Continuous Flow Gas Lift Design
By Jack R. Blann
Petroleum Engineering Handbook

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Chapter 12 was Co-authored by:
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Jack R. Blann
Two Types of Continuous Flow
Gas Lift Design

- Design for Normal Wells.
- Winkler Design for High gas Injection rates.
Iranian Gas Lift Well

In Agha Jhari Field

Produced:

Natural Flow = 37,000 B/D
Gas Lift = 43,000 B/D

Had 26 mandrels and valves to +3000 ft.
Libyan Gas Lift Well
Production Manifold in Libya
## Libyan Gas Lift Tests

### TABLE 5 – COMPARATIVE TEST RESULTS OF REDesign OF GAS LIFT INSTALLATIONS FOLLOWING 1978 TASK GROUP REVIEW

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Net results

10,066
346
API Design Technique

- Continuous Flow Installation Design Based on Constant Decrease in Operating Injection-Gas Pressure for Each Succeeding Lower Gas Lift Valve
- All Gas Lift Valves have same port size.
- There is a constant decrease in the operating injection pressure for each succeeding lower valve.
- Port size that allows the injection-gas throughput for unloading and operating the well.
API Design Technique

- This installation design method is recommended for gas lift valves with small production-pressure factors.
- When the ratio of the port area to the bellows area is low, the decrease in the injection gas pressure between gas lift valves, based on additional tubing effect pressure for the top valve, is not excessive.
Injection-Pressure Operated Gas Lift Valve

Production Pressure factor = Ratio of Area of Port to Area of Bellows
### Gas Lift Valve Specifications

<table>
<thead>
<tr>
<th>Port Size (ID), in.</th>
<th>Area of Port, $A_p$, in.$^2$</th>
<th>$A_p/A_b$</th>
<th>$1 - A_p/A_b$</th>
<th>Production Pressure Factor, $F_p$</th>
<th>Full-Open Stem Travel*, in.</th>
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<td>0.040</td>
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<td>1 1/2-in.-OD Gas Lift Valves With $A_b = 0.31$ in.$^2$</td>
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</table>

*Full-open stem travel is on the basis of a stem-ball OD that is 1/16 in. larger than the port ID.
The effect of bellows-assembly load rate on the performance of the valves is not considered in the installation design calculations.

Safety factors included in these calculations should allow sufficient increase in the operating injection gas pressure, which is necessary to provide valve stem travel for adequate injection-gas passage through each successively lower unloading valve without interference from upper valves.
API Design Technique

- Selection of a constant injection- gas pressure decrease, or drop, in the surface operating injection pressure for each succeeding lower gas lift valve should not be arbitrary, as proposed in some design methods.

- The pressure decrease should be based on the gas lift valve specification to minimize the possibility of upper valves remaining open while lifting from a lower valve.
API Design Technique

- The additional tubing-effect pressure for the top gas lift valve is a logical choice for this decrease in the operating injection-gas pressure between valves.
API Design Technique

- Closing or reopening of an injection-pressure-operated gas lift valve is partially controlled by the production pressure effect, which is equal to the production pressure factor for the valve multiplied by the difference in flowing production pressure at the top valve depth.
API Design Technique

- The flowing pressure at an unloading-valve depth changes from the transfer pressure, \((P_{ptfD})_{min}\), to a higher flowing-production pressure after the next lower valve becomes the operating pressure.
API Design Technique

- The additional tubing-effect pressure is the difference between \((P_{ptfD})_{\text{min}}\), and the maximum flowing-production pressure at the unlading valve depth, \((P_{ptfD})_{\text{max}}\), after the point of gas injection has transferred to the next lower valve.
API Design Technique

- As the unloading gas lift valve depths increase, the distance between valves and the difference between \((P_{ptfD})_{\text{min}}\) and \((P_{ptfD})_{\text{max}}\) decrease.
- Although the additional tubing-effect pressure decreases for lower valves, the injection-gas requirement for unloading increases with depth.
API Design Technique

