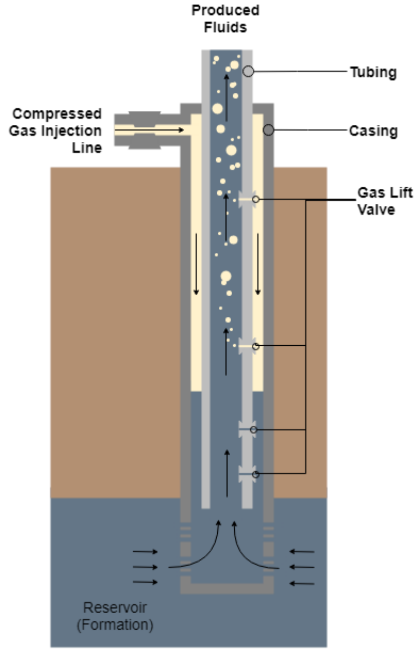
[414.371 Offshore Equipment, 2019 Spring Semester, Prof. Yutaek Seo]

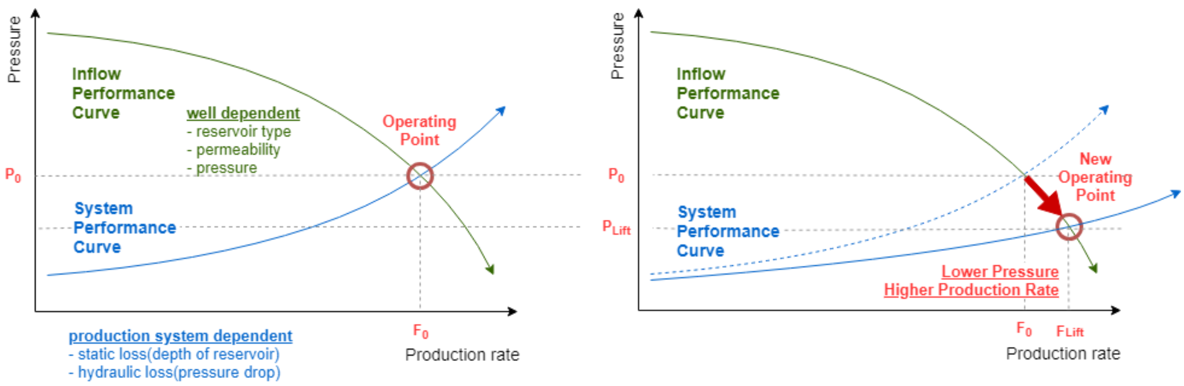
Gas Lift System Design



(Figure 1) Gas lift system configuration

1. What is Gas Lift?

Gas lift is one of the artificial lift methods, injecting external gas in the vertical pipeline. Purpose of the gas lift is to boost the production, making gas push the liquid upwards. Compressed gas is injected down the casing tubing annulus of a production well, entering the well at numerous entry points called gas-lift valves(Figure 1). As the gas enters the tubing at these different stages, it forms bubbles which lightenes fluids and facilitates flow velocity to be higher. So injecting the gas results decrease in pressure and increase in production rate(Figure 2).



(A) Performance Curve (Original) (B) Performance Curve (with Gas Lift)

(Figure 2) Performance curve without and with gas lift. With gas lift, pressure at the operation point becomes lower and production rate becomes higher.

2. Advantages and Disadvantages of Gas Lift

2.1. Advantages

- best artificial lift method for **handling sand or solid materials**.
- **flexible range of operation**. A wide range of volumes and lift depths can be achieved with essentially the same well equipment.
- **centralization** available with one gas supply system. A central gas-lift system easily can be used to service many wells or operate an entire field. this usually lowers total capital cost and permits easier well control and testing.
- relatively **inexpensive**. Repair and maintenance expenses of subsurface equipment normally are low. The equipment is easily pulled and repaired or replaced.

