ASNWER THIS PROBLEM USING THE FIELD BELOW

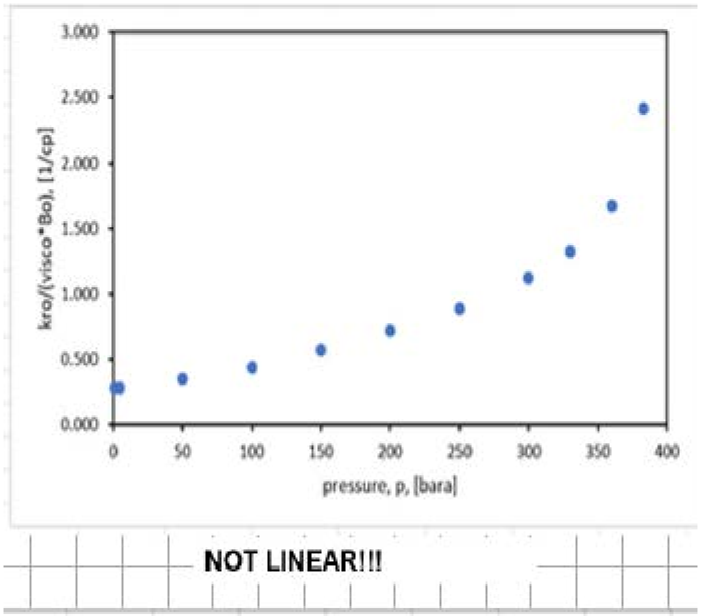
PROBLEM 1 (5 POINTS). When deriving analytically the IPR equation for a saturated oil well with solution gas drive, one needs to integrate the term $k_{ro}/(B_o \cdot \mu_o)$ from bottom-hole to reservoir pressure.

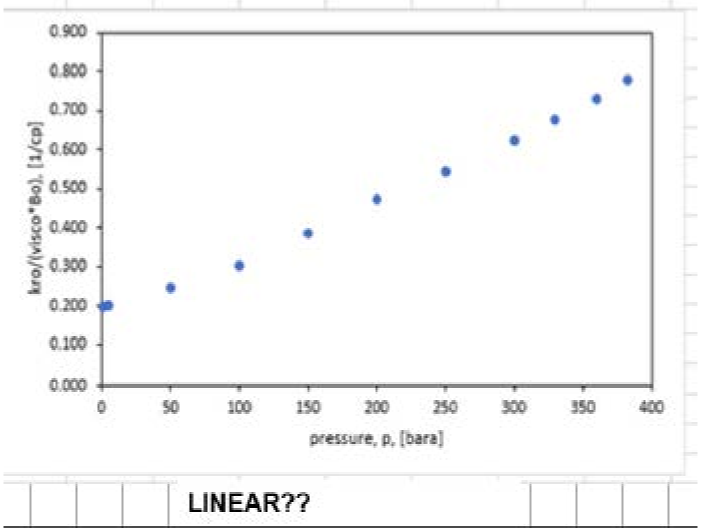
Task 1 (2 POINTS). Make a sketch showing how does the term $k_{ro}/(B_o \cdot \mu_o)$ behaves versus pressure.

Task 2 (3 POINTS). In the video lectures, for one particular case, the output of the analytical derivation was Vogel's equation. What assumptions must be taken for this to occur?

SOLUTION:

Task 1. Some examples from video lecture 19:





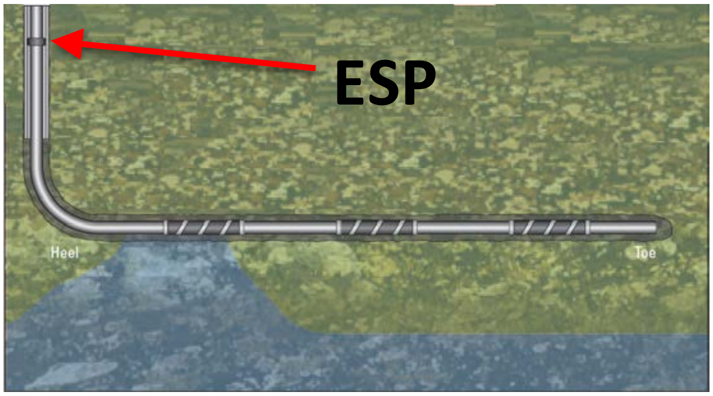
Task 2.