- An increased stem travel, or stroke, is usually needed for the lower valves to generate the larger equivalent port area necessary for the higher injection–gas requirements with the lower pressure differentials that occur across these deeper valves.
API Design Technique

- A constant decrease in the operating injection-gas pressure equal to the additional tubing effect pressure for the top valve allows a greater increase in the injection gas above initial opening pressure for lower gas lift valves.
API Gas Lift Design

\[ (P_{oil})_{\text{max}} = 852 \text{ psig} \]

\[ (P_{oil1}) = 1,051 \text{ psig} \]

\[ (P_{oil2}) = 1,068 \text{ psig} \]

\[ (P_{oil3}) = 1,088 \text{ psig} \]
Gradient Curve

Chart Basis
- Oil Gravity = 35° API
- Water Gravity = 1.08
- Gas Gravity = 0.65
- Average flowing temp. = 165°F

Depth, 1,000 ft.
0 1,000 2,000 3,000 4,000 5,000 6,000 7,000 8,000 9,000 10,000

Pressure, psig
0 400 800 1,200 1,600 2,000 2,400 2,800

Gas/liquid ratio scf/B
- 100
- 200
- 400
- 600
- 1,000
- 1,500
- 2,000
Gradient Curve

Chart Basis
- Oil Gravity = 35° API
- Water Gravity = 1.08
- Gas Gravity = 0.65
- Average flowing temp. = 165°F

Depth, 1,000 ft.
- 0
- 1,000
- 2,000
- 3,000
- 4,000
- 5,000
- 6,000
- 7,000
- 8,000
- 9,000
- 10,000

Pressure, psig
- 0
- 400
- 800
- 1,200
- 1,600
- 2,000
- 2,400
- 2,800

Gas/liquid ratio scf/B
- 0
- 100
- 200
- 400
- 600
- 1,000
- 1,500
- 2,000
When the injection-gas pressure significantly exceeds the flowing-production pressure, an arbitrary increase in injection-gas-pressure, $\Delta P_{io}$, can be added to the initial production-pressure effect for the top valve for calculating the spacing and the initial opening pressures of the unloading gas lift valves.
API Design Technique

- The total decrease in the injection-gas pressure is distributed equally between each successively lower gas lift valve rather than having a sizeable pressure drop across the operating gas lift valve or orifice-check valve.
- This reduces the possibility of multipoint injection through the upper unloading valves by ensuring that the valves remain closed after the point of gas injection has transferred to the next lower valve.
Because the final injection gas pressure is not known until the installation is designed, a pressure difference of 100 to 200 psi between the unloading $P_{ioD}$ and $P_{pfD}$ traverses is assumed for locating the deepest valve depth.
The assumption of $P_{ioD} - P_{pfD} = 100$ to $200$ psi should ensure calculation of the operating valve depth.

The static bottomhole pressure, $P_{wsD}$ and temperature, $T_{wsd}$ are usually referenced to the same depth, which is the lower end of the production conduit, $D_d$. 
API Design Technique
Determination of Valve Depths

- Calculate the maximum unloading GLR based on the maximum injection gas rate available for unloading and the maximum daily design total fluid rate.
Well Information

- Tubing size = 2 7/8 in. OD
- Tubing Length, \( Y = 6000 \) ft.
- Max. Valve Depth, \( D_{v(max)} = 5970 \) ft.
- Static bottomhole pressure at \( D_d \), \( P_{wsd} = 1800 \) psig at 6000ft.
- Daily production rate = 800 STBD
- Water Cut = 50%
- Formation GOR = 500 scf/STB
- Oil Gravity = 35\(^o\) API
- Gas Gravity \( Y_g = 0.65 \)
- Produced-water specific gravity, \( Y_w = 1.08 \)
- Bottomhole temperature, \( T_{wsd} = 170^\circ F \) at 6000ft.
- Design unloading wellhead temperature, \( T_{whf} = 100^\circ F \).
- Load-fluid pressure gradient, \( g_{ls} = 0.46 \) psi/ft.
- U-Tubing wellhead pressure, \( P_{whu} = 100 \) psig.
- Flowing wellhead pressure, \( P_{whf} = 100 \) psig.
Well Information

