluid gradients to make the design more conservative and easier to construct.

At each depth, we selected a specific rate and the corresponding injection gas rate. The rate from each depth is realistic because we validated the model with measured data for outflow and reservoir inflow. With gradient curve data at the selected rate, a spacing design can be constructed to give the number of valves for the available kickoff pressure. The procedure can be repeated for each potential depth of injection and future conditions, such as reservoir pressure decline. First of all, the production pressure along the depth of the well will be plotted from the wellhead pressure, Pwh, against the true vertical depth and not the measured depth. The production-pressure-traverse curve is determined from the liquid production, which is either given by the user (constant-liquid-flow-rate option) or it is calculated by the program using the iterative solver (in either case, this liquid production will be the final liquid production the well will have after the unloading operation is completed). The kickoff and operating injection pressures depend on the gas lift system capacity.

The final production-pressure-traverse curve is used only as a guide (during the mandrel spacing procedures) to find the production pressure (known as the transfer production pressure) from which the next deeper valve is located. This final pressure-traverse curve is highly recommended for IPO valves. Using the final production-pressure-traverse curve as a guide will set the production pressures of the unloading valves (for their design calculations) as close as possible to their actual production pressures during the normal operation of the well (once it has been fully unloaded). If the production pressures used for the unloading valves in their design calculations are smaller than their corresponding final production pressures, then the injection opening pressure of each unloading valve will decrease when the well is fully unloaded because the actual higher production pressure will help open the valve, with the result of lowering its required injection opening pressure (Hernandez, Ali. Fundamentals of Gaslift Engineering).

Once the production pressure, kick-off pressure, injection gas pressure, and design line are plotted with true vertical depth, we will start spacing the gaslift valve using the unloading gradient specified (kill fluid in our well is 0.45 psi/ft). Spacing can be solved with equations, one for the first valve (down from the surface) and another for all deeper unloading valves. Since two straight line gradients, one for the kill fluid in the tubing and the other for injection gas in the casing, are used in spacing, the equations are simple:

$$\mathrm{D}_{\text{first unloading valve}} = \frac{\mathrm{Pio}_{@\ \text{surf}} - P_{wh}}{G_{kill\ fluid} - G_{gas}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqi)$$

Where:

$D_{\text{first unloading valve}}$ = depth of the first unloading valve (from the surface), ft.

$Pio_{@surf}$ = operating gas injection pressure at the wellhead, psig.

P_{wh} = flowing wellhead pressure of production fluid, psig.

$G_{\text{kill fluid}}$ = gradient of the kill fluid in tubing (0.45 psi/ft salt water), psi/ft.

G_{gas} = = gradient of the gas in casing (0.04 psi/ft gas), psi/ft.

Figure 2 shows that the first unloading valve depth is located with the kill fluid gradient, the wellhead pressure Pwh, and the gas gradient line.

The remaining unloading valves (uv) start at the design line and stop at the gas gradient. The depth of each valve is based on the increment added to the depth of the valve above it:

$$\mathrm{D}_{\text{second uv}} = \frac{\mathrm{Pio}_{@\ \text{first uv}} - P_{dl@\ first\ uv}}{G_{kill\ fluid} - G_{gas}} + \ D_{first\ uv} \ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqii)$$

Where:

$D_{\text{second unloading valve}}$ = depth of the second unloading valve (from the surface), ft.

$P_{\text{iod @ first uv}}$ = gas injection pressure at the first unloading valve depth, psig.

$P_{\text{dl @ first uv}}$ = pressure on spacing design line at first unloading valve, psig.

$G_{\text{kill fluid}}$ = gradient of the kill fluid in tubing (0.45 psi/ft in the case of our well), psi/ft.

G_{gas} = = gradient of the gas in casing (typically 0.04 psi/ft gas), psi/ft.

Figure 3 shows that second unloading valve depth is located with the kill fluid gradient, the pressure on the spacing design line, and the gas gradient line. The remaining unloading valve depths are calculated using equations i) and ii) along with the data from the fluid and gas gradients obtained from the nodal analysis program. Figure 4 shows the procedure is repeated for the third unloading valve.