Vogel's equation was obtained if the term $k_{ro}/(B_o \cdot \mu_o)$ is assumed to be linear with pressure, and the value at the origin is equal to 1/9 the value at reservoir pressure.

SOLVE THIS PROBLEM USING THE EXCEL FILE PROVIDED

PROBLEM 2 (20 POINTS). Estimation and verification of ESP requirements

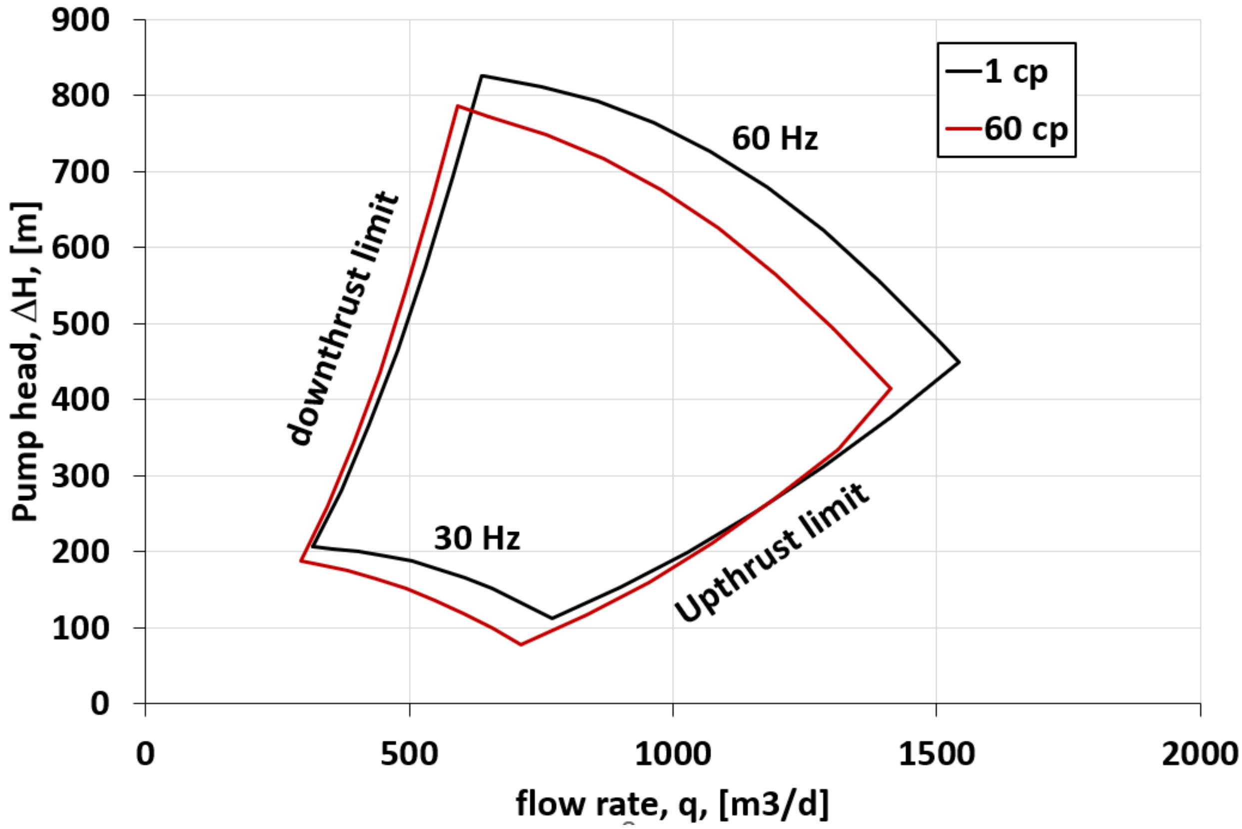
The Rio Ariari complex is a field currently under development in the region of “Los llanos” in Colombia. The reservoir has a thin layer (19 m) containing undersaturated oil and a very strong bottom aquifer. There is coning from the water layer into the well
The field will be produced with ESP-lifted horizontal wells like the one shown in the figure below.