- Static fluid level = 0 ft.
- Surface kickoff injection-gas pressure, $P_{ko} = 1000$ psig.
- Surface operating injection-gas pressure, $P_{io} = 1000$ psig.
- Maximum unloading injection-gas rate, $q_{giu} = 800$ Mcf/D.
- Operating daily injection-gas rate, $q_{gi} = 500$ Mcf/D.
- Wellhead injection-gas temperature, $T_{gio} = 100^\circ$F
- Assigned valve-spacing pressure differential at valve depth, $\Delta P_{SD} = 50$ psi.
- Test rack valve temperature, $T_{vo} = 60^\circ$F.
- Assigned minimum decrease in surface operating injection-gas pressure between valves, $\Delta P_{io} = 20$ psi.
- Minimum distance between valves, $D_{bv(min)} = 150$ ft.
- Gas lift valves: 1.5 inch O.D. nitrogen charged with $A_b = 0.77$ in$^2$, and sharp edged seat.
API Design Technique

Step 1:
Calculate Maximum Unloading GLR

\[ R_{giu} = \frac{q_{giu}}{q_{lt}} \]

Where

- \( q_{giu} = \text{maximum unloading injection rate, Mscf/D,} \)
- \( q_{lt} = \text{total liquid daily production rate, B/D,} \)
- \( R_{giu} = \text{maximum unloading GLR, scf/STB} \)
API Design Technique
Calculate Maximum Unloading GLR

\[ R_{giu} = \frac{q_{giu}}{q_{lt}} \]

\[ = \frac{800,000 \text{ scf/D}}{800 \text{ STB/D}} \]

\[ R_{giu} = 1000 \text{ scf/STB} \]
API Design Technique

Step 2: Determine flowing Production pressure, $P_{pfd}$ at $D_d$
Gradient Curve

Chart Basis
- Oil Gravity = 35° API
- Water Gravity = 1.08
- Gas Gravity = 0.65
- Average flowing temp. = 165°F

Depth, 1,000 ft.

Pressure, psig
Step 3: Calculate the unloading-flowing-pressure-at-depth gradient, \( g_{pfa} \) above point of gas injection, \( g_{pf} \).

\[
g_{pfa} = \frac{900-100}{6000} = 0.1333 \text{ psi/ ft.}
\]
Step 4
Calculate the operating injection gas pressure at the lower end of the production conduit.

where:

- $P_{io}$ = injection-gas pressure at surface, psia
- $P_{ioD}$ = injection-gas pressure at depth, psia
- $e$ = Napierian logarithm base = 2.718...
- $\gamma_g$ = gas specific gravity (air = 1.0), dimensionless.
- $D$ = true vertical depth of gas column, ft.
- $\bar{T}$ = average gas column temperature, °R
- $\bar{z}$ = compressibility factor based on gas column average pressure P and temperature, T, dimensionless.
API Design Technique

Step 4

\[ P_{ioD} = 1154 \text{ psig at 6000 ft.} \]

\[ g_{gio} = \frac{1154 - 1000}{6000} = .0257 \text{ psi/ft} \]

Since \( P_{iod} - P_{pfd} = 1154 - 900 = 254 \text{ psi} \)

Exceeds 200 psi, the maximum valve depth of 5970 ft can be attained.
API Design Technique

Step 5:
Calculate the unloading gas lift valve temperature at depth gradient, $g_{Tv u}$.

