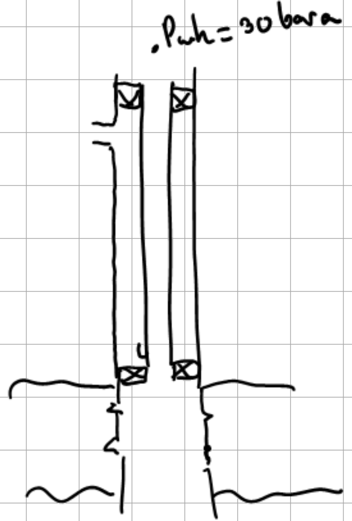
# Lecture 35: Gas lift exercise

Exercise goals:

1. -Learn how to use a VBA function to estimate flowing bottom-hole pressure by performing tubing pressure drop calculations from wellhead
2. -Calculate IPR and TPR and visualize results. Calculate TPR for several Rp and see the effect on the intersection and estimate how much gas lift gas is needed
3. -Calculate the gas lift performance curve of the well

Well details

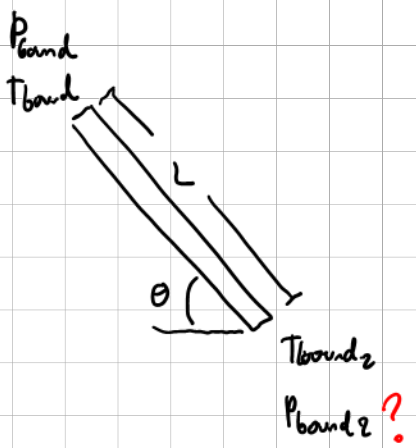



GOR = 53.7 $Sm^3/Sm^3$

| | | |
|---|---|---|
| Tubing diameter, D | [m] | 0.1 |
| Tubing angle from hor, angle | [deg] | 90 |
| Tubing length, L | [m] | 2500 |
| Tubing roughness | [m] | 2.00E-05 |
| wellhead pressure, pwh | [bara] | 30 |
| Wellhead temperature, Twh | [C] | 70 |
| Flowing bottom-hole temperature, Twf | [C] | 100 |

$P_R$ = 200 bara
use Fetkovich equation for IPR ($q_{o\,max}$ = 3000 $Sm^3/d$)

Part 1. For estimation of flowing bottom-hole pressure, we will use a VBA function




```
Function mpf_p(pBound, BoundType, qo_sc, qg_sc, qw_sc, L, angle, roughness, D, TBound, TBound2, PVTMatrix, Profile)
    'mpf_p, function that calculates pressure at inlet or outlet of pipe, in bara, depending on the input
    'pBound, pressure at the boundary, [bara]
    'BoundType, type of boundary, -1 for inlet, 1 for outlet
    'qo_sc, oil rate at standard conditions, [Sm3/d]
    'qg_sc, gas rate at standard conditions, [Sm3/d]
    'qw_sc, water rate at standard conditions, [Sm3/d]
    'L, pipe length, [m]
    'angle, pipe inclination angle, in deg, measured from the horizontal
    'roughness, pipe roughness, in [m],
    'D, pipe hydraulic radius, [m]
    'TBound, fluid temperature at the boundary, [C]
    'TBound2, fluid temperature at the other boundary, [C]
    'PVTMatrix, matrix with BO properties for the flowing composition, arranged in the following manner
    ''GOR(1)   p(2)     T(3)     PROP1  PROP2  PROP3  PROP4
    ' value  value  value  value  value  value
    ' value  value  value  value  value  value
    ' value  value  value  value  value  value
    ' value  value  value  value  value  value
    'profile, provides the profile along the conduit, 1 yes, 0, no
    'Preparing to perform interpolation in the property table
    ColRs = 4
    ColRv = 5
    ColBo = 6
    ColBg = 7
    ColViscg = 8
    ColDeng = 9
    ColVisco = 10
    ColDeno = 11
```

This function does the following:

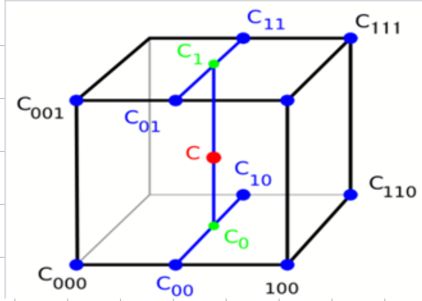
-Estimation of PVT properties by interpolating on a BO table.