The Wood company has proposed a unique ESP model (TE7000) with 50 stages which they claim has a wide operational envelope to handle all possible well operational conditions.
Your task is to estimate and verify the ESP requirements for a well in the Ariari Field.

TASKS:

Task 1 (5 POINTS). What is the effective viscosity (in cP) of the oil-water mixture (using the Richardson emulsion equation) when the well is producing a total liquid rate of 250 Sm^3/d with 54% water cut?
Explain how you have performed this task.
Task 2 (10 POINTS). -For the total liquid rates of 250 Sm^3/d, estimate the required pump pressure boost (DP in bar, input a positive number) and pump power (in kW) to deliver the rate if the wellhead pressure is constant and equal to 40 bara.
Explain how you have performed this task.
Task 3 (5 POINTS). -According to the ESP envelope given below, will the ESP model suggested be able to deliver the desired rate of 250 Sm^3/d?
Explain how you have performed this task.



Additional information

- Neglect the flow pressure drop from the bottom-hole to the pump suction (i.e. $p_{suc} = p_{wf}$).
- Assume that the oil compressibility and GOR can be neglected such as the rate at standard conditions is equal to the rate at local conditions p and T.
- The Water cut (WC, in fraction) is defined as

$$WC = \frac{q_{\overline{w}}}{q_{\overline{o}} + q_{\overline{w}}}$$

- The well inflow can be represented with a linear PI equation:

$$q = J \cdot \left(p_R - p_{wf}\right)$$

Where:

q……total liquid rate in Sm^3/d

J……productivity index for total liquid flow **[100 $Sm^3/d/bar$]**,

p_R…...reservoir pressure [**82.7 bara**]

p_{wf}…..bottom-hole flowing pressure [bara]

This equation is programmed in VBA functions called “IPRq” and “IPRpwf” provided in the Excel sheet. IPRq is the equation provided above. IPRpwf is when pwf is cleared out in the equation above.

- The density of the oil water mixture is calculated using the following expression:

$$\rho_m = WC \cdot \rho_w + (1 - WC) \cdot \rho_o$$

Where the water density is 1025 kg/m^3

The oil density is 897 kg/m^3

WC is input in fraction.
This equation is programmed in a VBA function called “Avprop” provided in the Excel sheet.

- The oil+water mixture exhibits an emulsion behavior where its viscosity is a function of the water volume fraction. The cutoff watercut is 60%.

Regime	Richardson emulsion viscosity
Oil continuous (WC < 60%)	$\mu_m = \mu_o \cdot e^{3.215 \cdot WC}$
Water continuous (WC > 60%)	$\mu_m = \mu_w \cdot e^{3.089 \cdot (1-WC)}$

The viscosity of the oil is 10 cp and viscosity of the water is 1 cp (1 cp = 1 E-3 Pa s). **WC is input in fraction.**

This equation is programmed in a VBA function called “Rich_emul_visc” provided in the Excel sheet.

- The pump power [in watts, W] can be estimated with:

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

Where Δp [bara], q in [m^3/d]. Assume a constant pump efficiency (η) of 0.6.

This equation is programmed in a VBA function called “ESPpower” provided in the Excel sheet.