2.2. Disadvantages

- Relatively **high backpressure** may seriously restrict production in continuous gas lift.
- Gas lift is **relatively inefficient due to the compressor**. Compressors are relatively expensive and often require long delivery times. The compressor takes up space and weight when used on offshore platforms.
- Adequate **gas supply is needed** throughout life of project. Not recommended if the field runs out of gas, or if gas becomes too expensive.
- There is increased **difficulty when lifting low gravity (less than 15°API) crude** because of greater friction, gas fingering, and liquid fallback.

3. Difference between the Gas Lift and Gas Injection

Gas lift and gas injection is different process in oil & gas production. gas lift is artificial lift, and gas injection is secondary production(or enhanced oil recovery, EOR). Both artificial lift and secondary production are used in increasing the production, but main difference is that gas lift does not need extra well and gas injection need extra well. gas lift inject gas in production well, but gas injection need gas injection well, apart from production well.

4. Design Method

Designing the gas lift includes the process of determining valve depths, injection pressure, et cetera. Factor for determining most economical gas lift system are :

- Bubblepoint and solution GOR of the produced oil.
- Well Productivity
- Pressure/volume/temperature (PVT) properties of the crude
- Water cut of the producing stream
- Density of the injected gas
- Wellhead backpressure
- Pressure rating of the equipment
- Design of the well facility

4.1. Valve depth calculation

1) Calculate **maximum unloading GLR**

$$R_{glu} = \frac{q_{giu}}{q_{lt}}$$

2) Get **production conduit diameter** (need additional data / simulator)
3) Find **unloading flowing pressure** at depth gradient

$$g_{pfa} = \frac{(P_{pfD} - P_{whu})}{D_d}$$

4) Find **static injection gas pressure** at depth gradient

$$g_{gio} = \frac{(P_{iod} - P_{io})}{D_d}$$

5) Find **unloading gas lift valve temperature** (at depth) gradient

$$g_{Tvu} = \frac{(T_{wsd} - T_{whu})}{D_d}$$

6) Calculate the **depth of the top(uppermost) valve**(D_v1)

$$D_{v1} = \frac{P_{ko} - P_{whu} - \Delta P_{sD}}{(g_{ls} - g_{gio})}$$

7) Calculate **minimum flowing production pressure**([P_pfD(n)]_min), **injection gas pressure**(P_ioD(n)), **unloading gas lift valve temperature**(T_vuD(n)), **depth difference between valves**(D_bv_1) at given valve.

$$\left[P_{pfD(n)}\right]_{\min} = P_{whu} + g_{pfa}\left[D_{v(n)}\right]$$

$$P_{ioD(n)} = P_{io} + g_{gio}\left[D_{v(n)}\right]$$

$$T_{vuD(n)} = T_{whu} + g_{Tvu}\left[D_{v(n)}\right]$$

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

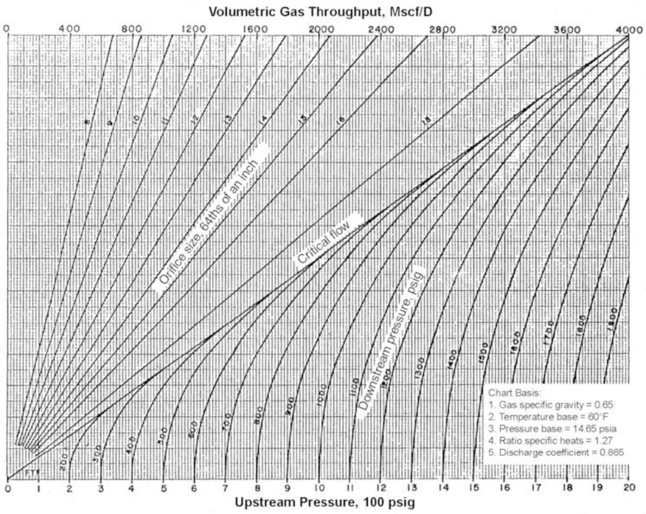
8) Calculate the **depth of the next valve**(D_v2) by adding D_bv_1 with D_v1

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

9) **Iterate step 7 and 8** until calculated valve depth exceeds the tubing length.