As Gas lift increases the GOR, then properties for several GORs, pressures and temperatures must be provided

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GOR [Sm3/Sm3] | Pressure [bara] | Temperature [C] | Rs [Sm3/Sm3] | rs [Sm3/Sm3] | Bo [m3/Sm3] | Bg [m3/Sm3] | viscg [cp] | deng [kg/m3] | visco [cp] | deno [kg/m3] | IFTog [N/m] | rsw [Sm3/Sm3] | Bw [m3/Sm3] | viscw [cp] | denw [kg/m3] |
| 54 | 10 | 20 | 10.4 | 0.00E+00 | 1.030 | 1.00E-01 | 1.12E-02 | 7.8 | 0.65 | 711.8 | 2.04E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 10 | 60 | 7.1 | 2.63E-05 | 1.072 | 1.15E-01 | 1.25E-02 | 7.6 | 0.43 | 680.6 | 1.74E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 10 | 100 | 5.2 | 2.45E-04 | 1.123 | 1.33E-01 | 1.39E-02 | 8.1 | 0.30 | 647.8 | 1.44E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 20 | 20 | 21.0 | 0.00E+00 | 1.054 | 4.88E-02 | 1.15E-02 | 15.4 | 0.60 | 706.1 | 1.92E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 20 | 60 | 16.0 | 8.90E-06 | 1.096 | 5.63E-02 | 1.28E-02 | 14.4 | 0.40 | 674.5 | 1.64E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 20 | 100 | 12.8 | 1.18E-04 | 1.148 | 6.45E-02 | 1.41E-02 | 14.6 | 0.28 | 640.8 | 1.36E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 30 | 20 | 30.1 | 0.00E+00 | 1.073 | 3.18E-02 | 1.17E-02 | 23.2 | 0.56 | 700.3 | 1.81E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 30 | 60 | 24.0 | 5.53E-06 | 1.116 | 3.69E-02 | 1.30E-02 | 21.3 | 0.38 | 668.8 | 1.56E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 30 | 100 | 20.3 | 8.28E-05 | 1.171 | 4.23E-02 | 1.44E-02 | 21.0 | 0.27 | 634.4 | 1.29E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 40 | 20 | 39.2 | 0.00E+00 | 1.092 | 2.33E-02 | 1.20E-02 | 31.4 | 0.53 | 694.2 | 1.72E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 40 | 60 | 31.6 | 4.79E-06 | 1.134 | 2.73E-02 | 1.33E-02 | 28.4 | 0.36 | 663.0 | 1.49E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 40 | 100 | 27.2 | 6.89E-05 | 1.191 | 3.13E-02 | 1.46E-02 | 27.5 | 0.26 | 628.1 | 1.24E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 50 | 20 | 48.5 | 0.00E+00 | 1.112 | 1.82E-02 | 1.24E-02 | 40.0 | 0.50 | 687.9 | 1.64E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 50 | 60 | 39.4 | 5.08E-06 | 1.154 | 2.15E-02 | 1.35E-02 | 35.6 | 0.35 | 657.1 | 1.43E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 50 | 100 | 34.3 | 6.32E-05 | 1.213 | 2.48E-02 | 1.48E-02 | 34.1 | 0.25 | 621.7 | 1.18E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 60 | 20 | 53.7 | 0.00E+00 | 1.123 | 0.00E+00 | 0.00E+00 | 0.0 | 0.49 | 684.8 | 0.00E+00 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 60 | 60 | 47.3 | 5.99E-06 | 1.174 | 1.77E-02 | 1.38E-02 | 43.1 | 0.34 | 651.0 | 1.36E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 60 | 100 | 41.5 | 6.15E-05 | 1.235 | 2.05E-02 | 1.51E-02 | 40.8 | 0.24 | 615.1 | 1.13E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 70 | 20 | 53.7 | 0.00E+00 | 1.121 | 0.00E+00 | 0.00E+00 | 0.0 | 0.50 | 686.0 | 0.00E+00 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 70 | 60 | 53.7 | 0.00E+00 | 1.190 | 0.00E+00 | 0.00E+00 | 0.0 | 0.33 | 646.4 | 0.00E+00 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 70 | 100 | 49.0 | 6.22E-05 | 1.258 | 1.74E-02 | 1.54E-02 | 47.7 | 0.23 | 608.3 | 1.09E-02 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 80 | 20 | 53.7 | 0.00E+00 | 1.119 | 0.00E+00 | 0.00E+00 | 0.0 | 0.50 | 687.2 | 0.00E+00 | 0.00E+00 | 1.000 | 1.0 | 997.0 |
| 54 | 80 | 60 | 53.7 | 0.00E+00 | 1.187 | 0.00E+00 | 0.00E+00 | 0.0 | 0.33 | 648.1 | 0.00E+00 | 0.00E+00 | 1.000 | 1.0 | 997.0 |

