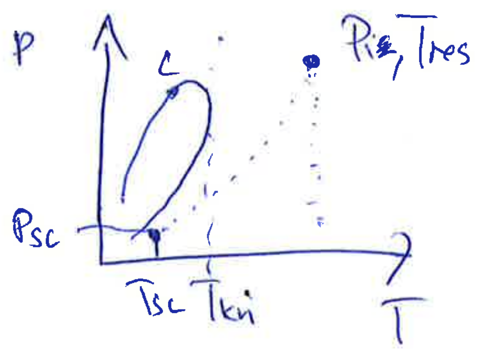
MATERIAL BALANCE

DRY GAS

Q: What is the volume of produced gas, G_p, at standard conditions, given initial reservoir pressure P_i, P_{ic} and actual reservoir pressure

Reservoir fluid is one-phase gas, only gas produced at standard conditions. No produced liquid, no condensed liquid in reservoir.



Assume closed reservoir, constant reservoir volume
Assume constant T_{res} during production.

Standard conditions - at surface P and T

For an ideal gas, gas EOS equation of state
tilstandslignningen.

$$\boxed{PV = nRT}$$

P = pressure
V = volume
n = number of moles
R = universal gas constant
T = temperature

	Petroleum / Field	SI
P	psia	kPa
V	ft^3	m^3
n	lb mol	kg mol
R	10.732	8.3145
T	°R	°K

Ideal gas : assume gas particles have no volume, no contact between gas particle, only at low temperatures and pressures.

In a reservoir, conditions are not ideal. Modify the gas law to be valid for real gases.

$$\boxed{PV = znRT}$$ Real gas law

z = kompressibilitetsfactor
gas deviation factor.

z contains deviation from an ideal gas at elevated P and T

Definition : $$z = \frac{\text{actual gas volume at P and T } (V_a)}{\text{ideal gas volume at P and T } (V_{id})}$$

How to determine z?

Use fig. 1.3.

$z = f(T, P, \text{composition})$

$f(P_{pr}, T_{pr})$
pseudo reduced
P and T
in fig. 1.3.

Find P_{pr}, T_{pr}.

First calculate reduced pressure, P_r : for every component
reduced temperature, T_r

$$P_r = \frac{P}{P_c} \quad - \text{critical pressure}$$

$$T_r = \frac{T}{T_c} \quad - \text{critical temperature}$$

Pseudoreduced values for the gas mixture

$$P_{pr} = \sum_{i=1}^{N} n_i \cdot (P_r)_i \qquad T_{pr} = \sum_{i=1}^{N} n_i \cdot (T_r)_i$$

P = psia

T = °R

Example Determine z

Gas:			
50 mol %	C_1	0.5	
30 mol %	C_2	0.3	
20 mol %	C_3	0.2	
100 %		1	

$P = 20$ MPa
$T = 100$ °C

Solution: $P = 2900$ psia
$T = 673$ °R

From Table 1.1 we find P_c, T_c values

Calculate reduced values: $P_r = \frac{P}{P_c}$

$T_r = \frac{T}{T_c}$

$P_r(C_1) = 4.35$ $\quad T_r(C_1) = 1.95$
$P_r(C_2) = 4.10$ $\quad T_r(C_2) = 1.22$
$P_r(C_3) = 4.71$ $\quad T_r(C_3) = 1.01$

Calculate pseudo-reduced values:

$$\underline{P_{pr}} = 0.5 \cdot 4.35 + 0.3 \cdot 4.10 + 0.2 \cdot 4.71 = \underline{4.35}$$

$$\underline{T_{pr}} = 0.5 \cdot 1.95 + 0.3 \cdot 1.22 + 0.2 \cdot 1.01 = \underline{1.55}$$

Use diagram 1.3, $P_{pr} = 4.35$, $T_{pr} = 1.55$

$$\Rightarrow \underline{z \approx 0.8}$$

$$\boxed{\text{at sc. } z = 1 \quad z_{sc} = 1}$$

Produced gas calculations material balance

Real gas law is used to calculate gas production in the pressure interval

$P_i \longrightarrow P$

$P_{ic} \longrightarrow P_{res}$

Assume closed reservoir, initial HCPV is constant

Assume constant temperature during production in the reservoir

$$PV = znRT$$

Pressure interval $P_{ic} \longrightarrow P_{res}$

mol produced (sc) = mol initially in reservoir (ic) − mol left in reservoir (res)

$$\left(\frac{PV}{zRT}\right)_{sc} = \left(\frac{PV}{zRT}\right)_{ic} - \left(\frac{PV}{zRT}\right)_{res}$$

Volume gas produced

$$\boxed{G_p = n \cdot V_m}$$

volume of 1 mol gas at sc

Determine IGIP - initial gas in place.

