Note Title 2/10/2017

* OIL Compositional Analysis - GC

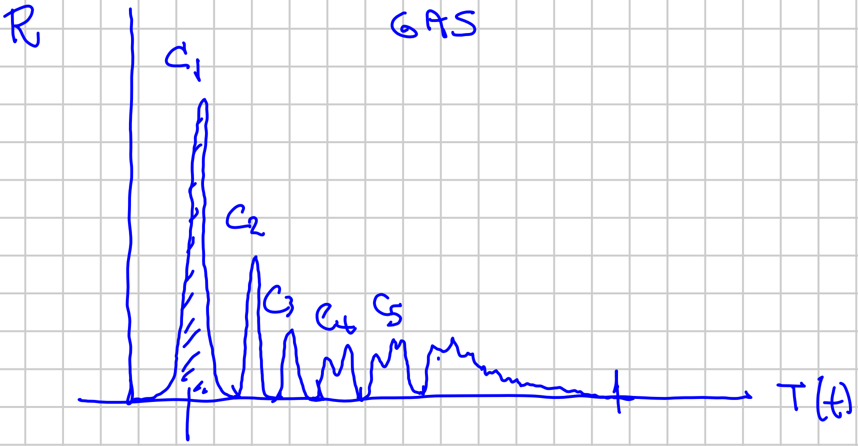
- Finish up previous lecture

* SATURATION PRESSURE calculation

- Problem 3

* SAMPLING

- Not in SPEPBM (book)



$A_i \propto m_i$

$$w_i = \frac{A_i}{\{\sum A_j\}_{seen}} \checkmark$$

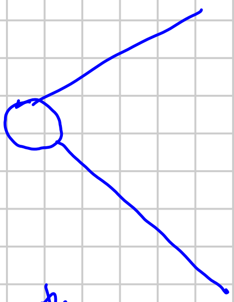
M_i known ✓

$$\Rightarrow y_i = \frac{w_i / M_i}{\sum w_j / M_j} \checkmark$$

Reservoir Sample (RG|RO)

@ p_R

FLASHED OIL



Separator Oil Sample

@ p_{sp}

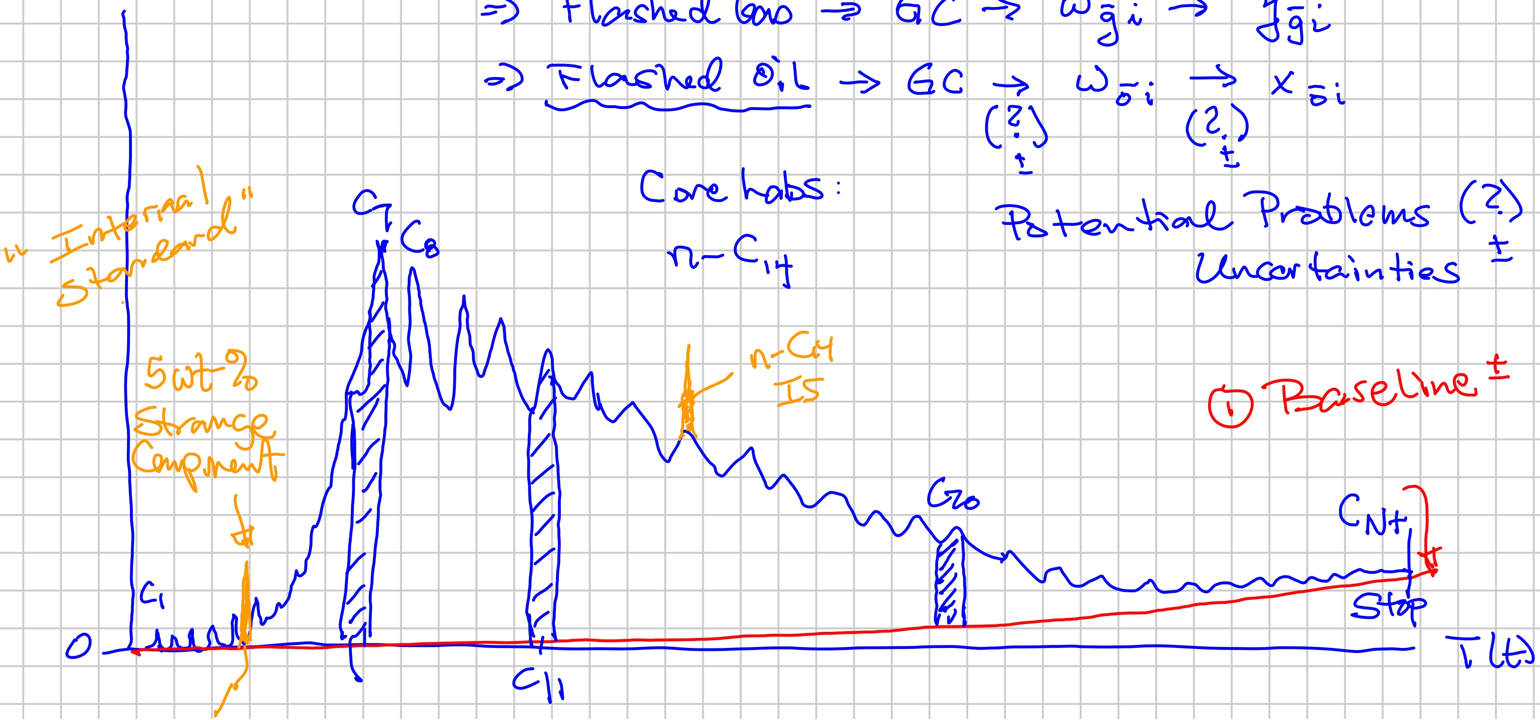
SAMPLE → "Flash" bring the sample to 2-phases @p_{sc} & $T_{ambient}$

