Exam questions

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Contents

1 Exam questions

1.1 Define what is a petroleum system, the essential processes required for a working petroleum system, and the elements of a petroleum system

The petroleum system is a concept that integrates the relations in time and space of the individual elements and processes of petroleum geology that are essential if a hydrocarbon accumulation is to exist

- Processes: HC generation, Accumulation, Migration and Preservation
- Elements: Source rock, Migration path, Reservoir rock, Trap, Seal rock

1.2 Characterize petroleum migration from active source rock to reservoir, including four types of migration

Petroleum migrates from low permeability source rock into high permeability reservoir rocks. The main driving force for migration is buoyancy, because HC's are less dense than water. The forces acting against migration are the capillary forces, and the resistance to flow through low permeability rocks. Because of this, migration will almost always occur in the upward direction. The different migration types:

1. **Primary migration:** Involves the expulsion of petroleum out of the source rock and into an adjacent carrier bed
2. **Secondary migration:** It is the movement of HC's alongside a carrier bed from the source area to the trap
3. **Tertiary migration:** Occurs when petroleum moves from one trap to another, or through a seep to the surface
4. **Re-migration:** Migration from one reservoir position through an intervening section (Fault) into another reservoir point in the same reservoir, or to a different reservoir.

1.3 What are resources, and what are reserves

Resources: It is the total amount of hydrocarbons existing in a particular accumulation

Reserves: The amount of resources that can be technically and economically viable to extract at the time when the analysis was carried out.

1.4 What is a depositional system, and what is the principle of Walter's law in depositional modelling

It is a 3-dimensional array of sediments or lithofacies that fills a basin. Depositional systems vary according to the types of sediments available for deposition, as well as the depositional processes and environments in which they were deposited.

Walter's law: Sedimentary environments that started out side-by-side, will end up with one overlapping the other over time due to transgression and regression (Rise and drop in sea level). The result is a vertical sequence of sedimentary beds. Walter's law is only applicable to sections without unconformities.

1.5 Explain the volumetric formula for oil field reserves calculation (surface conditions), and how to get the parameters involved

Recoverable oil reserves = STOOIP · RF

$$STOOIP = \frac{Area \cdot h \cdot NTG \cdot \phi \cdot (1 - S_w)}{B_o}$$

First, the total amount of hydrocarbons has to be determined by a volumetric estimation, involving bulk rock volume ($Area \cdot h$). The next step is to multiply with the Net-to-Gross ratio (NTG), which represents the volume of the rock that is able to produce hydrocarbons. Then it has to be multiplied by the porosity (ϕ) to define the void space that the fluids can occupy. Then one takes into account of how much of the void spaces that are filled with hydrocarbons ($1 - S_w$). Once that calculation is done, the total volume of the available HC's is devided by the oil formation volume factor to determine the equivalent volumes of oil at surface conditions. This value (STOOIP) is finally multiplied by the recovery factor (RF) to account for the actual amount of HC's that can technically and economically be extracted with the techniques and resources available at the time of the calculation.

- $Area$: NPD maps
- NTG: seismic and logs
- Thickness (h), porosity (ϕ) and water saturation (S_w): Logs and/or core data
- Oil formation volume factor: Analysis of reservoir fluid sample
- Recovery factor: Based on calculations considering reservoir quality and drive mechanism

1.6 Explain how to estimate hydrocarbon reserves (surface conditions) in shale reservoirs. Describe the parameters involved

Recoverable shale oil reserves are calculated as

$$Recoverable = A \cdot Th. \cdot TOC \cdot HI \cdot RF$$

A: area
$Th.$: thickness
TOC: Total Orcanic Carbon (5% weight = 10% volume)
HI: Hydrogen Index
RF: Recovery factor

1.7 What is isostacy, and how is it calculated

Isostacy is the state of gravitational equilibrium between the crust and the mantle, such that the crust *"floats"* at an elevation that depends on its thickness and density.