Figure: 5 shows how the rest of the unloading valves can be spaced and plotted by drawing from the design line and intersecting at the gas gradient line. The depth of each valve is based on the increment added to the depth of the previous valve. The increment should be so adjusted that the unloading gradient associated with each valve should be parallel to each other until the operating point is reached.

Utilization of Safety Factor as a Function of Well Productivity to space valves:

An iterative approach has been followed to create a spacing line that is based on the solution point from the pressure-traverse curve. A safety factor as a function of well productivity is created in such a way that a well with higher productivity will have a higher safety factor and vice versa.

In this manner, a spacing envelope is created, and the width of this spacing envelope is directly proportional to the spacing factor and well productivity. This safety factor will rationalize the valve setting depth along the spacing line. The safety factor for different productivity cases is given in Table 1:

Figure 6 shows that valves can be spaced close to each other when the spacing factor of 0.25 is used. And when we decrease the safety factor to 0.2 due to well's productivity, it results in wide valve spacing, resulting in fewer valves in our gaslift design.

Lift depth as a function of available gas injection infrastructure:

The kickoff pressure is greater than the operating pressure. In our case, the operating pressure is 225 psi less than the kickoff pressure of 1200 PSI. The lower value of operating pressure is an additional safety margin to ensure the gas lift completion will still unload despite fluctuations in the compressor output pressure. It also compensates for any frictional pressure loss due to gas flow across the valve. This pressure drop between valves will be dependent on surface gas injection infrastructure and can be classified into different values, as shown in table 2.

The operating pressure can be calculated by choosing the right pressure drop from table 2 as a function of available kickoff pressure. The design technique provides a method to quickly check available pressure to reach the specified lift point by using the following equation.

$$Pio_{@\,0ft} = P_{ko} - [25 + P_{drop} * (No. of\ Valves)] \ldots\ldots\ldots..Eqiii)$$

Where,

$Pio_{@\,0\,ft}$ is the operating gas injection pressure at the wellhead.
P_{ko} is the available kickoff pressure.
P_{drop} is the gas pressure drop between valves from table 2

Figure 7 explains that in case of 20 psi pressure drop(P_{drop}=20), valves are spaced close to each other, depicting that high injection pressure is required for the system. Conversely, when pressure drop is 10psi, it results in wide valve spacing, resulting in fewer valves in our gaslift design. And also, it is clear from Figure 7 that incase of a 10psi pressure drop, there are two fewer valves in gaslift design.

PRESSURE GRADIENTS AT EARLY, MIDDLE, AND LATE RESERVOIR CONDITIONS.

In the meticulous process of designing a well to produce below its full potential, a better strategy is to design the point of injection above the deepest possible point. However, in our case study, we installed mandrels below this shallow injection point to accommodate reservoir pressure decline. Plotting gradients based on early, middle, and late reservoir conditions gives an indication of where the well will unload and operate at each stage.

Figure 7 shows that in early conditions, when the reservoir is still young and has a pressure of 3000psig, the well will unload to valve 2. As reservoir and tubing pressure decline to middle conditions, the well will unload and operate at valve 4, then will continue to unload to the bottom as additional decline occurs. The design uses late conditions to finalize valve set pressures to locate mandrels to the bottom near the packer.

CONCLUSION AND RECOMMENDATIONS.

This type of design technique is sometimes used, giving a more significant number of mandrels than necessary, but the designs are more flexible (which is especially helpful if the data needed for the design is missing or unreliable). In today's market, where a valve is not expensive, it is an effective method to control the spacing between valves, as a function of well productivity, valve intrinsics, and injection infrastructure.

Table 1: Spacing factor based on productivity of the well

Safety Factor	Productivity Index
0.2	<2
0.25	2 to 20
0.3	>20

Table 2: Gas pressure drop between unloading valves

Surface Kickoff Pressure	**Gas Pressure Drop Between Valves**
Psig	Psi
<800	15
800 to 1100	20
1100 to 1300	25
1300 to 1500	30
1500 to 1700	40
1700 to 2000	50
> 2000	60