$\Rightarrow$ Flashed Gas → GC $\overset{\checkmark}{\rightarrow}$ $w_{\bar{g}i}$ → $y_{\bar{g}i}$

$\Rightarrow$ Flashed Oil → GC $\underset{(?)\,\pm}{\rightarrow}$ $w_{\bar{o}i}$ $\underset{(?)\,\pm}{\rightarrow}$ $x_{\bar{o}i}$

Core Labs:
n-C_{14}

Potential Problems (?)
Uncertainties ±



A_{IS} ✓

$w_{IS} = 0.05$

$\Downarrow$

$C = \frac{A_{IS}}{w_{IS}}$

$$A_7 \propto m_7$$

$$\uparrow$$

$$A_i = C\, m_i$$

C_7 : all compounds boiling between $(T_{b,n-C_6}^{+}) - (T_{b,n-C_7})$

$\uparrow$

Benzene

C_{N+}	1990s	C_{11+}
	2000s	$C_{15+} - C_{21+}$
	2010s	$C_{25+} - C_{30+}$
	Now	$C_{31+} - C_{36+}$

A_{N+} NOT measured

$\Rightarrow$ Estimate

Know A_i ... C_{N-1}

$$w_{\bar{o}i} = \frac{A_i}{A_t} = \frac{A_i}{\sum\limits_{C_{N-1}} A_i + \underset{?}{A_{N+}}}$$

$$\sum w_{oi} = 1 \quad \left\{ \begin{array}{l} w_{\bar{o}i} = \dfrac{m_i}{m_t} = \dfrac{A_i/C}{\sum\limits_{i \to C_{N-1}} A_i/C + \dfrac{A_{N+}}{C}} \\[2em] \boxed{w_{\bar{o}N+}} = 1 - \underbrace{\sum_{i=}^{C_{N-1}} w_i}_{GC} \end{array} \right.$$

By differencing

3rd Callenge

$w_{\bar{o}i}$ ✓ (±)

Need mole fractions for engineering calculations

$$w_{\bar{o}i} \rightarrow x_{\bar{o}i}$$

$$\pm \; x_{\bar{o}i} = \frac{\overset{\checkmark}{w_{\bar{o}i}}}{\sum_{i=1}^{CN+} \overset{\checkmark}{w_{\bar{o}i}} / \underset{\pm}{M_i}}$$