- The pump head [m] is

$$\Delta h = \frac{\Delta p \cdot 10^5}{\rho_m \cdot g}$$

Where Δp [bara], ρ_m [kg/m^3] and g = 9.81 [m/s^2]

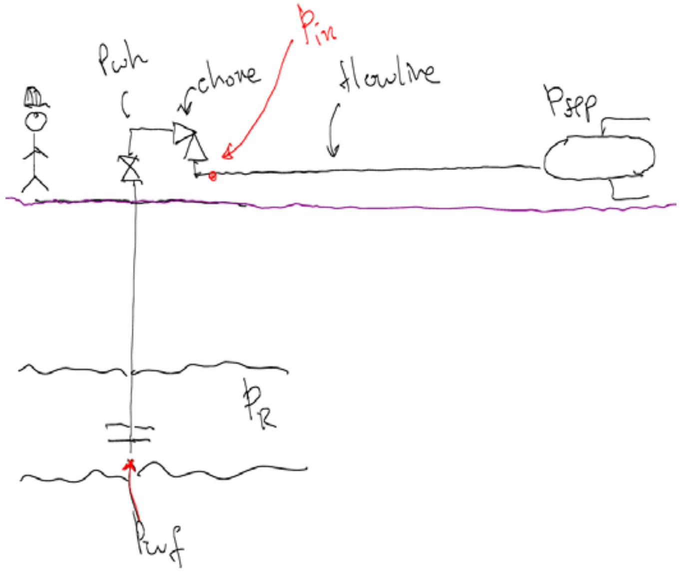
- Two VBA functions are provided in the Excel sheet to calculate pressure drop in pipe for incompressible flow:
  - “pin” allows to estimate required pressure at the inlet of the pipe if outlet pressure and rate are provided.
  - “pout” allows to estimate available pressure at the pipe outlet if inlet pressure and rate are provided.

- **SOLUTION:**
- **See the excel file attached.**

SOLVE THIS PROBLEM USING THE EXCEL FILE PROVIDED

PROBLEM 3 (15 POINTS).

Consider the dry gas production system shown in the figure below:



Assume that the wellhead choke is 20% closed and that the system is producing a dry gas rate of 2.0 E6 Sm³/d.

Task (15 POINTS): The engineering team wants to increase the well rate by opening the wellhead choke, but this might take time since the well is located in a remote location with difficult access and the choke is manually actuated. Instead of opening the choke, a member of the team has suggested to route the production of the well to another separator that has lower pressure (20 bara). **Assess this idea and provide your recommendation**.

Additional information:

- The choke critical pressure ratio is 0.5
- Neglect the pressure drop in the flowline, i.e. assume $p_{in} = p_{sep} = 40$ bara
- Use the following equations:

Inflow equation: $q_{\bar{g}} = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$ With C_R = 104 Sm³/d/bar^2n n= 0.9 p_R = 304 bara
Tubing equation: $q_{\bar{g}} = C_T \cdot \left(\frac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$ C_T = 4.41 E4 Sm³/d/bar S = 0.31

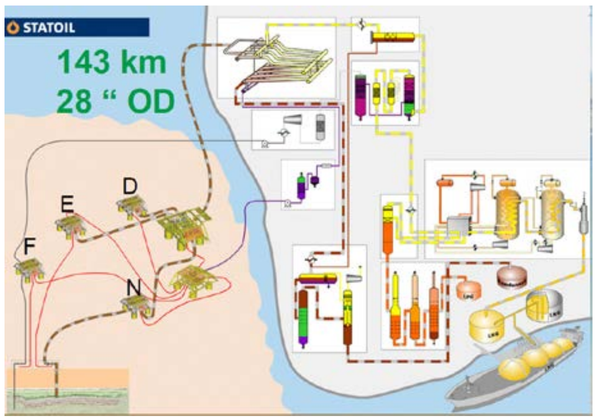
SOLUTION

See the Excel file attached.

SOLVE THIS PROBLEM USING THE EXCEL FILE PROVIDED

PROBLEM 4 (25 POINTS). Flow equilibrium in the Snøhvit CO_2 injection well using the equations for incompressible liquid flow.