4.2. Gas lift valve port size and test rack opening pressures calculation

1) Find **required equivalent orifice size** and **next largest gas lift valve port ID** (This step need additional data or simulator like table below)



2) Calculate (**port area / effective bellows area**) and **production-pressure factor**
3) Calculate **Injection gas pressure** at uppermost valve, using depth of valve and production-pressure factor, etc.

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

4) Calculate **Nitrogen-charged bellows pressure** at valve temperature
5) Calculate **test-rack valve opening pressure**

$$P_{bvD(n)} = P_{oD(n)}(1 - A_p / A_b) + \left[P_{pfD(n)}\right]_{\min}(A_p / A_b)$$

$$P_{vo(n)} = C_{T(n)}\left\{F_p\left[P_{pfD(n)}\right] + P_{oD(n)}\right\}$$

6) Iterate step 4 and 5 for 2nd valve

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

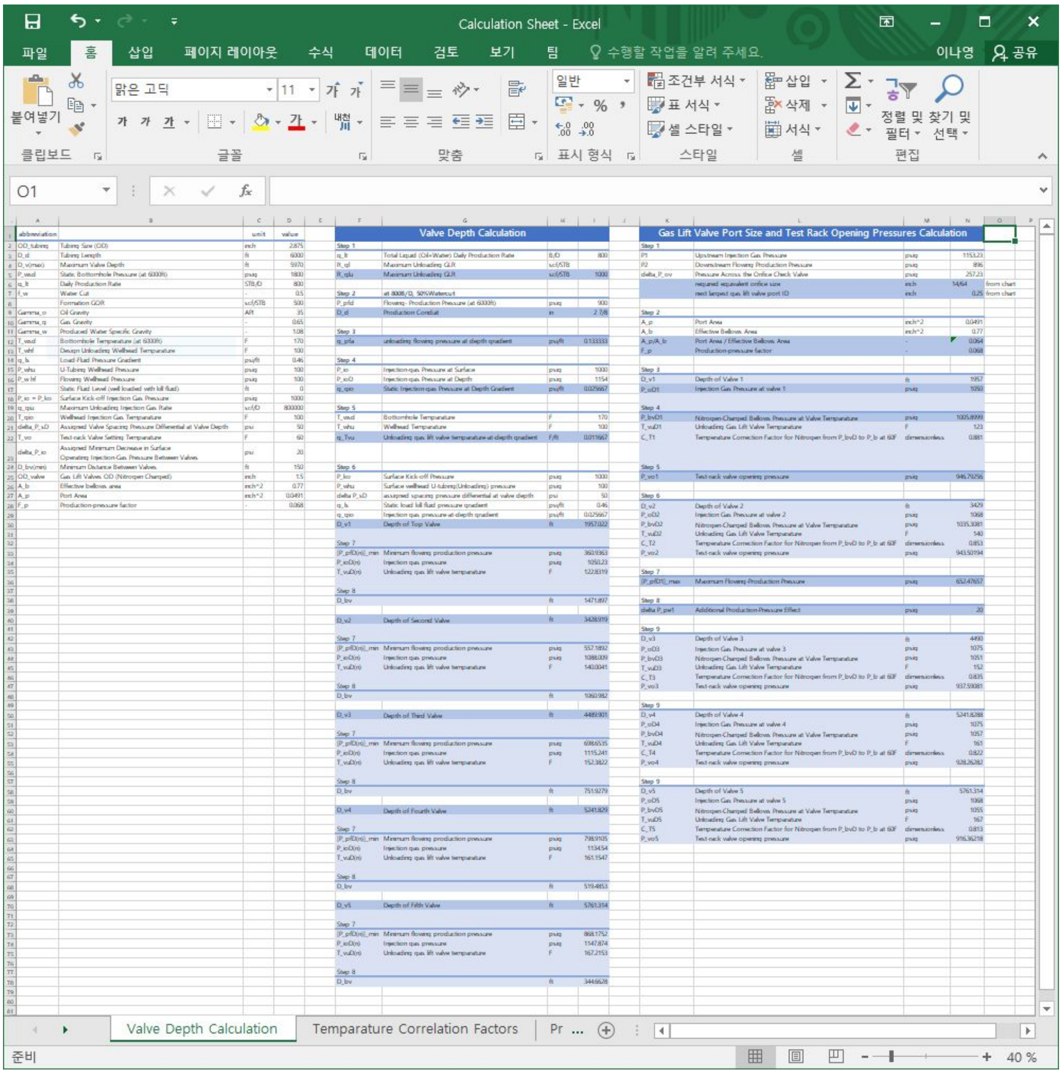
7) Calculate **maximum flowing-production pressure**