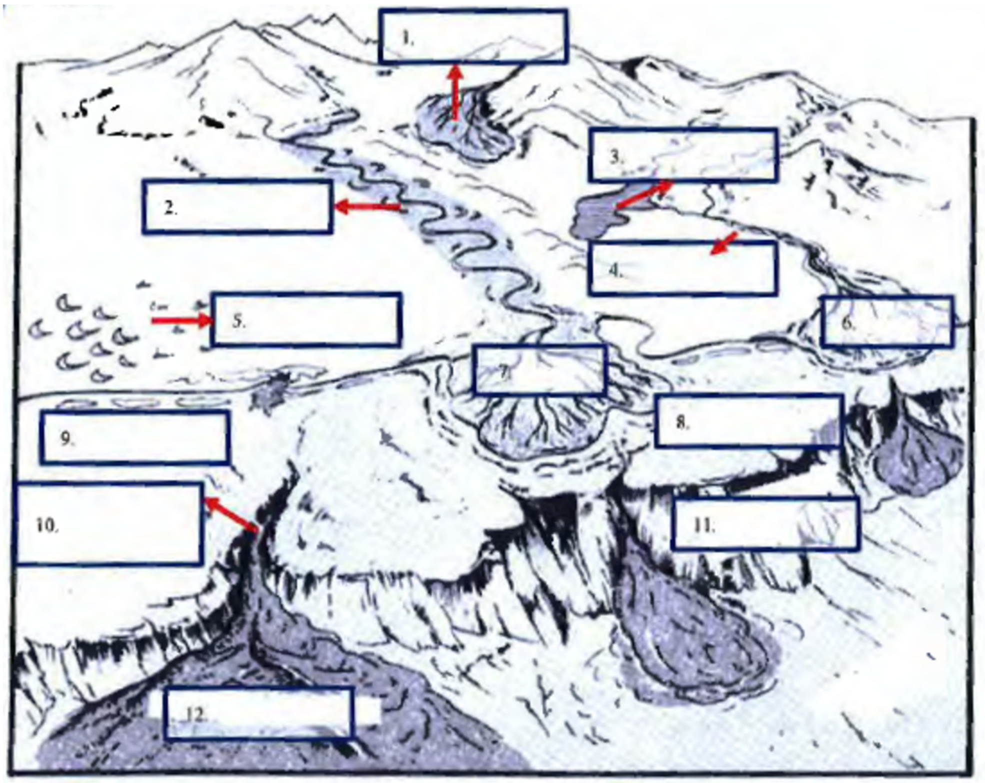
It is calculated assuming that the weight of columns of rock at depth of compensation is equal everywhere.

$$\sum(\rho g h)_1 = \sum(\rho g h)_2$$

1.8 Calculate the isostatic subsidence caused by 2.5 km of loading (1.65 g/cm^3). The density of the underlaying mantle is 3.3 g/cm^3

$$\boxed{\text{H}} = \frac{\rho_s}{\rho_m} \cdot h = \frac{1.65}{3.3} \cdot 2.5 = \boxed{1.25 \text{ km}}$$

1.9 Depositional environment diagram



1. Alluvial fan
2. Meandering river
3. Lake
4. Braided river
5. Desert (Aeolian)
6. Fan delta
7. Delta
8. Continental shelf
9. Barrier islands
10. Submarine canyon
11. Continental slope
12. Submarine fan

1.10 Compare the following for Sandstone vs. Carbonate reservoirs

Aspect	Sandstone	Carbonates
Amount of primary porosity in sediments	Commonly 25 - 40%	Commonly 40 - 70%
Amount of ultimate porosity in sediments	Commonly half or more of initial porosity. 15 - 30%	Commonly none or only small fraction of initial porosity. 5 - 15%
Permeability-Porosity interrelation	Dependent on particle size and sorting. Medium to high porosity. Low/medium permeability.	Independent of particle size and sorting. Low porosity. High permeability.
Influence of Diagenesis	Minor reduction of primary porosity by compaction and sedimentation. Quartz cementation decreases porosity.	Can create, obliterate or completely modify porosity. Dissolution of calcite by acidic water can decrease porosity.
Influence of fracturing	Generally not of major importance in reservoir properties.	Of major importance in reservoir properties if present.
Percentage of reservoirs	80%	20%
Percentage of reserves	50%	50%
Heterogeneity	Fairly homogeneous. Generally good sorting.	Highly heterogeneous due to local deposition. Poor sorting.

