Exercise 1 – Review of PVT behavior and simple volumetric reservoir calculations

Conversion factors

1 *bar*	=	100.000 *pascal* = 14.5 *psi*
1 m^3	=	35.31 ft^3 = 6.290 *bbl*

Definitions:

Formation volume factor	$B = \frac{\text{(reservoir volume of fluid)}}{\text{(surface volume of fluid)}}$
Solution gas-oil ratio	$R_{so} = \frac{\text{(surface volume of solution gas)}}{\text{(surface volume of oil)}}$
Fluid compressibility	$c = -\frac{1}{V}(\frac{\partial V}{\partial P})_T$
Pore compressibility	$c_r = +\frac{1}{\phi}(\frac{\partial \phi}{\partial P})_T$
Total compressibility	$c_T = c_r + \sum_{i=o,w,g} c_i S_i$
Expansion due to compressibility	$\Delta V = V_2 - V_1 \approx -V_1 c(P_2 - P_1)$
Gas law for hydrocarbon gas	$PV = nZRT$
Reservoir oil density	$\rho_{oR} = \frac{\rho_{oS} + \rho_{gS} R_{so}}{B_o}$
Reservoir gas density	$\rho_{gR} = \frac{\rho_{gS}}{B_g}$
Reservoir water density	$\rho_{wR} = \frac{\rho_{wS}}{B_w}$

Reservoir data (reservoir is initially undersaturated):

Gross reservoir volume	$V = 10^9 \, m^3$
Porosity	$\phi = 0.3$
Water saturation	$S_w = 0.2$
Pressure	P = 331 bar
Pore compressibility	$c_r = 4 \cdot 10^{-5} bar^{-1}$
Water compressibility	$c_w = 5 \cdot 10^{-5} bar^{-1}$
Gas density at surface	$\rho_{gS} = 0,5 \, kg / sm^3$
Oil density at surface	$\rho_{oS} = 760 \, kg / sm^3$
Water density at surface	$\rho_{wS} = 1030 \, kg / sm^3$
Water formation volume factor	$B_W = 1.05$

In the following, use values for B_o , R_{so} and *Z* from the figures on the next page as needed.

Part 1. Derive and compute following fluid parameters:

1. An expression for oil compressibility expressed in B_o
2. An approximate value for initial B_o
3. An approximate value for initial compressibility of oil
4. An expression for gas formation volume factor expressed in Z and P
5. An expression for gas compressibility expressed in Z and P
6. An approximate value for initial compressibility of gas
7. At which pressure is the gas compressibility highest?
8. An approximate value for initial B_g
9. An approximate value for initial oil density in the reservoir
10. An approximate value for initial gas density in the reservoir

11. An approximate value for initial water density in the reservoir

Part 2. Compute following initial volumes for the reservoir:

1. Pore volume (rm^3)
2. Hydrocarbon pore volume (rm^3)
3. Water pore volume (rm^3)
4. Oil reserves, OOIP (sm^3)
5. Solution gas reserves (sm^3)
6. Water reserves (sm^3)

Part 3. Volumetric calculations for an undersaturated reservoir:

The reservoir is producing oil only until the pressure reaches 275.86 bar. Use initial oil compressibility.

1. Neglect pore and water compressibilities and compute oil recovery in % of *OOIP*
2. Neglect water compressibility and compute oil recovery in % of OOIP
3. Compute oil recovery in % of *OOIP* with all compressibilities included

Part 4. Volumetric calculations for a gas cap reservoir:

Assume (hypothetically!) that the reservoir has a gas cap of equal volume to that of the oil zone, and that we can

- neglect that gas comes out of solution,
- assume that the relative volumes in the reservoir are constant, and
- we can use fluid parameters at initial pressure.

Again let the reservoir produce only oil until the pressure reaches 275.86 *bar*.

1. Compute oil recovery in % of *OOIP* with all compressibilities included
2. Compute oil recovery in % of *OOIP* if only gas compressibility is included

Part 5. Volumetric calculations for a reservoir under water injection:

If the reservoir is to be pressure maintained through water injection, and the oil production initially is kept at 3000 sm^3 per day, what water injection rate is required?

Part 6. Gas drive reservoir:

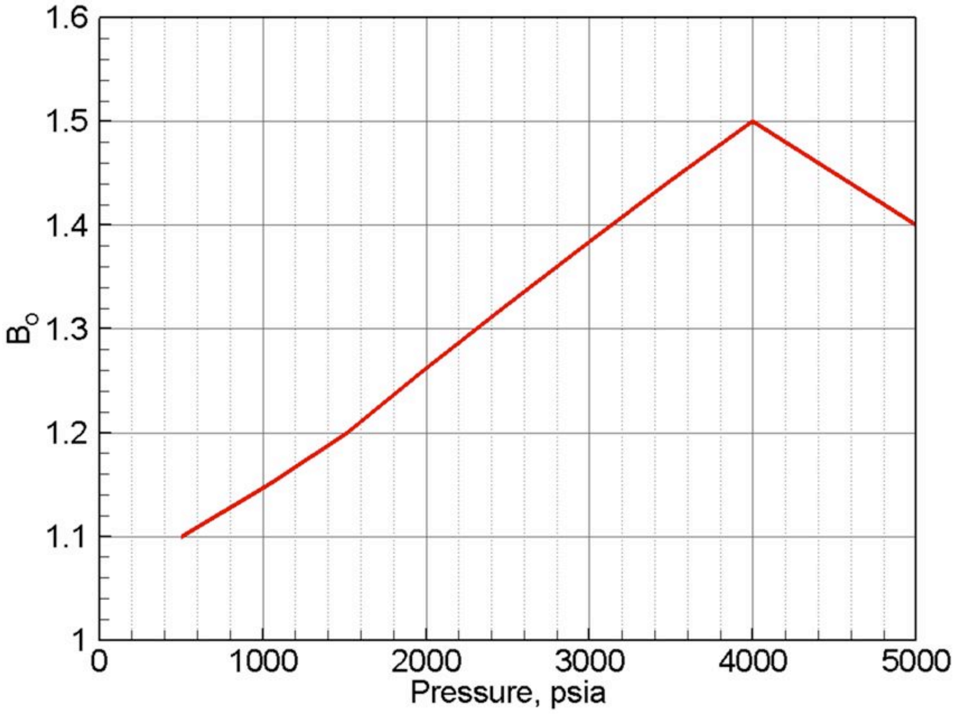
1. Show a typical plot of producing gas oil ratio as a function of the average reservoir pressure for a typical solution gas drive reservoir. Explain the plot briefly.
2. The oil and gas rates during the production time are:
   Oil rate: A stb oil/day
   Gas rate: B scf gas/day