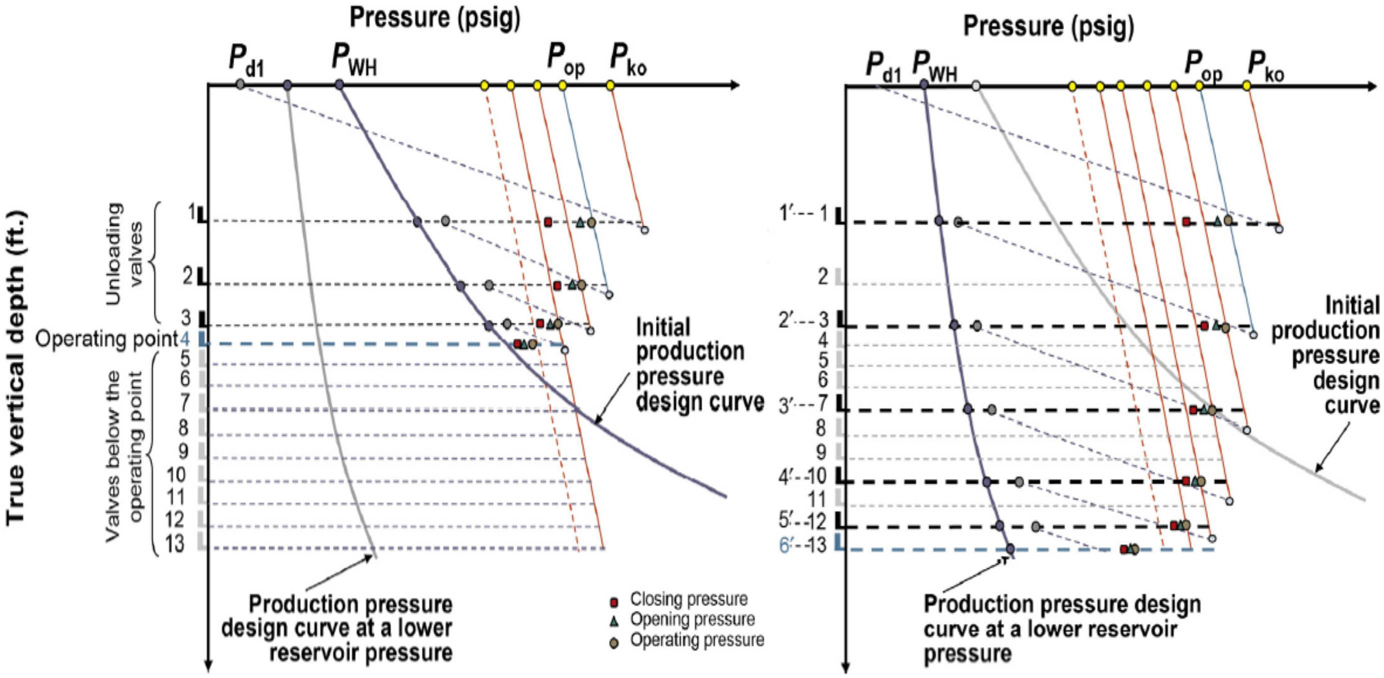

Figure 1: Comparison of valve spacing in dynamical reservoir conditions.
(Hernandez, Ali. Fundamentals of Gaslift Engineering)