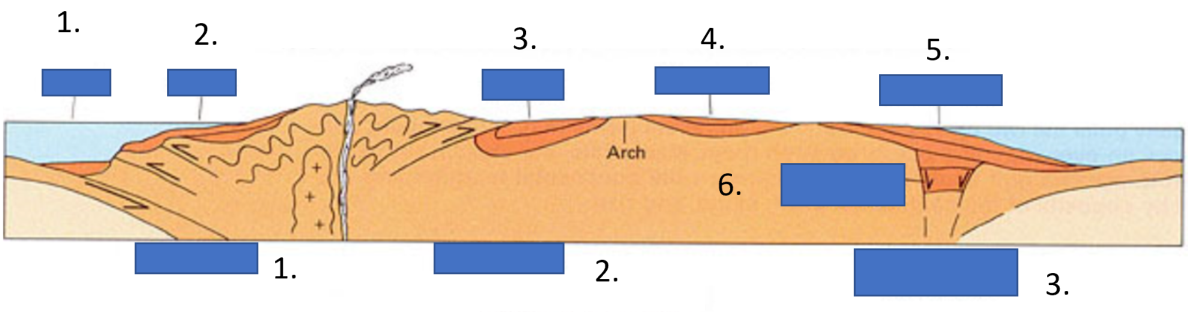
1.11 Define the "Golden Zone" in terms of subsurface temperatures, and what it also is known as

It is also known as the "Accumulation Zone". The temperatures vary between 60-120°C.

1.12 The precipitation rate of quartz cementation in sandstone reservoirs is an exponential function of what subsurface parameter, and linear to what other parameter

The precipitation rate of quatrz cementation is an exponential function of temperature, and linear function of time (geological age).

1.13 On the tectonic illustration below, identify the various 6 basin types, as well as the 3 major causes of subsidence



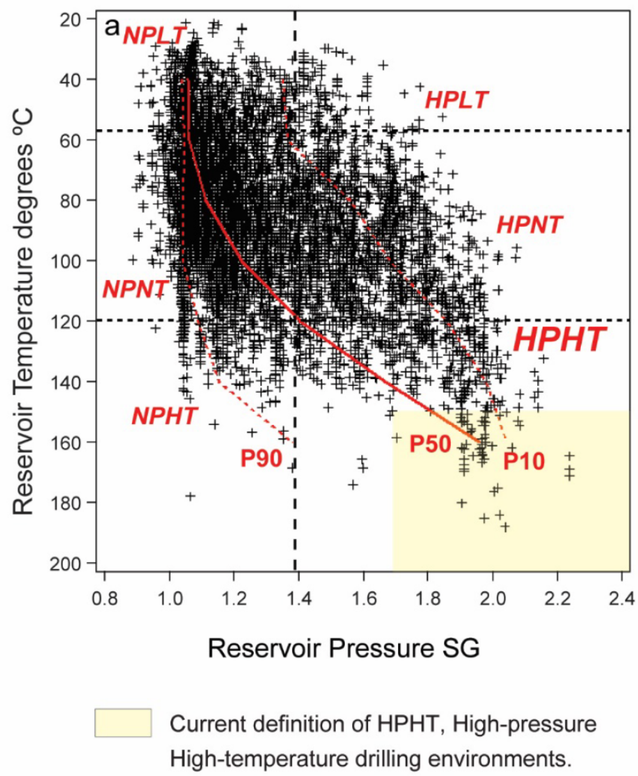
Basin types:

1. Trench
2. Fore-arc basin
3. Foreland basin
4. Intracratonic
5. Passive margin
6. Rift basin

Types of subsidence

1. Subduction
2. Thrust loading
3. Thinning, cooling and loading

1.14 The figure below show the relation of pressure and temperature for GoM reservoirs. Divide the diagram into NPLT, NPNT, NPHT, HPLT, HPNT and HPHT. Name two geological processes which may generate HPHT conditions. What are the petroleum industry pressure and temperature boundaries for HPHT drilling



The industry definition of HPHT drilling wells: P = 1.7 SG, and T = 149°.

Thermally driven chemically cementational porosity loss.
Subsidence of fault-bounded pressure compartments in sedimentary basins.

1.15 What is basin modelling, and what are the two main purposes of this kind of modelling

Basin modelling is a reconstruction of the evolution of a sedimentary basin in order to make quantitative predictions of hydrocarbon accumulations. The two main purposes is to get information about the thermal history and the burial history of the basin.