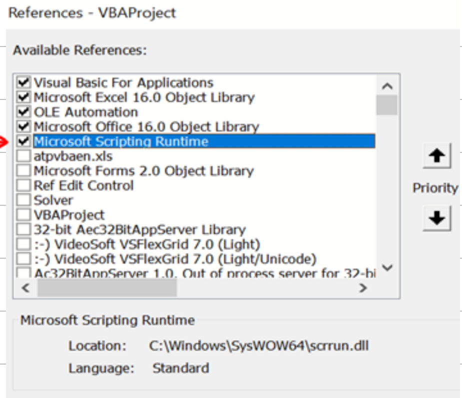
Interpolation is performed using a tri-linear interpolation (GOR, p and T must be provided)

https://en.wikipedia.org/wiki/Trilinear_interpolation




```
Rs = TrilinearInterpol(GOR, p, T, GOR_bounds(0), GC
Rv = TrilinearInterpol(GOR, p, T, GOR_bounds(0), GC
Bo = TrilinearInterpol(GOR, p, T, GOR_bounds(0), GC
Bg = TrilinearInterpol(GOR, p, T, GOR_bounds(0), GC
viscg = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
deng = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
visco = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
deno = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
IFTog = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
'rsw = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
Bw = TrilinearInterpol(GOR, p, T, GOR_bounds(0), GC
denw = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
Viscw = TrilinearInterpol(GOR, p, T, GOR_bounds(0),
```

To make the interpolation efficient, a "dictionary" is used in the VBA code. Therefore, you must have this library active (inside the VBA menu Tools--> references)




```
Set dictx = CreateObject("Scripting.Dictionary")
Set dictx1 = CreateObject("Scripting.Dictionary")
Set dictx2 = CreateObject("Scripting.Dictionary")
Set dictx3 = CreateObject("Scripting.Dictionary")
```

-pressure gradients (dp/dx) are calculated using the drift flux model (neglecting the acceleration term)

$$\frac{dp}{dx} + \rho_{TP} g_x + \rho_g v_{sg} \frac{dv_g}{dx} + \rho_l v_{sl} \frac{dv_l}{dx} = 0$$

-The gas holdup (void fraction) was calculated using the correlation by Woldesemayat and Ghajar

$$\varepsilon = \frac{U_{SG}}{U_{SG}\left(1 + \left(\frac{U_{SL}}{U_{SG}}\right)^{\left(\frac{\rho_G}{\rho_L}\right)^{0.1}}\right) + 2.9\left[\frac{gD\sigma(1+\cos\theta)(\rho_L - \rho_G)}{\rho_L^2}\right]^{0.25}(1.22 + 1.22\sin\theta)^{\frac{P_{atm}}{P_{system}}}}$$

Comparison of void fraction correlations for different flow patterns in horizontal and upward inclined pipes

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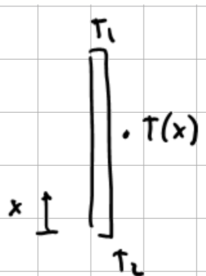
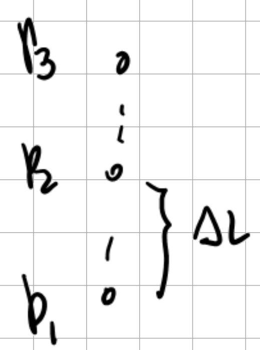
-Temperature of an intermediate point was calculated by doing a linear interpolation between inlet and outlet and using the position of the point



The pressure integration was performed using Euler's method. 10 intervals were used

```
Nsec = 10
deltaL = L / Nsec
```