Bottomhole temperature,

$$T_{wsd} = 170^\circ F \text{ at } 6000 \text{ft.}$$

Design unloading wellhead temperature,

$$T_{whf} = 100^\circ F \text{ at surface.}$$

$$g_{Tv u} = (170 - 100) / 6000 = 0.0117^\circ F/ft.$$
API Design Technique

\[ D_{v1} = \frac{P_{ko} - P_{whu} - \Delta P_{SD}}{g_{ls} - g_{gio}} \]

Step 6

- \( D_{v1} \) = depth of top valve, ft
- \( P_{ko} \) = surface kick-off or average field injection-gas pressure (optional), psig
- \( P_{whu} \) = surface wellhead U-tubing (unloading) pressure, psig
- \( \Delta P_{SD} \) = assigned spacing pressure differential at valve depth, psi

where

- \( g_{ls} \) = static-load (kill) fluid pressure gradient, psi/ft
- \( g_{gio} \) = injection-gas pressure at depth gradient, psi/ft

Step 6:

\[ D_{v1} = \frac{(1000 - 100 - 50)}{(0.46 - .0257)} \]

\[ D_{v1} = 1957 \text{ ft.} \]
API Design Technique

Step 7
Calculate the minimum flowing-production pressure, \((P_{pfD1})_{min}\), the injection-gas pressure, \(P_{ioD1}\), and the unloading gas-lift valve temperature, \(T_{vUD1}\), at the top valve depth by multiplying the appropriate gradient by the valve depth, \(D_{v1}\), and adding to the appropriate surface values (where \(n = 1\) for top valve):
API Design Technique

Step 7.

Calculate the minimum flowing-production pressure, \((P_{pfD1})_{min}\), injection-gas pressure, \(P_{ioD1}\), and the unloading flowing temperature, \(T_{vuD1}\) at \(D_{v1}\) of 1,957 ft as described on previous slide:

- \((P_{pfD1})_{min} = 100 + 0.1333 (1,957) = 361 \text{ psig}\)
- \(P_{ioD1} = 1,000 + 0.0257 (1,957) = 1,050 \text{ psig}\)
- \(T_{vuD1} = 100 + 0.0117 (1,957) = 123 ^\circ \text{F}\)
API Design Technique

Step 8

- Calculate the depth of the second gas-lift valve, $D_{v2}$, where $n = 2$ on the basis of the assigned minimum decrease in surface injection-gas pressure, $\Delta p_{io}$, for spacing the gas-lift valves and the $P_{ioD}$-traverse.

- A valve spacing differential of around 20 to 30 psi will usually be sufficient for most 1.5-in. OD gas-lift valves. However, 1-in. OD valves with large ports may require a higher, $\Delta p_{io}$. This can be checked by calculating the additional production-pressure effect, $\Delta P_{pe1}$, after the valve depths are calculated for the assigned $\Delta p_{io}$. 

API Design Technique

Step 8

\[(P_{pfD(n-1)})_{min} + g_{ls}(D_{bv}) = (P_{ioD(n-1)} - (n-1)\Delta P_{io}) - \Delta P_{SD} + g_{gio}(D_{bv})\]

Solve For \(D_{bv}\):

\[D_{bv} = P_{ioD(n-1)} - [(n-1)\Delta P_{io}] - (P_{pfD(n-1)})_{min} - \Delta P_{SD} \div (g_{ls} - g_{gio})\]

and

\[D_{v(n)} = D_{v(n-1)} + D_{bv}\]

The decrease in surface injection-gas pressure for calculating \(D_{v2}\) is \(\Delta P_{io}\), and for \(D_{v3}\) is 2 \((\Delta P_{io})\), and for \(D_{v4}\) is 3 \((\Delta P_{io})\), and this procedure continues for each succeeding lower valve.
API Design Technique

Step 8

Solve For $D_{bv}$:

$$D_{bv} = P_{ioD(n-1)} - [(n-1)\Delta P_{io}] - (P_{pfD(n-1)})_{min} - \Delta P_{SD} / (g_{ls} - g_{gio})$$

$$D_{bv} = 1050 - 0 - 361 - 50 / (0.46 - 0.0257) = 1472 \text{ ft.}$$

and

$$D_{v(2)} = D_{v(n-1)} + D_{bv}$$

$$D_{v(2)} = 1957 + 1472 = 3429 \text{ ft.}$$

Repeat steps 7 and 8 for each valve location until reaching maximum depth
The calculated valve spacing for the sixth valve, $D_{v6}$, would exceed the maximum valve depth, $D_{v(max)}$, of 5,970 ft. Because an orifice-check valve will be placed in the bottom wireline-retrievable valve mandrel, no test-rack valve setting information is required. This completes the valve spacing calculations.
API Design Technique
Graphical Representation

![Graphical Representation](image-url)
API Design Technique

Determination of Gas-Lift Valve Port Size and Calculation of Test-Rack Opening Pressures.