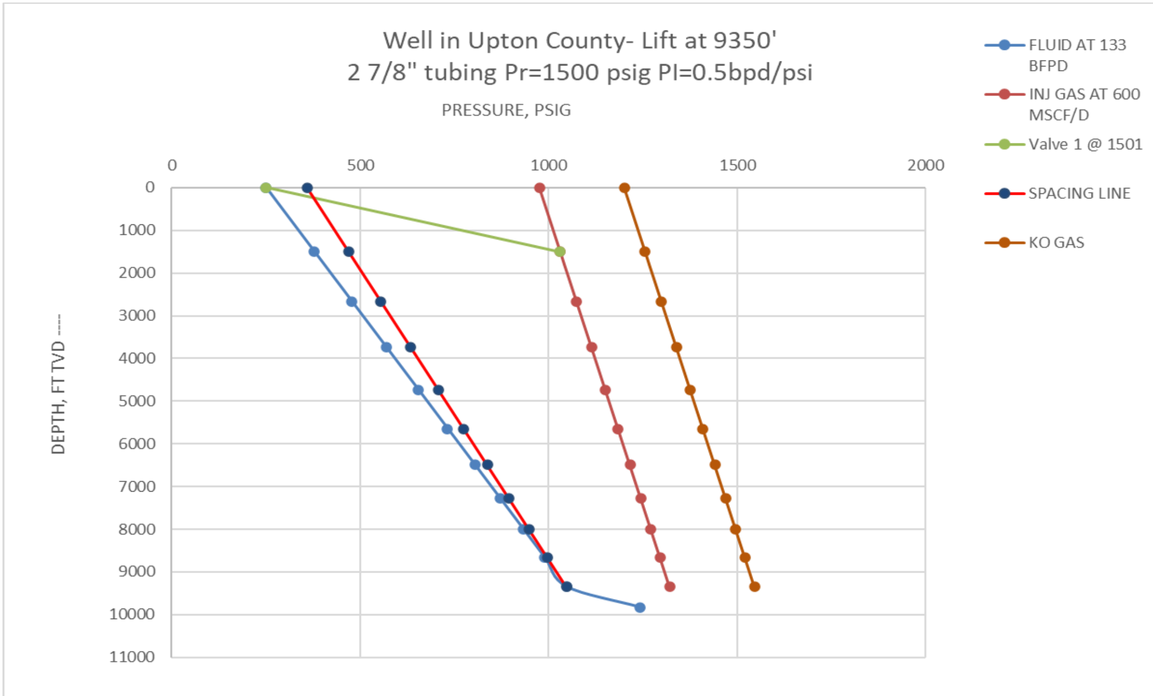

Figure 2: Placement of 1st unloading valve.

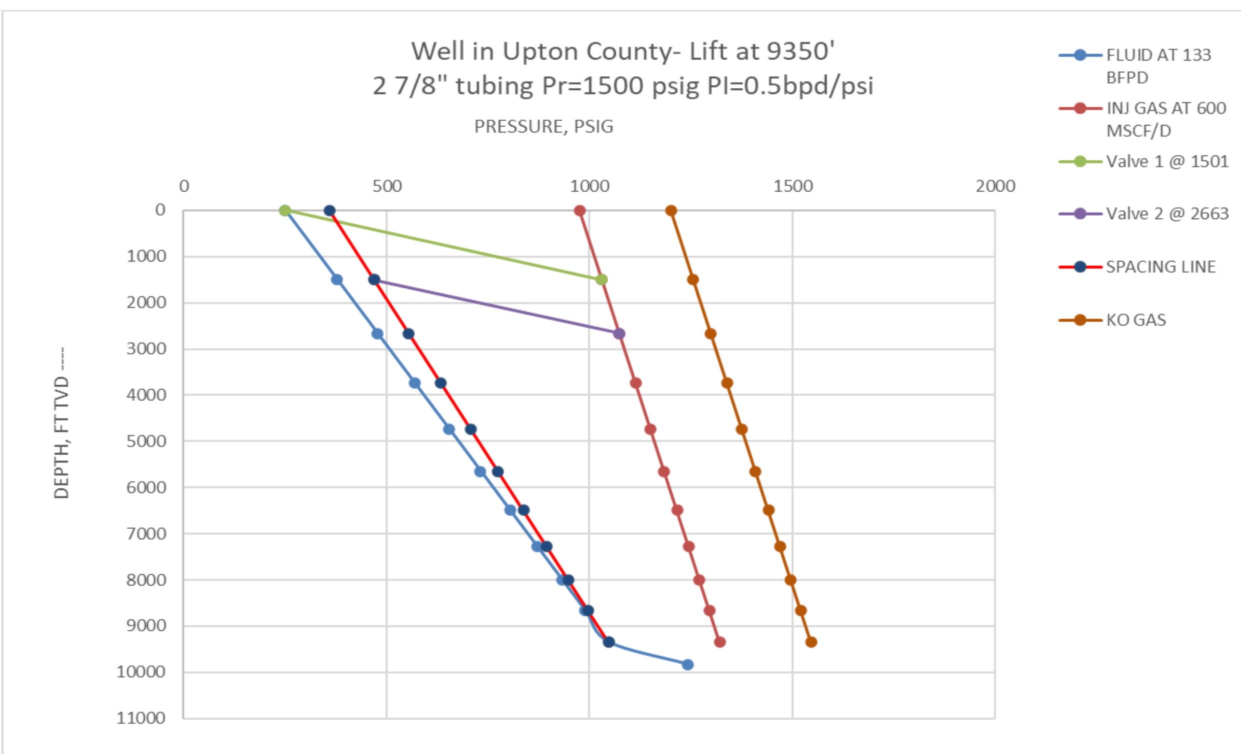

Figure3: Placement of 2nd unloading valve.