Pressure integration method



$$p_2 = p_1 + \left.\frac{dp}{dx}\right|_{@ p_1} \cdot \Delta L$$

| PART 1: Learning how to use the VBA tubing function to calculate pwf | | | |
|---|---|---|---|
| qo [Sm3/d] | qw [Sm3/d] | qg [Sm3/d] | pwf [bara] |
| 500 | 500 | 50000 | 271 |

-Calculate IPR and TPR and visualize results. Calculate TPR for several Rp and see the effect on the intersection and estimate how much gas lift gas is needed

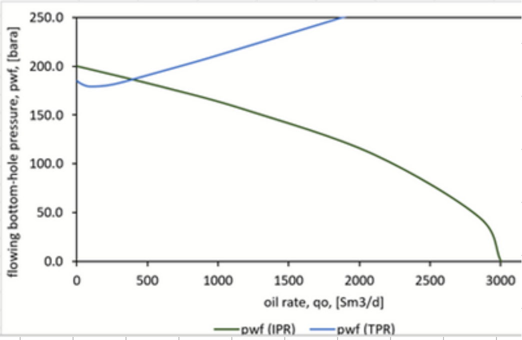
Natural flow

PART 2: IPR vs TPR

WC= 0 $Rp_R$= 54 $Rp^*$= 54

| qo [Sm3/d] | WC [-] | qw [Sm3/d] | $Rp_R$ [Sm3/Sm3] | $qg_R$ [Sm3/d] | $Rp^*$ [Sm3/Sm3] | $qg_{total}$ [Sm3/d] | $qg_{inj}$ [Sm3/d] | pwf (TPR) [bara] |
|---|---|---|---|---|---|---|---|---|
| 0.1 | 0 | 0 | 54 | 5.37E+00 | 54 | 5.37E+00 | 0.00E+00 | 185 |
| 1 | 0 | 0 | 54 | 5.37E+01 | 54 | 5.37E+01 | 0.00E+00 | 185 |
| 10 | 0 | 0 | 54 | 5.37E+02 | 54 | 5.37E+02 | 0.00E+00 | 184 |
| 50 | 0 | 0 | 54 | 2.69E+03 | 54 | 2.69E+03 | 0.00E+00 | 181 |
| 100 | 0 | 0 | 54 | 5.37E+03 | 54 | 5.37E+03 | 0.00E+00 | 179 |
| 250 | 0 | 0 | 54 | 1.34E+04 | 54 | 1.34E+04 | 0.00E+00 | 181 |
| 500 | 0 | 0 | 54 | 2.69E+04 | 54 | 2.69E+04 | 0.00E+00 | 191 |
| 750 | 0 | 0 | 54 | 4.03E+04 | 54 | 4.03E+04 | 0.00E+00 | 201 |
| 1000 | 0 | 0 | 54 | 5.37E+04 | 54 | 5.37E+04 | 0.00E+00 | 211 |
| 2000 | 0 | 0 | 54 | 1.07E+05 | 54 | 1.07E+05 | 0.00E+00 | 256 |