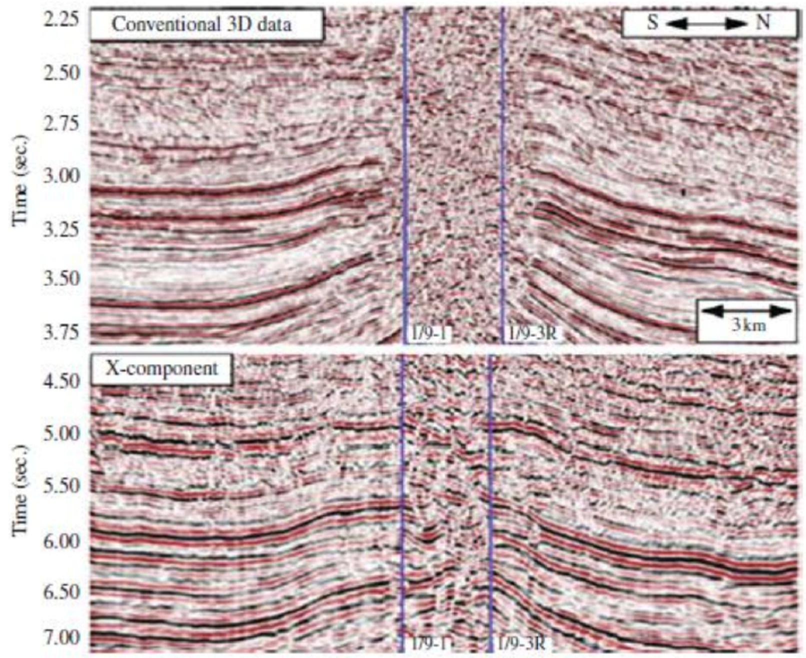
1.16 For depositional systems, according to Walter's law, what generates vertical sequences of sediments

The lateral shifting of depositional environments, due to changes in environment conditions during their deposition generates vertical sequences.

1.17 North Sea chalk reservoir quality is different from typical Limestone and Dolomite reservoirs in what way

North Sea chalks show higher porosity values than regular Limestone reservoirs, and lower permeability. They also show less presence of stylolites.

1.18 The figure below shows two seismic datasets aquired at approximately the same location.



1.18.1 Describe as fully as you can these two sections and the several differences between them:

1.18.1.1 The details of what kind of dataset each one is

The set on the top is a conventional 3D-survey based on the reflection of P-waves (compressional waves). The set on the bottom is a 4-component marine seismic data set which also includes geophones to measure S-waves (shear waves).

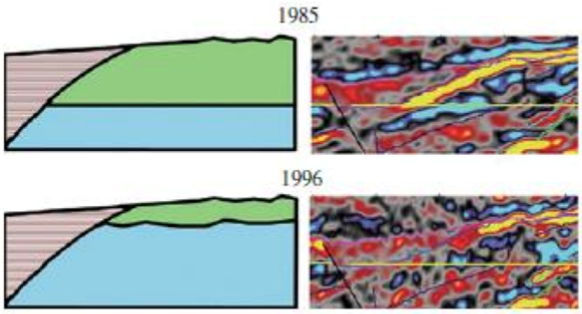
1.18.1.2 What the zone in the middle represents, and why it looks better on one section than on the other

The P-waves travel through both rock matrix and pore fluids, and they are drastically affected by the presence of gas, which leads to scattering of the waves, and hence poor seismic resolution. The S-waves are not affected by the presence of gas as they just travel through the rock matrix. Based on that, the section in the middle is a gas accumulation, and that is why we see a different quality in the datasets.

1.18.1.3 An explanation of the time-scale values on the left

The P-waves are the fastest waves, and therefore the first to arrive and to be recorded by the instruments. The lower section is when the S-waves also has arrived. This is why we see different time scales on the left axis.

1.19 In a similar way, give your own account of what the figure below shows after 11 years of reservoir production history, and what type of seismic data this would be called. Name two changes in reservoir properties that result in the observed seismic response.



This is a 4D seismic dataset. The 4D-seismic method involves acquisition, processing and interpretation of repeated seismic surveys over a producing hydrocarbon field. The objective is to determine the changes occuring in the reservoir as a result of production or injection of the field by comparing the repeated datasets. In general, hydrocarbons have lower density and sonic velocity than water, so we can see a clear contrast between the type of fluids in the rock.

In the section presented, green is oil and blue is water, so we can see the change in the oil-water contact level of a water driven reservoir.

Two properties that change over time on this particular section are the water saturation, and the relative permeabilities.

1.20 Name 4 geological depositional environments for sandstone reservoirs

1. Aeolian dunes
2. Fluvial river channels
3. Coastal/shallow marine
4. Deep marine fans

1.21 Name 4 geological controls on reservoir porosity

1. Compaction
2. Cementation
3. Diagenesis
4. Dissolution

1.22 Name 4 geological controls on reservoir permeability

- Structural deformation (Fracturing)
- Wettability (Relative permeabilities)
- Dissolution
- Clay content

1.23 Which clay mineral is often associated with anomaliously high porosity in deeply buried sandstone reservoirs, and what geological process does it slow down (inhibits)

Chlorite. It inhibits the quartz cementation process in sandstones by reducing the quartz surface area.