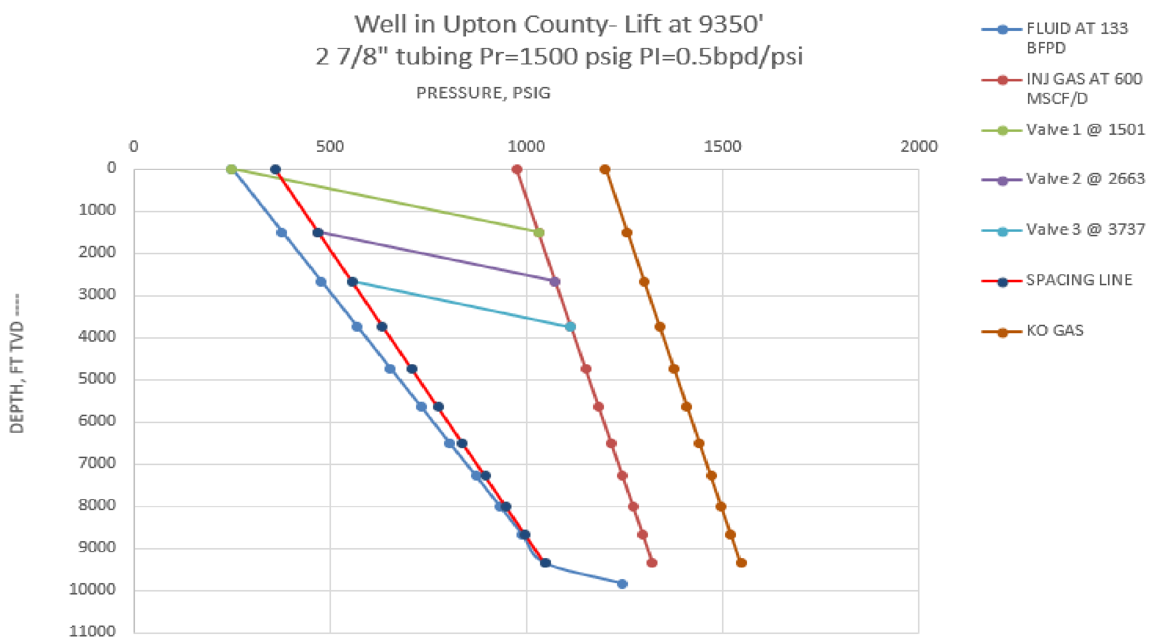

Figure 4: Placement of 3rd unloading valve.