The gas-lift valves port ID and test-rack opening pressure calculations follow:

Step 1. Determine the port size required for the gas-lift unloading valves and the operating orifice-check valve orifice ID. The upstream injection-gas pressure, $P_1$, is based on $P_{OD5}$ of the last unloading valve corrected to the orifice-check valve valve depth of 5970 ft:

$$P_1 = 1,068 + 0.0257 (5,970 - 5,762) = 1,073 \text{ psig at 5,970 ft}$$
API Design Technique

Determination of Gas-Lift Valve Port Size and Calculation of Test-Rack Opening Pressures.

Step 1 (Continued)

- The downstream flowing-production pressure, $P_2$, is equal to the minimum flowing-production pressure at 5,970 ft.
- $P_2 = 100 + 0.1333 \times (5,970) = 896$ psig at 5,970 ft
- $\Delta P_{ov} = 1,073 - 896 = 177$ psi across the orifice-check valve
From the Thornhill / Craver correlation, the required equivalent orifice size is near 14/64-in.; therefore, the next largest gas-lift valve port ID is 1/4-in. This size is sufficient for all of the upper unloading valves because they have a higher injection-gas operating pressure and a greater differential pressure between $P_{iOd}$ and $(P_{pfD})_{min}$.

An equivalent orifice size of 12/64-in. to 13/64-in. is required to pass the operating injection-gas rate of 500 Mscf/D.
API Design Technique

Determination of Gas-Lift Valve Port Size and Calculation of Test-Rack Opening Pressures.

Step 2

Record the valve specifications for a 1.5-in. OD gas-lift valve having a 1/4-in. ID port with a sharp-edged seat where $A_b = 0.77$ sq. in.

from table:

\[
\left( A_p/A_b \right) = 0.064, \\
(1 - A_p/A_b) = 0.936, \\
\text{and } F_p = 0.068.
\]
API Design Technique

Determination of Gas-Lift Valve Port Size and Calculation of Test-Rack Opening Pressures.

Step 3
Calculate $P_{oD1}$

$$P_{oD1} = P_{ioD1}$$

where

$P_{ioD1}$ = injection-gas pressure at valve depth, psig

$P_{oD1}$ = injection-gas initial gas-lift valve opening pressure at valve depth, psig

$P_{oD1} = 1,050$ psig at 1,957 ft
API Design Technique

Step 4

Calculate the test-rack set opening pressure of the first valve \((n = 1)\), \(P_{vo1}\), using Eqs. 12.44 and 12.45 or 12.46:

\[
\begin{align*}
P_{bvD(n)} &= P_{oD(n)} (1 - A_p/A_b) + P_{pfD(n)min} + (A_p/A_b) \\
P_{vo(n)} &= C_{T(n)} (P_{bvD(n)}) / (1 - A_p/A_b) \\
P_{vo(n)} &= 1050 \times (0.936) + 361 \times (0.064) = 1006 \text{ psig.}
\end{align*}
\]
Step 5

\[ P_{vo(n)} = C_T(n) \left( P_{bVD(n)} \right) / \left( 1 - A_p/A_b \right) \]

for \( C_{T1} = 0.876 \) (Calculated using \( T_{vuD1} = 123^\circ F \)):

\[ P_{vo1} = 0.876 \left( 1006 \right)/0.936 = 942 \text{ psig at } 60^\circ F \]

Step 6

Calculate the injection-gas initial opening pressure of the second gas-lift valve at depth (n = 2),

\[ P_{oD(n)} = P_{ioD(n)} - (n-1) \Delta P_{io} \]

\[ P_{oD(2)} = 1088 - 20 = 1068 \text{ psig at } 3429 \text{ ft.} \]
API Design Technique

Step 7

Calculate the maximum flowing-production pressure opposite top unloading valve immediately after the point of gas injection has transferred to the second (lower) valve, \((P_{pfD1})_{max}\).