PART 3: gas lift performance curve




Natural flow approx. 400 Sm3/d oil

Gas lift, GOR in tubing = 100

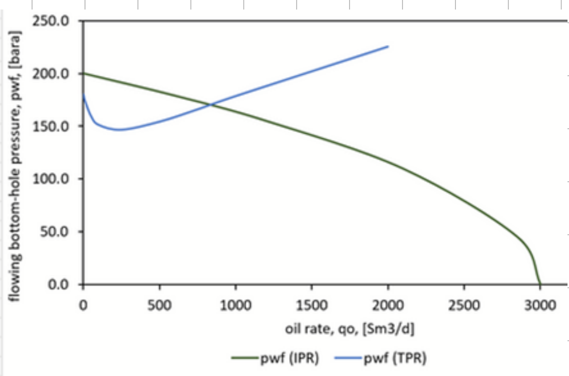
PART 2: IPR vs TPR

WC= 0 $Rp_R$= 54 $Rp^*$= 100

| qo [Sm3/d] | WC [-] | qw [Sm3/d] | $Rp_R$ [Sm3/Sm3] | $qg_R$ [Sm3/d] | $Rp^*$ [Sm3/Sm3] | $qg_{total}$ [Sm3/d] | $qg_{inj}$ [Sm3/d] | pwf (TPR) [bara] |
|---|---|---|---|---|---|---|---|---|
| 0.1 | 0 | 0 | 54 | 5.37E+00 | 100 | 1.00E+01 | 4.63E+00 | 180 |
| 1 | 0 | 0 | 54 | 5.37E+01 | 100 | 1.00E+02 | 4.63E+01 | 180 |
| 10 | 0 | 0 | 54 | 5.37E+02 | 100 | 1.00E+03 | 4.63E+02 | 174 |
| 50 | 0 | 0 | 54 | 2.69E+03 | 100 | 5.00E+03 | 2.31E+03 | 160 |
| 100 | 0 | 0 | 54 | 5.37E+03 | 100 | 1.00E+04 | 4.63E+03 | 151 |
| 250 | 0 | 0 | 54 | 1.34E+04 | 100 | 2.50E+04 | 1.16E+04 | 147 |
| 500 | 0 | 0 | 54 | 2.69E+04 | 100 | 5.00E+04 | 2.31E+04 | 154 |
| 750 | 0 | 0 | 54 | 4.03E+04 | 100 | 7.50E+04 | 3.47E+04 | 166 |
| 1000 | 0 | 0 | 54 | 5.37E+04 | 100 | 1.00E+05 | 4.63E+04 | 179 |
| 2000 | 0 | 0 | 54 | 1.07E+05 | 100 | 2.00E+05 | 9.25E+04 | 226 |

PART 3: gas lift performance curve

SOLVER




Intersection approx. 800 Sm3/d oil
qginj between 34 700-46 300 Sm3/d gas

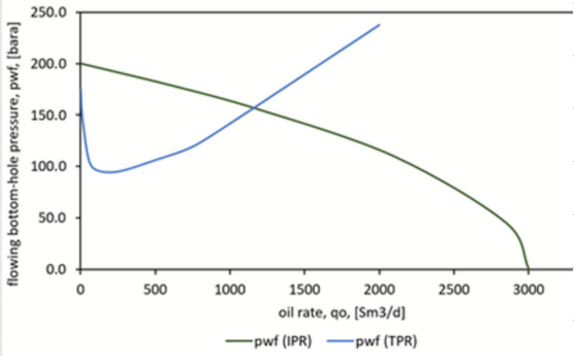
gas lift, GOR in tubing =300

PART 2: IPR vs TPR

| WC= | 0 | $Rp_R$= | 54 | $Rp^*$= | 300 | | | |
|---|---|---|---|---|---|---|---|---|
| qo | WC | qw | $Rp_R$ | $qg_R$ | $Rp^*$ | $qg_{total}$ | $qg_{inj}$ | pwf (TPR) |
| [Sm3/d] | [-] | [Sm3/d] | [Sm3/Sm3] | [Sm3/d] | [Sm3/Sm3] | [Sm3/d] | [Sm3/d] | [bara] |
| 0.1 | 0 | 0 | 54 | 5.37E+00 | 300 | 3.00E+01 | 2.46E+01 | 175 |
| 1 | 0 | 0 | 54 | 5.37E+01 | 300 | 3.00E+02 | 2.46E+02 | 172 |
| 10 | 0 | 0 | 54 | 5.37E+02 | 300 | 3.00E+03 | 2.46E+03 | 149 |
| 50 | 0 | 0 | 54 | 2.69E+03 | 300 | 1.50E+04 | 1.23E+04 | 109 |
| 100 | 0 | 0 | 54 | 5.37E+03 | 300 | 3.00E+04 | 2.46E+04 | 97 |
| 250 | 0 | 0 | 54 | 1.34E+04 | 300 | 7.50E+04 | 6.16E+04 | 95 |
| 500 | 0 | 0 | 54 | 2.69E+04 | 300 | 1.50E+05 | 1.23E+05 | 106 |
| 750 | 0 | 0 | 54 | 4.03E+04 | 300 | 2.25E+05 | 1.85E+05 | 119 |
| 1000 | 0 | 0 | 54 | 5.37E+04 | 300 | 3.00E+05 | 2.46E+05 | 141 |
| 2000 | 0 | 0 | 54 | 1.07E+05 | 300 | 6.00E+05 | 4.93E+05 | 237 |