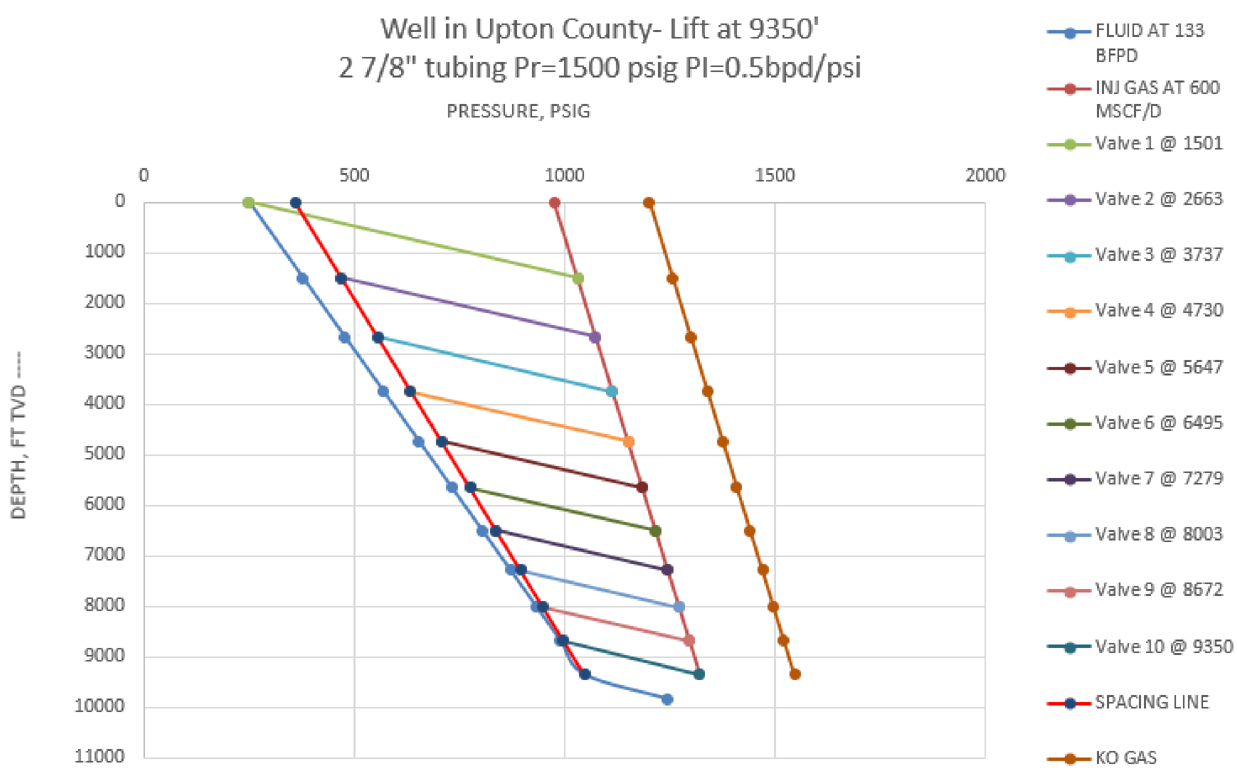

Figure 5: Placement of all unloading valves.