The Snøhvit field is a subsea dry gas field, located in the Barents Sea. The field produces to a LNG facility on the island of Melkøya through a pipeline that is 140 km long. In the LNG plan, CO2 is captured, it is then pumped and transported for 140 km back to the field and injected in a deep formation (Tubåen). The CO2 is injected in an aquifer, but in this problem, we will assume that the layer has only CO2.



Task (25 POINTS). Perform a flow equilibrium calculation in the Snøhvit CO2 injection well to find the equilibrium rate. Use the well bottom-hole as equilibrium point. Plot the IPR and TPR. Explain how you have performed this task.

Additional information:

- The maximum allowed flowing bottom-hole pressure is 390 bara (to avoid fracking the reservoir)
- For the IPR use a linear equation with J = 240 [t/d/bar]. Assume a reservoir pressure equal to 300 bara.
- Assume the wellhead pressure is kept fixed at a value of 100 bara.
- For the TPR use the Bernoulli equation for pressure drop in conduit for incompressible liquid flow. Two VBA equations are provided in the Excel file:
  - "pin" that allows to calculate required inlet pressure if outlet pressure and mass flow are given
  - "pout" that allows to calculate available pressure at the discharge of the pipe if inlet pressure and mass flow are given
- It is recommended you perform your flow equilibrium calculations using mass flow rate instead of standard conditions volumetric rates or local conditions volumetric rates.

- SOLUTION
- See the Excel file attached.
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SOLVE THIS PROBLEM USING THE EXCEL FILE PROVIDED

PROBLEM 5 (25 POINTS).

A pressure survey has been performed in a producing oil well (production rate of 1394 Sm3/d and GOR = 155.1), and pressure and temperature at several depths have been recorded. The values are provided in the Excel file attached.

Task (25 POINTS). Calculate the following variables along the well:

- Non-slip gas volume fraction
- Gas void fraction
- Oil and gas real velocities
- The slip ratio
- The hydrostatic pressure gradient

Useful information:

- ε is the gas void fraction, equal to:

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

A VBA function named "e_simpson" is provided to calculate the void fraction using the gas density, liquid density, and non-slip gas volume fraction (λ_g).

- The following matrix to convert from standard conditions to local conditions

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

There are two VBA functions available in the Excel sheet.: "qg_local", to calculate local gas rates from SC oil and gas rates and black oil properties and "qo_local", to calculate local oil rates from SC oil and gas rates and black oil properties

- A VBA function called "TwoDimInterpol" is provided to find BO properties at any p-T by interpolating on the table provided on the sheet "BO_tables"

SOLUTION

See the Excel file attached.

ANSWER THIS PROBLEM USING PEN AND PAPER

PROBLEM 6 (10 POINTS).

A test has been performed on an oil well and the following pairs of oil rate and flowing bottomhole pressure are reported:

Test point	qo [Sm3/d]	pwf [bara]
1	1080	270
2	2050	180

The reservoir pressure is 360 bara and the bubble point pressure at reservoir pressure is 250 bara.

Task (10 POINTS): Propose an IPR equation to use for this well and calculate all the parameters in the equation suggested using the test data. Justify your answer.

Additional information:

Some IPRs:

Dry gas backpressure equation:

$$q_{\bar{g}} = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$$

Saturated oil Vogel equation

$$q_{\bar{o}} = q_{\bar{o},max}\left[1 - 0.2 \cdot \frac{p_{wf}}{p_R} - 0.8 \cdot \left(\frac{p_{wf}}{p_R}\right)^2\right]$$

Saturated oil Fetkovich equation

$$q_{\bar{o}} = q_{\bar{o},max}\left[1 - \left(\frac{p_{wf}}{p_R}\right)^2\right]$$

Undersaturated oil, OR high pressure gas equation

$$q = J \cdot \left(p_R - p_{wf}\right)$$

SOLUTION

See the Excel file attached.