Need ALL M_i

Typically labs use 1978 Katz-Firoozabadi Table 5.2 M_i SCN

$i \geq C_7$ ± M_i differ from field to field

± M_{N+} differ WILDLY from field to field

Flashed Gas $y_{\bar{g}i}$ ✓✓

Flashed Oil $x_{\bar{o}i}$ (?) ±

$\Big\}$ RECOMBINE. $\left(\frac{V_{\bar{g}}^{\pm}}{V_{\bar{o}}}\right)$ ± 5%

$$n_i = n_{\bar{g}i} + n_{\bar{o}i}$$

$GOR_{recombination}$

GOR_r

$\overset{}{m_{\bar{o}}}$ ✓ $\rho_{\bar{o}}$ ✓ $\Rightarrow \overset{\checkmark}{V_{\bar{o}}} = \frac{m_{\bar{o}}}{\rho_{\bar{o}}}$

$M_{\bar{o}}$

±5-10%

z_i (RG/RO)

$$= \boxed{f_g \, y_{\bar{g}i} + (1-f_g)\, x_{\bar{o}i}} \leftarrow$$

$\Rightarrow V_{\bar{g}} = GOR_r \cdot V_{\bar{o}}$

$V_{\bar{o}}$ = Basis: 1 m^3 $\bar{o}$

x_{ospi}

(Separator Oil)

$$f_g = \frac{n_{\bar{g}}}{n_{\bar{g}} + n_{\bar{o}}} = \frac{V_{\bar{g}} / (RT_{sc}/p_{sc})}{V_{\bar{g}} / (RT_{sc}/p_{sc}) + V_{\bar{o}}\left(\frac{\rho_{\bar{o}}}{M_{\bar{o}}}\right)}$$

$$= \frac{GOR_r \cdot (1) / (RT_{sc}/p_{sc})}{GOR_r (1) / (RT_{sc}/p_{sc}) + (1)\left(\frac{\rho_{\bar{o}}}{M_{\bar{o}}}\right)}$$

23.68

$$f_g = \left\{ 1 + \underbrace{\left(\frac{RT_{sc}}{p_{sc}}\right)\left(\frac{\overset{\checkmark}{\rho_{\bar{o}}}}{M_{\bar{o}}}\right)}_{\text{constant for your field sample}} \cdot \frac{1}{GOR_r} \right\}^{-1}$$

GOR_r $[Sm^3/Sm^3]$

$\rho_{\bar{o}}$ $[kg/m^3]$

$M_{\bar{o}}$ $[kg/kg\text{-}mole]$

$\frac{RT_{sc}}{p_{sc}}$ $\left[\frac{Sm^3}{kg\text{-}mole}\right]$ = 23.68

Separator oil : $GOR_r \sim 5 - 100$ Sm^3/Sm^3
(1st-stage separator)

p_{sp} low ↑ p_{sp} high ↑

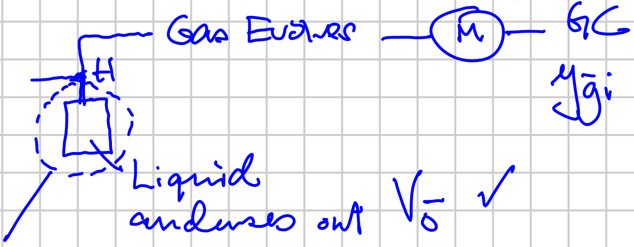
RO : $GOR_r \sim (5)\ 50 - 600$ Sm^3/Sm^3

RG : GOR_r $\underbrace{600 - 10{,}000^+}_{V_{\bar o} \to \text{small}}$ Sm^3/Sm^3

} Sample @ 1 phase @ (p_{sp} | p_R) ~10 cc

- Cryogenic Flash
  - Freeze the RG sample
  - Controlled injection of sample (L) into the "flash" equipment slow flash @ increasing T and 1 atm