- volume measured at standard ~~condition~~ conditions.

* ~~Ex~~ Use: $V_{sc} = G_p$ gas produced

* Closed reservoir w/ constant T

$V_{ic} = V_{res}$ constant reservoir volume HCPV

$T_{ic} = T_{res}$

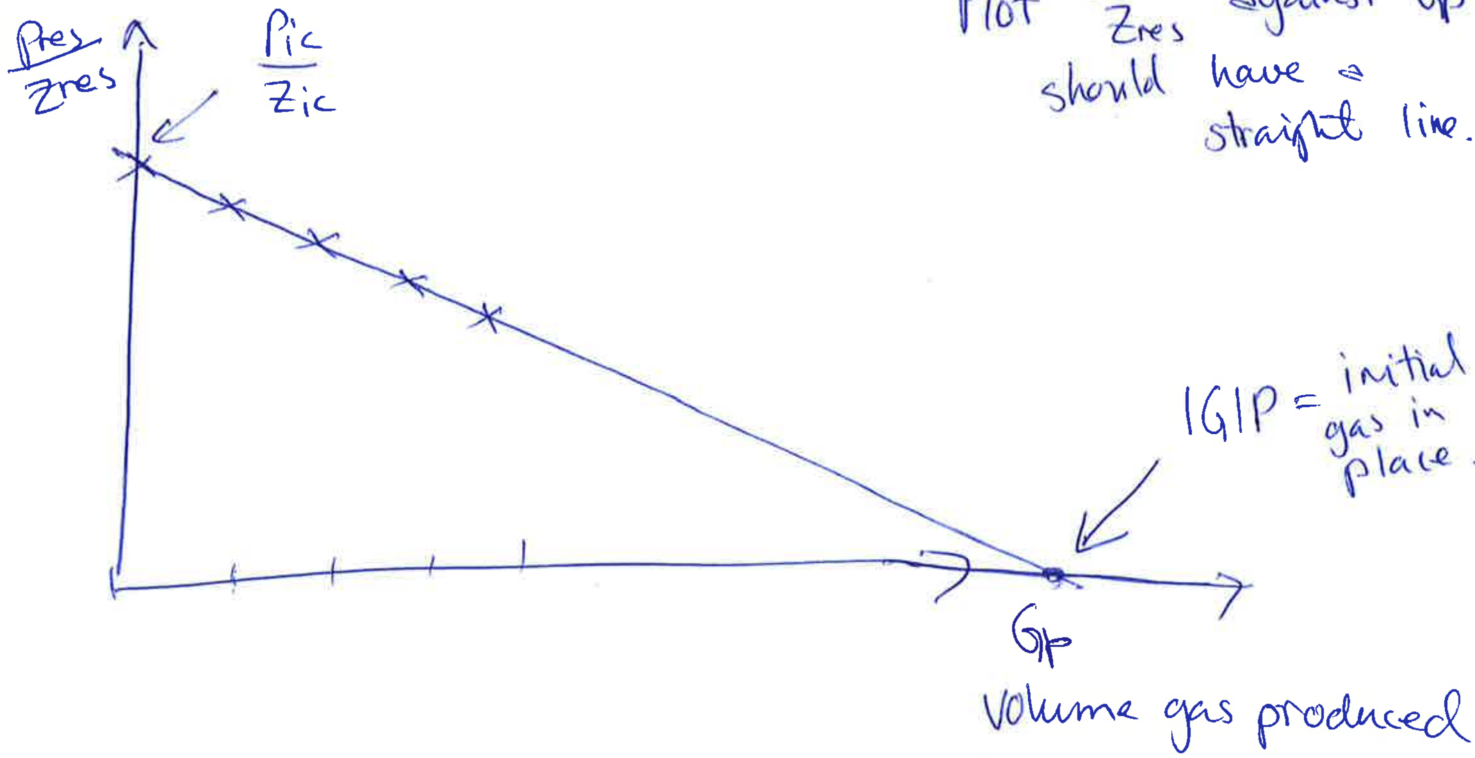
$$\frac{P_{sc}\, G_p}{Z_{sc}\, R\, T_{sc}} = \frac{P_{ic}\, V_{ic}}{Z_{ic}\, R\, T_{ic}} - \frac{P_{res}\, V_{ic}}{Z_{res}\, R\, T_{ic}}$$

$Z_{sc} = 1$

Solve for $\frac{P_{res}}{Z_{res}}$:

$$\frac{P_{res}}{Z_{res}} = \frac{P_{ic}}{Z_{ic}} - \frac{P_{sc}\, T_{ic}}{V_{ic}\, T_{sc}} \cdot G_p$$

Plot $\frac{P_{res}}{Z_{res}}$ against G_p should have a straight line.