\((P_{pfD1})_{max}\) is shown graphically in Figure and can be calculated using the following equation:

\[
(P_{pfD1})_{max} = P_{wf} + Dv1 \left[ \frac{(P_{oD2} - P_{whf})}{Dv2} \right]
\]

\[
(P_{pfD1})_{max} = 100 + 1957 \left( \frac{(1068 - 100)}{3429} \right)
\]

\[
(P_{pfD1})_{max} = 652 \text{ psig at 1957 ft.}
\]
API Design Technique

![Graph showing depth vs. pressure with points labeled for specific pressures and depths.](image)

- \((P_{o0}t)_{max} = 852 \text{ psig}\)
- \((P_{o0}t) = 1,051 \text{ psig}\)
- \((P_{o0}t) = 1,058 \text{ psig}\)
- \((P_{o0}t) = 1,068 \text{ psig}\)
API Design Technique

Step 8

Determine if the assumed decrease in surface injection-gas pressure, $\Delta P_{io}$, is sufficient for the required gas-lift valve port size by calculating the additional production-pressure effect, $\Delta P_{pe1}$, at the top valve:

$$\Delta P_{pe1} = F_p \left[ (P_{D1D1})_{max} - (P_{D1D1})_{min} \right]$$

$$\Delta P_{pe1} = 0.068 \ (652 = 361 = 20 \text{ psi}).$$

If $\Delta P_{pe1}$ is less than or equal to the assumed $\Delta P_{io}$ proceed with the design. If $\Delta P_{pe1}$ is greater than the assumed $\Delta P_{io}$ then set $\Delta P_{io} = \Delta P_{pe1}$ and redo the spacing design. This is a conservative approach and many operators use actual operating experience to determine which $\Delta P_{io}$ to use.
API Design Technique

- Repeat Steps 6, 4 and 5 for remaining gas-lift valves:
- An orifice-check valve is recommended for the sixth valve at 5,962 ft. The orifice ID should be 1/4-in. to pass sufficient gas to gas lift the well. A tabulation form for these calculations is given in table.
## API Design Technique

<table>
<thead>
<tr>
<th>Valve Number</th>
<th>$D$, ft</th>
<th>$P_{in}$, psig</th>
<th>$P_{out}$, psig</th>
<th>$(P_{f/D})_{min}$, psig</th>
<th>$P_{svD}$, psig</th>
<th>$T_{VD}$, °F</th>
<th>$C_T$</th>
<th>$P_{VO}$, psig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.957</td>
<td>1.050</td>
<td>1.050</td>
<td>361</td>
<td>1.006</td>
<td>123</td>
<td>0.876</td>
<td>942</td>
</tr>
<tr>
<td>2</td>
<td>3.429</td>
<td>1.088</td>
<td>1.068</td>
<td>557</td>
<td>1.035</td>
<td>140</td>
<td>0.847</td>
<td>937</td>
</tr>
<tr>
<td>3</td>
<td>4.490</td>
<td>1.115</td>
<td>1.075</td>
<td>699</td>
<td>1.051</td>
<td>152</td>
<td>0.828</td>
<td>929</td>
</tr>
<tr>
<td>4</td>
<td>5.242</td>
<td>1.135</td>
<td>1.075</td>
<td>799</td>
<td>1.057</td>
<td>161</td>
<td>0.814</td>
<td>919</td>
</tr>
<tr>
<td>5</td>
<td>5.762</td>
<td>1.148</td>
<td>1.068</td>
<td>868</td>
<td>1.055</td>
<td>167</td>
<td>0.805</td>
<td>907</td>
</tr>
<tr>
<td>6</td>
<td>5.970</td>
<td>1.153</td>
<td>896</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An orifice check valve is used.
High Rate Continuous-Flow Installation Design (Winkler)