$$(P_{pfD1})_{\max} = P_{whf} + D_{v1}\left(\frac{P_{oD2} - P_{whf}}{D_{v2}}\right)$$

8) Calculate **additional production-pressure effect**

$$\Delta P_{pe1} = F_p\left[(P_{pfD1})_{\max} - (P_{pfD1})_{\min}\right]$$

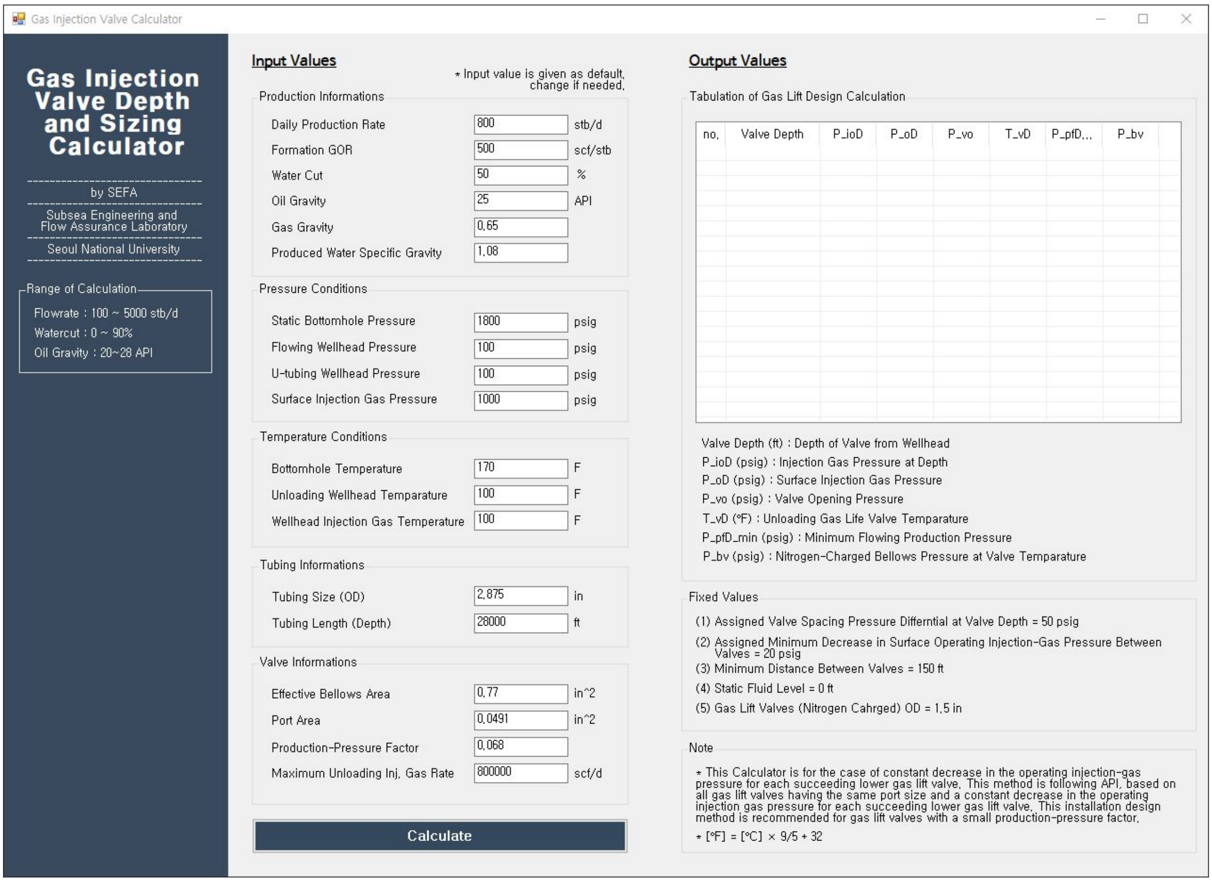
9) **Iterate step 4 and 5** for entire valve