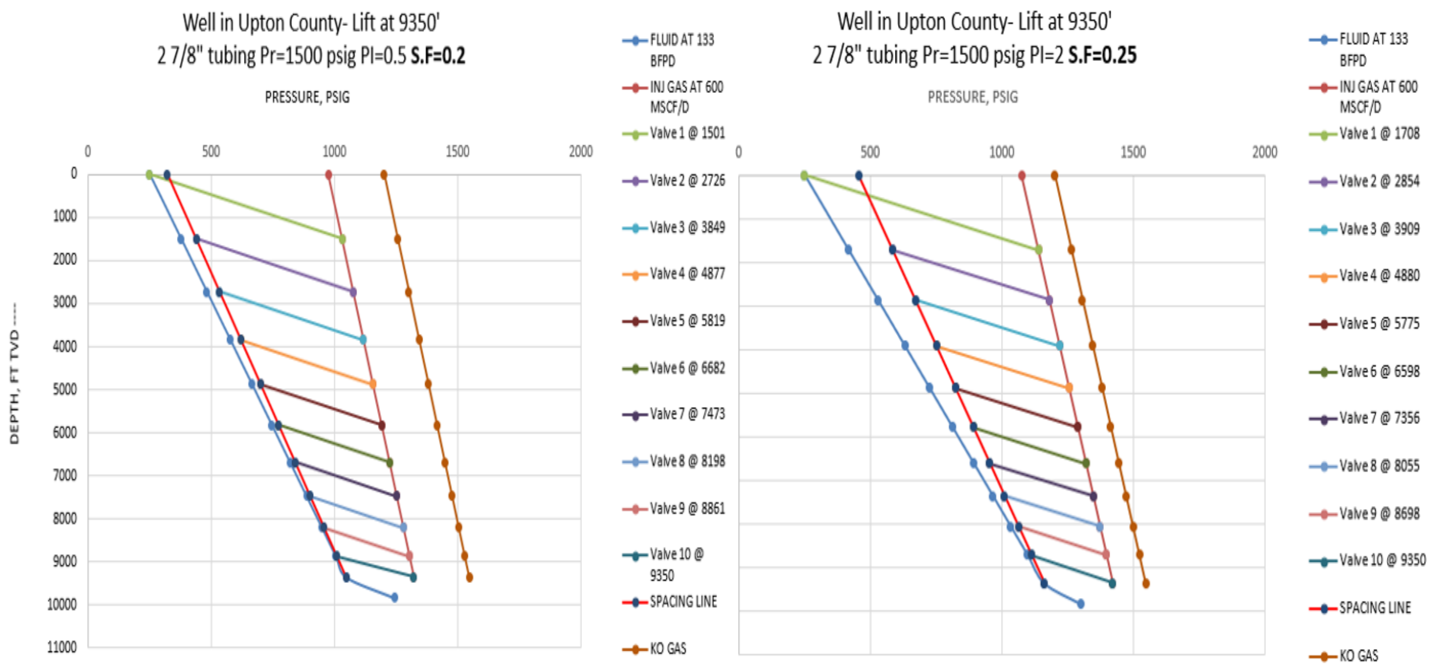

Figure 6: Comparison of valve spacing incase of different safety factors.

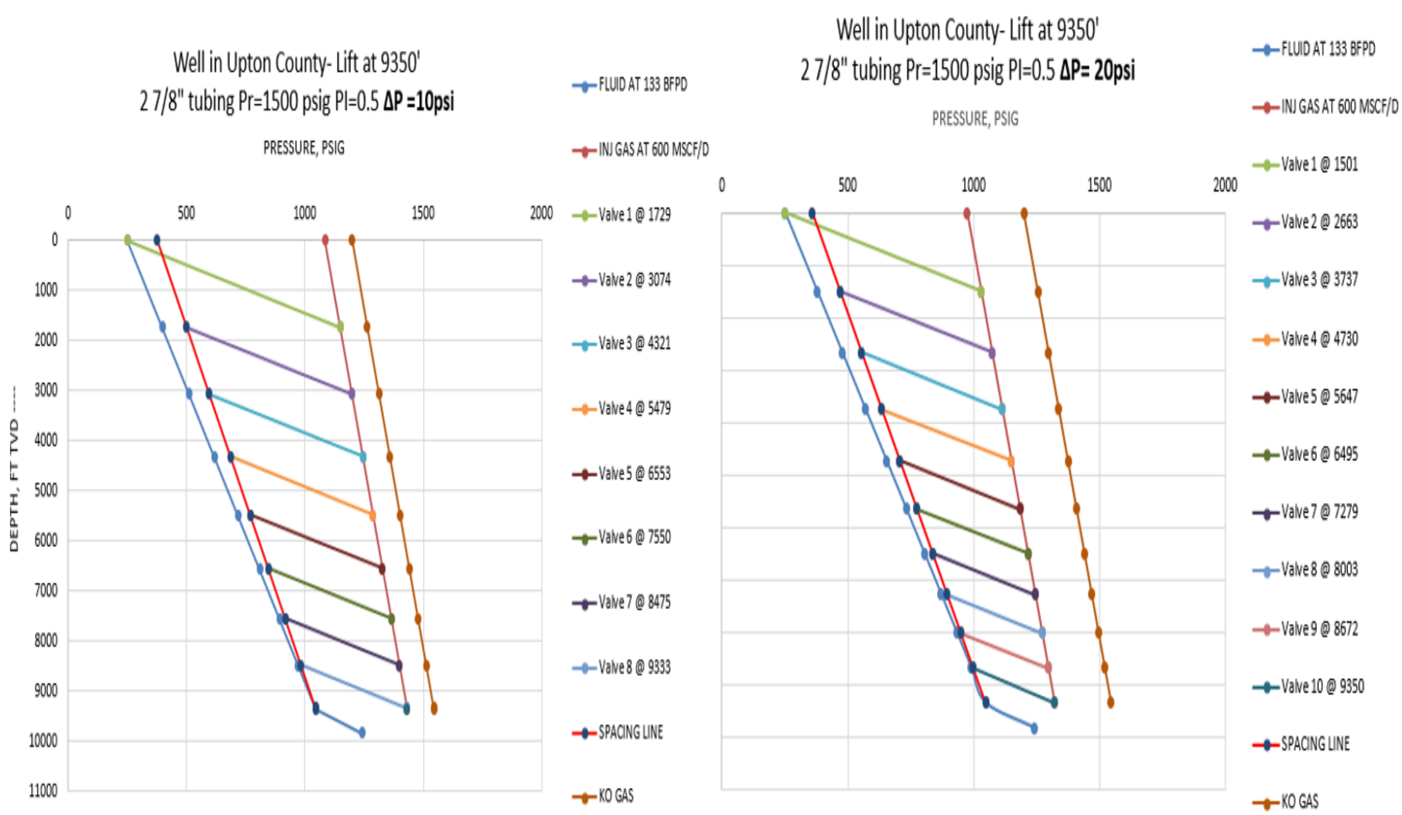

Figure 1: Comparison of valve spacing in case of different pressure drops.