Gas formation volume factor, B_g, determines ratio between reservoir volumes and volumes at standard conditions.

Definition: $B_g = \dfrac{V_{res}}{V_{sc}}$

$$PV = ZnRT$$

$$P = \frac{ZnRT}{V}$$

$$V = \frac{ZnRT}{P}$$

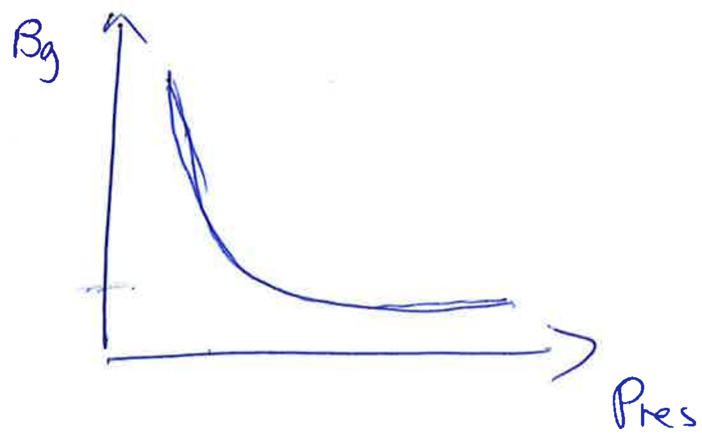
$$B_g = \frac{V_{res}}{V_{sc}} = \frac{\dfrac{Z_{res}\cancel{n}\cancel{R}T_{res}}{P_{res}}}{\dfrac{Z_{sc}\cancel{n}\cancel{R}T_{sc}}{P_{sc}}}$$

$$= \frac{Z_{res}T_{res}P_{sc}}{P_{res}\underbrace{Z_{sc}}_{\approx 1}T_{sc}} = \frac{Z_{res}P_{sc}T_{res}}{P_{res}\cdot T_{sc}}$$

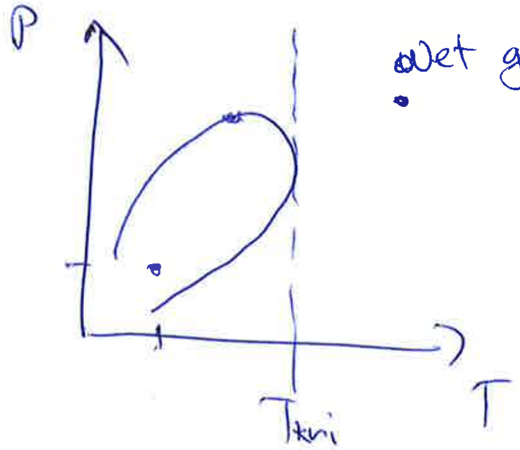
Field units: $T_{sc} = 60°F = 520°R$

$P_{sc} = 14.7$ psia

$$\boxed{B_g = 0.028728\,\frac{Z_{res}T_{res}}{P_{res}} \quad ft^3/SCF}$$



WET GAS MATERIAL BALANCE



during production produced reservoir fluid is moving into the two phase and both gas and oil is produced.

Material balance calculations are performed as for dry gas AFTER produced ~~STO~~ STO stock tank oil and water have been converted into gas equivalents.

Base: 1 bbl STO, how many SCF gas equivalents does this corresponds to? GE - gas equivalent

$z_{sc} = 1$

1 bbl:
$$GE_{STO} = V_{sc} = \frac{nRT_{sc}}{P_{sc}} = n \cdot \frac{10.732 \cdot (60+460)}{14.7}$$

must find number of lb mol in 1 bbl STO

If: γ_{STO} and M_{STO} are available $\rightarrow$ we can find n_{STO}

$$\gamma_{STO} = \frac{\rho_o}{\rho_w} \Rightarrow \rho_o = \gamma_{STO} \cdot \rho_w$$

$$\rho_o = \frac{m_o}{V_o} \Rightarrow m_o = \rho_o \cdot V_o$$

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$$n_{STO} = \frac{m_{STO}}{M_{STO}} = \frac{\rho_{STO} \cdot V_{STO}}{M_{STO}} = \frac{\gamma_{STO} \cdot \rho_w \cdot V_{STO}}{M_{STO}}$$

$$n_{STO} = \frac{\gamma_{STO} \cdot 1\, g/cm^3 \cdot 62{,}43\, \frac{lb/ft^3}{g/cm^3} \cdot 1\, bbl \cdot 5{,}615\, ft^3/bbl}{M_{STO}}$$

$$n_{STO} = 350{,}54 \cdot \frac{\gamma_{STO}}{M_{STO}} \qquad (lb\text{-}mol)$$