$V_{\bar g}$ ✓



$V_{\bar o}$ ✓

Contain ALL of the collected flashed oil (no drops lost) } GC $x_{\bar o i}$

Surface

② Sep. Samples

Flash-GC-Recombine
(2)

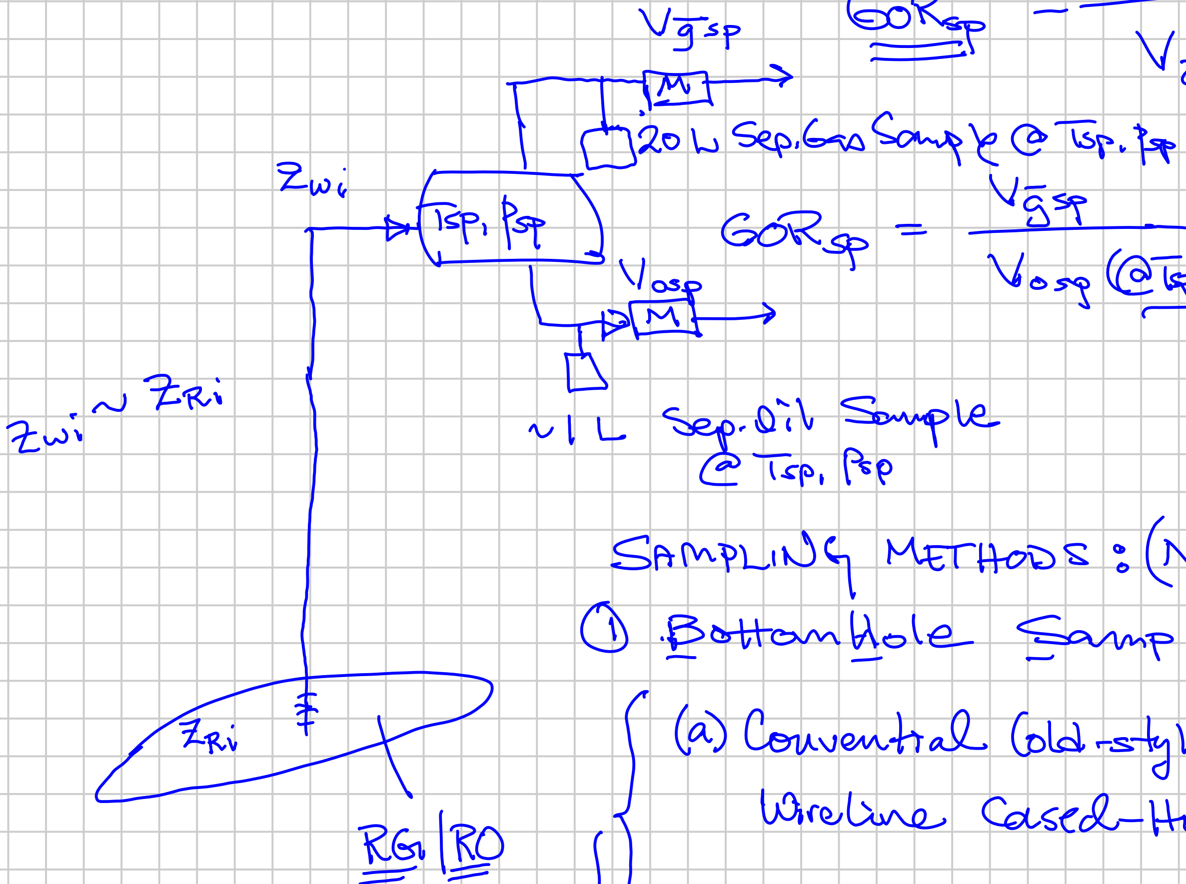
$$\boxed{z_{wi}} = f_{gsp} \underbrace{y_{spi}}_{GC} + (1-f_{gsp})\, x_{spi}$$