The application of the injection-gas rate throughput performance for injection-pressure-operated gas-lift valves is illustrated in the high daily liquid rate continuous-flow installation design. The importance of valve performance data for high daily injection-gas rates is shown, and its unimportance for low injection-gas rate installation designs is illustrated. Valve performance data is of no value in selection of the top two unloading gas-lift valves in this installation. For these two upper valves, an assumed reasonable decrease in the surface injection-gas pressure of 20 psi for each valve ensures unloading the well and these upper valves remaining closed while lifting from a lower valve. When the required daily injection-gas rate increases for lifting from the third and fourth gas-lift valves, valve performance information becomes very important. A pressure vs. depth plot for this continuous-flow installation is shown in the Figure.
High Rate Continuous-Flow Installation Design (Winkler)
High Rate Continuous-Flow Installation Design (Winkler)

- Although the flowing-production transfer pressure traverse method for locating the depths of the valves may require an additional valve, or valves, in some installations, this design method has several advantages in wells requiring a high daily injection-gas rate for unloading. Because the injection-gas requirement to uncover the next lower valve is reduced, smaller valve ports can be used and the increase in the injection-gas pressure to stroke the valve stem is less. The unloading operations are faster because of the lesser difference in injection-gas requirement between unloading valves.
High Rate Continuous-Flow Installation Design (Winkler)

- The surface origin and final downhole termination pressures for the flowing-production transfer pressure traverse are arbitrary. The 20% in this example for locating the surface transfer pressure traverse is widely used. The unloading injection-gas requirements for uncovering each lower valve increases as the percentage decreases and decreases as the percentages increase. The flowing-production transfer pressure at datum depth should be at least 100 to 200 psi less than the available design operating injection-gas pressure at the same depth.
Simplified Mathematical Gas-Lift Valve Performance Model

Because performance equations for specific gas-lift valves are not available from gas-lift valve manufacturers, a simplified gas-lift valve performance computer model was used to illustrate the calculations in this paper. The model is based on static force balance equations and several simplifying assumptions. This computer model describes qualitatively the injection-gas rate throughput of unbalanced, single-element gas-lift valves using the Thornhill-Craver equation.
High Rate Design Data

- Tubing size = 4-1/2-in. OD (ID = 3.958-in.) and Length = 6,000 ft
- Casing size = 8-5/8-in. OD, 44 lb/ft (ID = 7.725-in.)
- Datum depth for bottomhole pressures and temperature, \( D_d = 6,000 \) ft
- Bottomhole temperature at \( D_{df} T_{wsd} = 170 \) oF
- Shut-in (static) bottomhole pressure at \( D_{df} P_{wsd} = 2,000 \) psig
- Maximum depth for bottom valve, \( D_{v(max)} = 5,900 \) ft
- Productivity index (gross liquid), \( PI = 6.3 \) BPD/psi
- Oil gravity = 35 oAPI \( (\gamma_o = 0.850) \)
- Gas specific gravity (air = 1.0), \( \gamma_g = 0.65 \)
- Water specific gravity, \( \gamma_w = 1.08 \)
- Water fraction, \( f_w = 0.50 \) (50%)
- Formation gas/oil ratio, \( R_{go} = 400 \) scf/STB
- Formation gas/liquid ratio, \( R_{glf} = 200 \) scf/STB
- Assigned minimum daily unloading production rate, \( q_{lu} = 1,000 \) BPD
- Design total (oil + water) daily production rate, \( q_{lt} = 5,000 \) BPD
- Wellhead U-tubing unloading pressure, \( P_{whu} = 100 \) psig
- Surface flowing wellhead pressure, \( P_{whf} = 100 \) psig
- Static load (kill) fluid pressure gradient, \( g_{ls} = 0.468 \) psi/ft
High Rate Design Data (Continued)

