PROBLEM. (100 POINTS)

You are part of the well planning team in AkerBP that is tasked with designing a vertical production well for the Noaka development. The reservoir consists of an undersaturated oil layer.

The well is vertical, it has a tubing and a bottom packer, both placed close to the formation and to the perforations, therefore the pressure drop from the perforations to the bottom of the tubing can be neglected. The lower completion consists of a perforated cemented casing.

The well will be produced at a constant wellhead pressure, equal to 100 bara.

Samples were taken of reservoir fluids and the PVT expert has created tables of black oil properties for your use (available in the Excel file attached, in the tab "PVT").

A colleague has generated Tubing Performance Relationship tables (TPR) that depict rate of oil versus required flowing bottom-hole pressure to flow against a constant wellhead pressure of 100 bara. The colleague generated TPR tables for different values of producing gas-oil ratios (R_p or GOR). The tables are available in the Excel file attached, in the tab "TPR".

The analysis will be performed at initial reservoir pressure equal to 400 bara.

You are asked to work on the following tasks. Provide a short explanation about how you have solved each task in the Excel file (on the cells next to the column called "Task X - Explanation"):

1. **(5 POINTS)** What is the bubble point pressure of the oil at reservoir temperature?
2. **(20 POINTS)** Considering natural flow, what is the oil equilibrium flow rate?
3. **(15 POINTS)** The well exhibits skin damage with s equal to 3. A service company has approached you and offered to perform an acid treatment that would restore the skin to the original undamaged formation (s=0). What increase will this represent in oil rate? Assume that the product $B_o \cdot \mu_o$ remains constant, and that the term $ln\left(\frac{r_e}{r_w}\right)$ is equal to 8.

For all subsequent tasks use the original J (10 Sm3/d/bar).

4. **(20 POINTS)** The reservoir engineers have determined that the natural flow rate is not high enough and that artificial lift is required. Consider a downhole electric submersible pump located at the end of the tubing, in front of the perforations. Estimate pump delta pressure, oil volumetric rate at pump suction and required pumping power to produce as much oil as possible. Make sure that the suction pressure does not go below the bubble point pressure of the oil at reservoir temperature.
5. **(20 POINTS)** An engineer in the office has suggested using gas lift, because then the suction pressure can go below the bubble point pressure and one can potentially produce more from the reservoir. The gas lift valve will be placed as close as possible to the bottom of the tubing, and therefore, the gas-lift analysis can be performed considering that the tubing GOR is changing. In the Excel file, several TPR curves are given for different values of Rp (GOR). Determine if using gas lift is a better idea to increase production and estimate the optimal amount of gas lift rate required.
6. **(20 POINTS)** There are suspicions that the TPR curve has been calculated for other fluid properties and that they might be wrong. You have been tasked with performing a

verification of the curves, by performing pressure drop calculations for the equilibrium rate found in task 2. For your calculations assume that the fluid is at a constant temperature equal to reservoir temperature. Assume that there is no slip between the gas and the liquid phases (homogeneous flow). Provide the following:

- o Plots of local volumetric rates of oil and gas versus depth.
- o Plot of non-slip volume fraction versus depth.

Use proper plot formatting, axis with variable names, symbols, and units. Use legible font size.

Additional information:

- The productivity index of a vertical, undersaturated oil well is estimated with the following equation:

$$J = \frac{k \cdot h}{18.68 \cdot \left[ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right]} \cdot \left(\frac{1}{\mu_o \cdot B_o}\right)_{@p_{av}}$$

  With viscosity in cP, k in md, h in m. This J can be used in a IPR equation with pressures in bara and rate in Sm3/d.
- To model the inflow performance relationship of the formation, use a "composite IPR" consisting of the following:
  - o A linear IPR if the flowing bottom-hole pressure (p_{wf}) is above the bubble point pressure

$$q_{\bar{o}} = J \cdot \left[p_R - p_{wf}\right]$$

  - o The Fetkovitch equation is used if the flowing bottom-hole pressure is below the bubble point pressure

$$q_{\bar{o}} = J \cdot \left[p_R - p_b\right] + \frac{J \cdot p_b}{2} \cdot \left[1 - \left(\frac{p_{wf}}{p_b}\right)^2\right]$$

This equation has been programmed in VBA for your use and has the name "CompositeIPR_qo"

- To interpolate on tables (for example 1) to calculate PVT BO properties at p, or 2) to find required flowing bottomhole pressure at a given rate), you can use the linear interpolation VBA function "tabinterpol".
- The power required by an Electric Submersible Pump, in watts, W, neglecting mechanical efficiency, is calculated with the following equation:

$$Power = \frac{q \cdot \Delta p \cdot 1E5}{\eta \cdot 24 \cdot 3600}$$

Where Δp [bara], q, volume rate at pump inlet, in [m^3/d]. Assume a constant pump hydraulic efficiency (η) of 0.6. This equation has been programmed in VBA for your use and has the name "ESP_power"

- To estimate pressure gradient at a tubing location, use the drift flux model by Harald Asheim.

$$\frac{dp}{dl} = -\left(\rho_L \cdot (1 - \varepsilon) + \rho_g \cdot \varepsilon\right) \cdot g \cdot sin(\theta) - \frac{1}{2 \cdot d}\left(f_g \rho_g v_g |v_g| y_g + f_l \rho_l v_l |v_l| y_l\right)$$

Here ε is the gas void fraction, equal to:

$$\varepsilon = \frac{A_g}{A_l + A_g}$$

v_l and v_g are the real liquid and gas velocities respectively. A_g and A_l are the cross-section areas of the pipe occupied by the gas and liquid respectively.

θ is the inclination angle formed by the tubing with respect to the horizontal.

This equation has been programmed in VBA for your use and has the name "dpdx_mpf".

- Remember the following matrix to convert from standard conditions to local conditions

$$\begin{bmatrix} q_g \\ q_o \\ q_w \end{bmatrix} = \begin{bmatrix} \frac{B_g}{1 - R_s \cdot r_s} & \frac{-R_s \cdot B_g}{1 - R_s \cdot r_s} & 0 \\ \frac{-B_o . r_s}{1 - R_s \cdot r_s} & \frac{B_o}{1 - R_s \cdot r_s} & 0 \\ 0 & 0 & B_w \end{bmatrix}_{(p,T)} \cdot \begin{bmatrix} q_{\bar{g}} \\ q_{\bar{o}} \\ q_{\bar{w}} \end{bmatrix}$$

The equations to calculate the local gas and local oil rate have been programmed in VBA and are available with the names "qg_local" and "qo_local"

Computer shortcuts (for Windows)

- To access the VBA module press Alt+F11 while in Excel