(Figure 3) Example of calculation step using Microsoft Excel

5. Gas Injection Valve Depth and Sizing Calculator

This calculator contains for the result of valve design, based on API rule(API RP 11V6). Input values comes as default, and you can replace them into another values, as long as they are inside the range of calculation. Fill all the form in the "Input Values" section, and click "Calculate". Then you can get the "Output Values", including valve depths, injection gas pressure at depth… etc.



(Figure 4) Configuration of the calculator

6. Examples

Below is the example of calculation results, by varying conditions. Except the given condition, value is used as default value.

(Example 1) Changing Pressure Conditions

(1) Flowing wellhead pressure

(a) P_wh = 100 psig

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1001.851	95.107	396.841	95.107
2	5173.616	1132.791	1132.791	1148.590	87.066	1213.457	87.066
3	10154.719	1260.641	1240.641	1365.727	74.613	2478.040	74.613
4	17447.277	1447.819	1407.819	1702.695	56.382	4329.446	56.382
5	27540.471	1706.881	1646.881	2116.281	31.149	6891.866	31.149
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) P_wh = 500 psig

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1003.622	95.107	424.799	95.107
2	5237.985	1134.443	1134.443	1156.019	86.905	1304.627	86.905
3	10428.996	1267.681	1247.681	1389.839	73.928	2696.658	73.928
4	18208.688	1467.362	1427.362	1753.121	54.478	4782.874	54.478
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) P_wh = 1000 psig

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1005.836	95.107	459.746	95.107
2	5318.446	1136.509	1136.509	1165.472	86.704	1421.176	86.704
3	10777.797	1276.634	1256.634	1420.366	73.056	2982.654	73.056
4	19195.347	1492.687	1452.687	1819.812	52.012	5390.232	52.012
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(2) Surface Injection Gas Pressure

(a) P_si = 500psig

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	805.833	520.683	520.683	487.693	97.985	104.582	97.985
2	2130.313	554.679	554.679	543.774	94.674	440.835	94.674
3	4181.355	607.323	587.323	612.991	89.547	961.546	89.547
4	7184.173	684.396	644.396	727.528	82.040	1723.889	82.040
5	11340.194	791.069	731.069	897.336	71.650	2779.004	71.650
6	16764.136	930.285	850.285	1133.348	58.090	4156.013	58.090
7	23406.211	1100.767	1000.767	1398.681	41.484	5842.276	41.484
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) P_si = 1000psig

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1001.851	95.107	396.841	95.107
2	5173.616	1132.791	1132.791	1148.590	87.066	1213.457	87.066
3	10154.719	1260.641	1240.641	1365.727	74.613	2478.040	74.613
4	17447.277	1447.819	1407.819	1702.695	56.382	4329.446	56.382
5	27540.471	1706.881	1646.881	2116.281	31.149	6891.866	31.149
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) P_si = 2000