- Surface operating injection-gas pressure, $P_{io} = 1,400$ psig (at wellsite)
- Assigned daily injection-gas rate, $q_{gi} = 2,000$ Mscf/day
- Unloading wellhead temperature, $T_{whu} = 120^\circ$F (basis for calculation of $P_{vo}$)
- Wellhead injection-gas temperature, $T_{gio} = 120^\circ$F
- Surface kickoff injection-gas pressure, $P_{ko} = 1,400$ psig (at wellsite)
- Minimum assigned surface injection-gas pressure decrease between valves, $\Delta P_{io} = 20$ psi (represents minimum surface injection-gas pressure increase for stroking gas-lift valve)
- Valve spacing design line percent factor at surface = 20% ($f_{pt} = 0.20$)
- Minimum transfer-production pressure difference ($P_{iod} - P_{ptd}$) at $D_{dr}$ $\Delta P_{ptd} = 200$ psi
- Valve spacing pressure differential at valve depth, $\Delta P_{sD} = 50$ psi
- Minimum distance between valves $D_{bv(min)} = 400$ ft
- Gas-lift valve test-rack setting temperature, $T_{vo} = 60$ oF
- Gas-lift valves: 1.5-in. OD wireline-retrievable, unbalanced, single-element, nitrogen-charged bellows with $A_b = 0.77$ in.$^2$, $B_{lr} = 600$ psi/in., and square sharp-edged seat.
Valve Performance – First Valve

### Table 12.4 - Flowing-Production Pressure and Performance Data for Gas-Lift Valve at 2,778 ft in Fig. 12.34

<table>
<thead>
<tr>
<th>Tubing Performance</th>
<th>Gas-Lift Valve Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4-in. ID Port – $B_l = 600$ psig/in.</td>
</tr>
<tr>
<td>$R_{gft}$ scf/STB</td>
<td>$q_{gi}$* Mscf/D</td>
</tr>
<tr>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>05</td>
<td>105</td>
</tr>
</tbody>
</table>

*Since $R_{gft} = R_{gli}$, $q_{gi} = R_{gft}$ (in Mscf/D for 1,000 BPD)
Valve Performance – First Valve
# Winkler High Rate Gas Lift Design

## TABLE 12.9 – INJECTION-GAS VALVE SPACING, INITIAL VALVE OPENING, VALVE STEM STROKING $\Delta P_{io}$ AND GAS-LIFT VALVE TEST-RACK OPENING PRESSURES

<table>
<thead>
<tr>
<th>Valve No. $(n)$</th>
<th>Port ID in.</th>
<th>$D_{v(n)}$ ft</th>
<th>$T_{gD(n)} = T_{VD}$ °F</th>
<th>$P_{pPD(n)}$ psig</th>
<th>$P_{io(n)}$ psig</th>
<th>$P_{IoD(n)}$ psig</th>
<th>$\Delta P_{io(n)}$ psi</th>
<th>Initial $P_{o(n)}$ psig</th>
<th>Initial $P_{oD(n)}$ psig</th>
<th>$P_{vo(n)}$ psig 60 °F psig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>2,778</td>
<td>143</td>
<td>849</td>
<td>1,400</td>
<td>1,500</td>
<td>20</td>
<td>1,380</td>
<td>1,480</td>
<td>1,288</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>4,170</td>
<td>155</td>
<td>1,095</td>
<td>1,400</td>
<td>1,551</td>
<td>20</td>
<td>1,360</td>
<td>1,511</td>
<td>1,298</td>
</tr>
<tr>
<td>3</td>
<td>0.375</td>
<td>5,064</td>
<td>162</td>
<td>1,252</td>
<td>1,380</td>
<td>1,583</td>
<td>20</td>
<td>1,340</td>
<td>1,523</td>
<td>1,399</td>
</tr>
<tr>
<td>4</td>
<td>0.50</td>
<td>5,622</td>
<td>167</td>
<td>1,373</td>
<td>1,360</td>
<td>1,603</td>
<td>30</td>
<td>1,310</td>
<td>1,513</td>
<td>1,588</td>
</tr>
<tr>
<td>5</td>
<td>0.3125</td>
<td>5,900</td>
<td>169</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. $P_{io} = 1,400$ psig available injection-gas line pressure at surface.

2. $P_{vo(n)}$ was calculated using the equations for $C_{T(n)}$ rather than $C_{T(n)}$ values from Table 12.1.
Continuous Flow Gas Lift Design

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