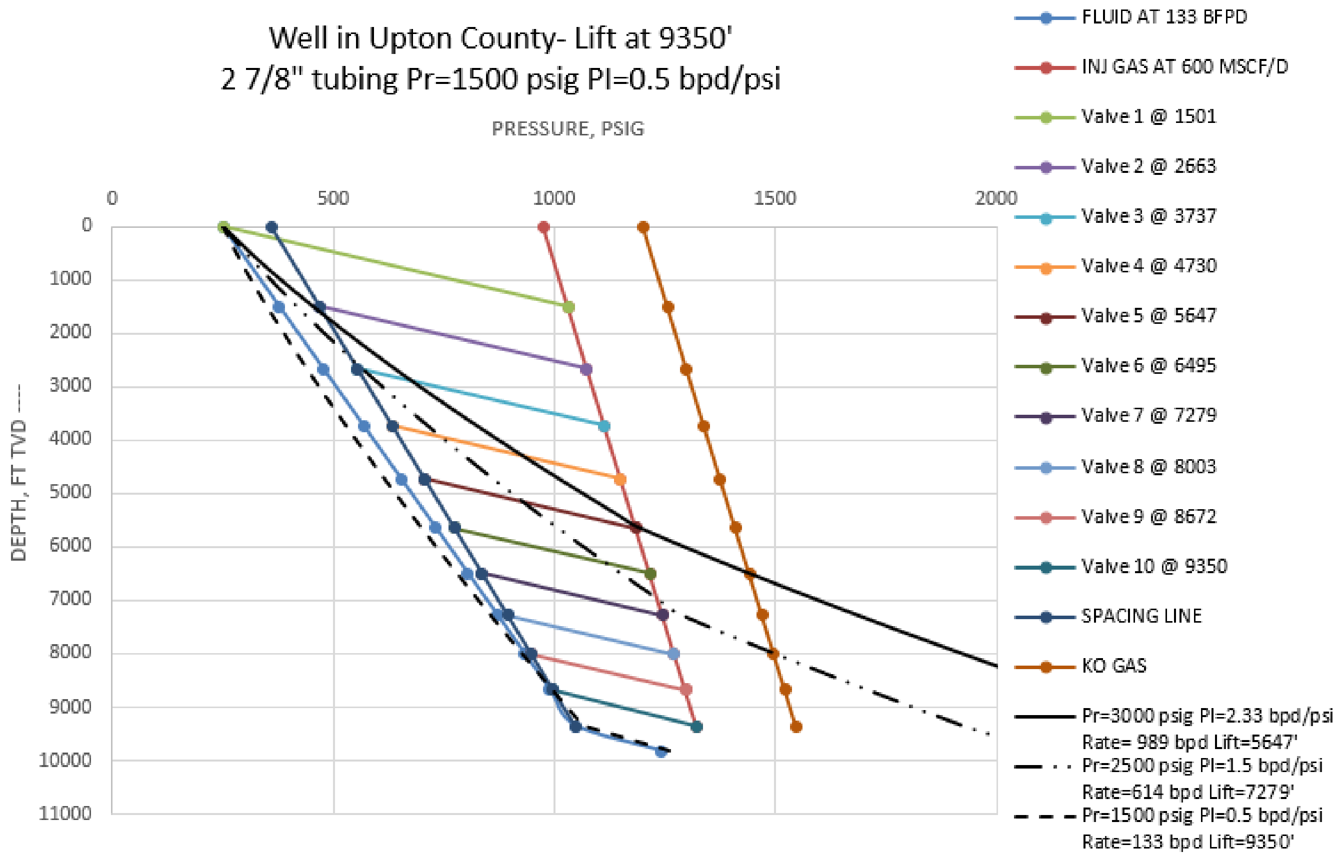

Figure 2: Pressure gradient at early, middle and late reservoir conditions showing different lift schemes.

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