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	4259.405	2109.326	2109.326	2047.772	89.351	981.361	89.351
2	11260.224	2289.016	2289.016	2414.987	71.849	2758.701	71.849
3	22101.447	2567.278	2547.278	2922.630	44.746	5511.028	44.746
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(Example 2) Changing Temperature Conditions

(1) Bottomhole Temperature

(a) T_bh = 170 F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1001.851	95.107	396.841	95.107
2	5173.616	1132.791	1132.791	1148.590	87.066	1213.457	87.066
3	10154.719	1260.641	1240.641	1365.727	74.613	2478.040	74.613
4	17447.277	1447.819	1407.819	1702.695	56.382	4329.446	56.382
5	27540.471	1706.881	1646.881	2116.281	31.149	6891.866	31.149
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) T_bh = 300 F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1020.165	86.021	396.841	86.021
2	5173.616	1132.791	1132.791	1208.146	63.046	1213.457	63.046
3	10154.719	1260.641	1240.641	1409.419	27.466	2478.040	27.466
4	17447.277	1447.819	1407.819	1702.695	-24.623	4329.446	-24.623
5	27540.471	1706.881	1646.881	2116.281	-96.718	6891.866	-96.718
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) T_bh = 500F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1050.328	72.043	396.841	72.043
2	5173.616	1132.791	1132.791	1215.439	26.091	1213.457	26.091
3	10154.719	1260.641	1240.641	1409.419	-45.067	2478.040	-45.067
4	17447.277	1447.819	1407.819	1702.695	-149.247	4329.446	-149.247
5	27540.471	1706.881	1646.881	2116.281	-293.435	6891.866	-293.435
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(2) Unloading Wellhead Temperature

(a) T_uw = 100 F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1001.851	95.107	396.841	95.107
2	5173.616	1132.791	1132.791	1148.590	87.066	1213.457	87.066
3	10154.719	1260.641	1240.641	1365.727	74.613	2478.040	74.613
4	17447.277	1447.819	1407.819	1702.695	56.382	4329.446	56.382
5	27540.471	1706.881	1646.881	2116.281	31.149	6891.866	31.149
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) T_uw = 120 F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	959.838	116.505	396.841	116.505
2	5173.616	1132.791	1132.791	1095.110	110.761	1213.457	110.761
3	10154.719	1260.641	1240.641	1292.437	101.867	2478.040	101.867
4	17447.277	1447.819	1407.819	1602.236	88.844	4329.446	88.844
5	27540.471	1706.881	1646.881	2067.607	70.821	6891.866	70.821
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) T_uw = 150F

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	903.821	148.602	396.841	148.602
2	5173.616	1132.791	1132.791	1025.830	146.305	1213.457	146.305
3	10154.719	1260.641	1240.641	1196.597	142.747	2478.040	142.747
4	17447.277	1447.819	1407.819	1457.507	137.538	4329.446	137.538
5	27540.471	1706.881	1646.881	1839.049	130.328	6891.866	130.328
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(Example 3) Changing Production Conditions

(1) Oil Gravity

(a) 20 API

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1006.454	95.107	469.506	95.107
2	5340.918	1137.085	1137.085	1168.145	86.648	1454.240	86.648
3	10876.395	1279.164	1259.164	1428.292	72.809	3065.098	72.809
4	19477.937	1499.940	1459.940	1839.186	51.305	5568.200	51.305
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) 24 API

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1000.807	95.107	380.351	95.107
2	5135.650	1131.817	1131.817	1144.263	87.161	1160.545	87.161
3	9994.929	1256.540	1236.540	1353.517	75.013	2353.255	75.013
4	17009.628	1436.586	1396.586	1674.132	57.476	4075.013	57.476
5	26568.747	1681.940	1621.940	2059.290	33.578	6421.298	33.578
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) 28 API