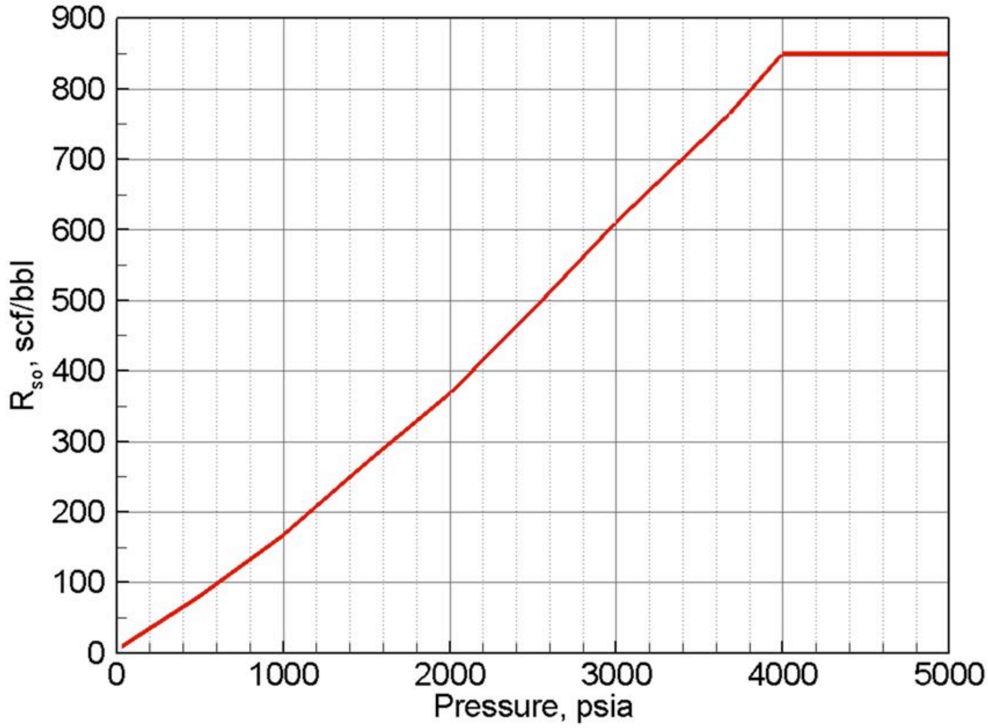
What is the total underground withdrawal rate in reservoir bbls/day?
Explain the difference withdrawal rate in saturated and undesaturated condition.
(Hint: producing gas oil ratio (R) is R = B/A)

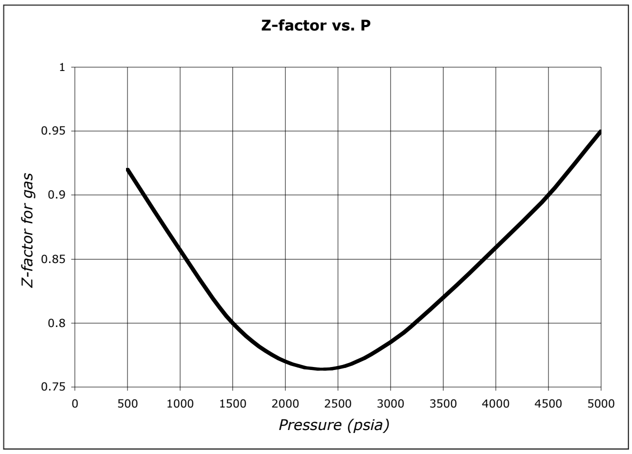
3. Calculate the daily underground withdrawal:

   - If the average reservoir pressure is 4800 psia?
   - If the average reservoir pressure is 3000 psia? In this pressure, an oil production of 3000 stb/day and a gas rate of 6000000 scf/day. (B_g = 0.001 rb/scf)

   Use the PVT relationship shown in figures below.


1.6
1.5
1.4
1.3
1.2
1.1
1
B_o
0
1000
2000
3000
4000
5000
Pressure, psia


900
800
700
600
500
400
300
200
100
0
R_{so}, scf/bbl
0
1000
2000
3000
4000
5000
Pressure, psia


Z-factor vs. P
Z-factor for gas
Pressure (psia)
1
0.95
0.9
0.85
0.8
0.75
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000