@ T_{sp}, p_{sp}

$$f_{gsp} = \left\{ 1 + \left(\frac{RT_{sc}}{p_{sc}}\right)\left(\frac{\rho_{osp}}{M_{osp}}\right)\underbrace{\frac{1}{GOR_{sp}}}_{sm^3/sep\text{-}m^3} \right\}^{-1}$$

sep. gas

$$\underline{\underline{GOR_{sp}}} = \frac{V_{\bar{g}sp}}{V_{\bar{o}sp}\,(@\,T_{sp}, p_{sp})}$$



$$GOR_{sp} = \frac{V_{\bar{g}sp}}{V_{osp}\,(@\,\underline{T_{sp}, p_{sp}})} \quad \frac{Sm^3}{sep\text{-}m^3}$$

SAMPLING METHODS: (Not in the book)

① Bottom Hole Samples

(a) Conventional (old-style), "BHS"
Wireline Cased-Hole samples

(b) Openhole Formation Tester
(e.g. MDT, RCI, ...)

late 1970s "RFT" (1)
MDT (2)
(3)

$\boxed{z_{Ri}}$:
Flash-GC-Recomb.
(2)

Saturation Pressure Calculation

Know : $\boxed{z_i}$ $K_i\,(p,T)$

z_i ← Samples | Lab GC

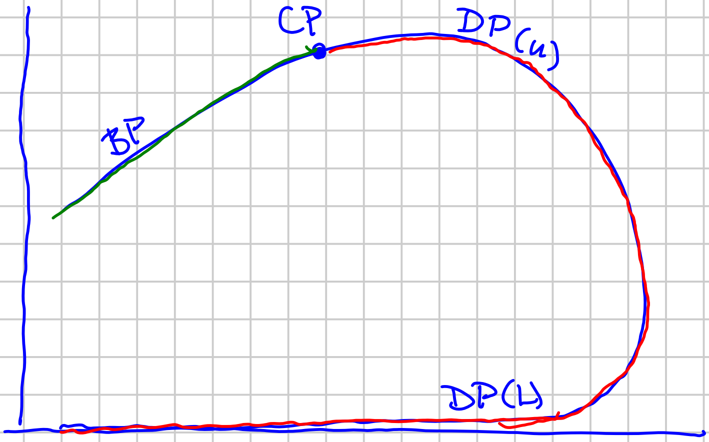
K_i ←
- Equation of State (EOS) Ch. 4
- Approx. from convergence pressure method

Modified Wilson Eq.

$$K_i = f\left(T_{ci}, p_{ci}, \omega_i \mid p_K \mid p, T\right)$$

p_K ← Find for a given z_i @ T

z_i = constant



Line $p_s(T)$

p_s : Two Phases

✓ – z_i we know

"u_{Ii}"

✓ – Incipient phase that appears forms from z_i in an ϵ amount

$z_i = x_i$ (oil) • BP : $y_i = u_{Ii}$ (gas phase)

$z_i = y_i$ (gas) • DP : $x_i = u_{Ii}$ (oil phase)

$$n_i = n_{gi} + n_{oi}$$

BP $\quad n_i = [\,y_i\,\epsilon + x_i(1-\epsilon)\,]\,n$

DP $\quad n_i = [\,y_i(1-\epsilon) + x_i\,\epsilon\,]\,n$

$z_i \equiv n_i / n$

Constraint (Requirement)

$x_i = z_i$

$\boxed{K_i = \frac{y_i}{z_i}}$

BP $\quad z_i = y_i \epsilon + x_i (1-\epsilon) \Rightarrow \boxed{\sum y_i = 1}$

$y_i = z_i$

$\boxed{K_i = \frac{z_i}{x_i}}$

DP $\quad z_i = y_i (1-\epsilon) + x_i \epsilon \Rightarrow \boxed{\sum x_i = 1}$

$$K_i \equiv \frac{y_i}{x_i}$$

$$\text{BP:} \quad \sum y_i = 1 = \sum z_i K_i (\underset{\checkmark}{p}, \underset{\checkmark}{T}, \underset{?}{p_K})$$

$$\text{DP:} \quad \sum x_i = 1 = \sum z_i / K_i (p, T, \underset{?}{p_K})$$

What is $p_K(T)$ for our z_i ?

Must know: P

$p_K(T)$