PART 3: gas lift performance curve

SOLVER




Intersection approx. 1200 Sm3/d oil
qinj betweeen 246 000-493 000 Sm3/d gas

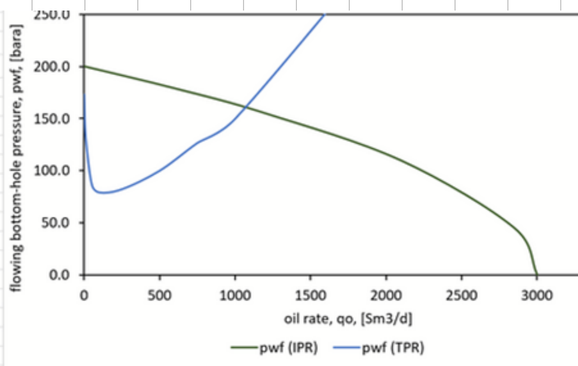
GOR = 500 (gas lift)

PART 2: IPR vs TPR

| WC= | 0 | $Rp_R$= | 54 | $Rp^*$= | 500 | | | |
|---|---|---|---|---|---|---|---|---|
| qo | WC | qw | $Rp_R$ | $qg_R$ | $Rp^*$ | $qg_{total}$ | $qg_{inj}$ | pwf (TPR) |
| [Sm3/d] | [-] | [Sm3/d] | [Sm3/Sm3] | [Sm3/d] | [Sm3/Sm3] | [Sm3/d] | [Sm3/d] | [bara] |
| 0.1 | 0 | 0 | 54 | 5.37E+00 | 500 | 5.00E+01 | 4.46E+01 | 173 |
| 1 | 0 | 0 | 54 | 5.37E+01 | 500 | 5.00E+02 | 4.46E+02 | 168 |
| 10 | 0 | 0 | 54 | 5.37E+02 | 500 | 5.00E+03 | 4.46E+03 | 132 |
| 50 | 0 | 0 | 54 | 2.69E+03 | 500 | 2.50E+04 | 2.23E+04 | 87 |
| 100 | 0 | 0 | 54 | 5.37E+03 | 500 | 5.00E+04 | 4.46E+04 | 79 |
| 250 | 0 | 0 | 54 | 1.34E+04 | 500 | 1.25E+05 | 1.12E+05 | 82 |
| 500 | 0 | 0 | 54 | 2.69E+04 | 500 | 2.50E+05 | 2.23E+05 | 100 |
| 750 | 0 | 0 | 54 | 4.03E+04 | 500 | 3.75E+05 | 3.35E+05 | 127 |
| 1000 | 0 | 0 | 54 | 5.37E+04 | 500 | 5.00E+05 | 4.46E+05 | 150 |
| 2000 | 0 | 0 | 54 | 1.07E+05 | 500 | 1.00E+06 | 8.93E+05 | 320 |

PART 3: gas lift performance curve

SOLVER

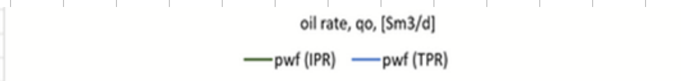



Intersection approx. 1100 Sm3/d of oil

# -Calculate the gas lift performance curve of the well

Flow equlibrium-> pwf calculated from TPR should be equal to pwf calculated from IPR by adjusting the rate

PART 3: gas lift performance curve




SOLVER

| qo | WC | qw | $Rp_R$ | $qg_R$ | $qg_{inj}$ | $qg_{total}$ | $Rp^*$ | pwf (TPR) | pwf (IPR) | error |
|---|---|---|---|---|---|---|---|---|---|---|
| [Sm3/d] | [-] | [Sm3/d] | [Sm3/Sm3] | [Sm3/d] | [Sm3/d] | [Sm3/d] | [Sm3/Sm3] | [bara] | [bara] | [bara] |
| 777.0667545 | 0 | 0 | 54 | 4.18E+04 | 7.50E+05 | 7.92E+05 | 1019 | 172 | 172 | 1 |

POINTS

| $qg_{inj}$ | $qo_R$ | $Rp^*$ |
|---|---|---|
| [Sm3/d] | [Sm3/d] | [Sm3/Sm3] |
| 0.00E+00 | 400 | 54 |
| 1.00E+03 | 423 | 56 |
| 1.00E+04 | 539 | 72 |
| 2.50E+04 | 679 | 91 |
| 5.00E+04 | 893 | 110 |
| 1.00E+05 | 1061 | 148 |
| 2.50E+05 | 1197 | 263 |
| 5.00E+05 | 1055 | 528 |
| 7.50E+05 | 777 | 1019 |