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1004.985	95.107	446.311	95.107
2	5287.515	1135.715	1135.715	1161.816	86.781	1376.032	86.781
3	10642.927	1273.172	1253.172	1409.600	73.393	2871.018	73.393
4	18811.420	1482.833	1442.833	1793.683	52.971	5151.287	52.971
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(2) Daily Production Rate

(a) 500 stb/d

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1003.794	95.107	427.515	95.107
2	5244.238	1134.604	1134.604	1156.747	86.889	1313.582	86.889
3	10455.867	1268.371	1248.371	1391.945	73.860	2718.374	73.860
4	18283.970	1469.295	1429.295	1758.156	54.290	4828.436	54.290
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(b) 1000 stb/d

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1000.556	95.107	376.392	95.107
2	5126.535	1131.583	1131.583	1143.231	87.184	1147.937	87.184
3	9956.786	1255.561	1235.561	1350.621	75.108	2323.751	75.108
4	16905.808	1433.921	1393.921	1667.403	57.735	4015.330	57.735
5	26339.785	1676.063	1616.063	2045.957	34.151	6311.815	34.151
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000

(c) 2000 stb/d

no.	Valve Depth	P_ioD	P_oD	P_vo	T_vD	P_pfD...	P_bv
1	1957.024	1050.231	1050.231	1007.670	95.107	488.705	95.107
2	5385.121	1138.220	1138.220	1173.446	86.537	1519.933	86.537
3	11071.846	1284.181	1264.181	1447.109	72.320	3230.593	72.320
4	20042.870	1514.440	1474.440	1878.276	49.893	5929.224	49.893
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000

7. Exercises

(1) Find the relationships between the parameters.

   (a) By manipulating the daily production rate, find the relation between production rate and valve number. Explain why.

   (b) By manipulating (1) formation GOR, (2) water cut, (3) oil gravity, (4) gas gravity, find the relation between them and valve depths. Explain why.

(2) Below table is the specification of unknown well. If there's parameter not specified in table below, use the default value.

Parameter	Value	Unit
Daily Production Rate	1000	stb/d
Formation GOR	700	scf/stb
Water Cut	30	%
Oil Gravity	22	API
Flowing Wellhead Pressure	120	psig
U-tubing Wellhead Pressure	200	psig
Surface Injection Pressure	1200	psig
Tubing Length	28000	ft

   (a) Table above is information from another engineer. Put the valves in the calculator and get the output values.

   (b) For each valve, calculate the flowrate passing through the valve with calculated pressure. let ID of Gas lift valves are 1.2 in. Let the gas component as 100% methane. z factor of methane is dependant on T, P : simplified as z = AP^2 + BP + CT + D. You can find A,B,C and D using the table below.

   - z factor values by different P and Ts.

T(F) / P(psig)	40	60	70	90	100
1300	0.8034	0.8317	0.8441	0.8659	0.8756
1400	0.7943	0.8240	0.8370	0.8600	0.8701
1500	0.7863	0.8172	0.8308	0.8547	0.8653
1600	0.7796	0.8114	0.8254	0.8502	0.8611
1800	0.7696	0.8027	0.8173	0.8432	0.8548

   (c) Calculate the inject gas flowrate at wellhead, assuming that the all the valves are open. You can use average value for the z value(don't have to integrate).

(3) Operator wants to save the cost on the given gas lift system. Design the optimum gas injection valve based on the given scenario. To minimize the cost, number and depth of gas lift valves should be lesser. How can you optimize it? Choose the values you want to manipulate, explain why you choose/or didn't choose, and find your optimum. Realistic consideration on given field could be included in you reasoning, both on your selection of variables and optimum value. Manipulatable values are : Daily production rate, Flowing

wellhead pressure, Surface injection gas pressure, Wellhead injection gas pressure, Wellhead injection gas temperature.