1.24 Define Diagenesis

Diagenesis is any chemical, physical or biological change undergone by a sediment after its initial deposition, exclusive of weathering or metamorphism.

1.25 Why do quartz-rich sandstones often have higher porosities than quartz-poor sandstones

Anomalously high porosity zones are associated to a high quartz content in the form of micro-quartz coatings from bio-silica. The high silica saturation shuts down the normal quartz dissolution process and thereby inhibits quartz cementation, hence preserving the porosity.

1.26 Fluvial channel sandstone reservoirs are classified into 3 main types (Turquist). What are they, and which type generally has the best lateral sand connectivity

Braided river, Meandering river and Anastomosing river. The braided river type generally gives the best lateral sand connectivity.

1.27 According to Reading and Richards, submarine fans can be devided into 3 systems. What are they, and which is more likely to characterize North Sea reservoirs with 80% NTG sand

Sand-rich, Mixed, and Mud-rich fans. The sand-rich fans normally give high NTG values, so North Sea reservoirs fall into this category.

1.28 What geological control influences the grain-size and sorting of reservoir sands

Energy of the depositional environment and the transport process.

1.29 What is a Fault, and what are the hanging wall and the foot wall

A fault is a planar fracture or discontinuity in a volume of rock, in which there has been significant displacement as a result of rock mass movement. The hanging wall is the section above the fault plane, while the foot wall is the section below the fault plane.

1.30 What are the 4 major types of petroleum bearing sedimentary basins

1. Foreland basins
2. Continental passive margins
3. Tectonic rift basins
4. Tertiary deltas

1.31 Foreland basins contain what percentage of global conventional recoverable oil reserves, and give two reasons to why they are so prolific

Contain 75% of reserves, because of multiple source rocks, and focused migration paths to the basin.

1.32 What is the process to identify an economically and technically viable project in exploration

1. Basin analysis
2. Play evaluation: A play is an area with similar geological controls on reservoir, trap and source
3. Prospect level evaluation: A prospect is a possible petroleum trap with a mappable and limited reservoir rock volume, and enough data to calculate this volume
4. Development

Sedimentary basin ⇒ Petroleum system ⇒ Play ⇒ Prospect ⇒ Development

1.33 What are the goals of reservoir description

1. Characterize the reservoir boundaries and internal properties of the reservoir in order to estimate OOIP
2. Generate a static reservoir model to be used in reservoir simulation to plan the development strategy and amount of recoverable reserves
3. Systematically identify the remaining hydrocarbons in the producing reservoirs

1.34 What is the amount of oil formed before the Pangean breakup

90% of oil reserves are Jurassic and younger.

1.35 Why do we normally find heavy oil reservoirs in shallow reservoirs

Because heavy oil is biodegraded. The risk of biodegredation decreases at temperature $> 60°C$.

1.36 List the estimated porosity values at the time of deposition, due to mechanical compaction, and due to chemical cementation

Deposition: $\sim 40\% \Rightarrow$ Mechanical compaction: $\sim 25\% \Rightarrow$
Chemical cementation: $< 20\%$

1.37 List the 3 zones and temperatures of the Golden Zone concept

- Compaction zone: $< 60°C$
- Accumulation zone: $< 60 - 120°C$
- Expulsion zone: $> 120°C$

1.38 What is the effect of uplift on the Golden Zone concept

The layers uplifted from the accumulation zone reduces the reservoir pressure, allowing the gas to expand, and hence, spilling of the oil from the trap.

1.39 List the types of kerogen and which type of hydrocarbons they can generate

1. Sapropelic (Laccustrine algal): oil
2. Planktonic (Marine algal): oil and gas
3. Humic (Land plants): gas

1.40 List the main geological controls for porosity and permeability in sandstone reservoirs

Sorting controls the porosity, while grain size controls the permeability.

1.41 Can oil stop quartz cementation

No, but it can slow it down, but only if $S_o > 85\%$. It is a very minor effect.

1.42 What is the importance of evaporite seals

They are present in about 20% of the world reservoirs, and in about 65% of the global reserves.

1.43 With respect to uplift, what is the risk zone for leakages compared to the distance of uplift

- 500 m: low risk of leakage
- 500 m - 1 km: medium risk for leakage
- $>$ 1 km: high risk for leakage ($>$ 50%)
- $>$ 2 km: very high risk for leakage ($>$ 80%)

2 Equations to remember

2.1 Freezing point depression

$$\Delta T = k_f \frac{\frac{m_o}{M_o}}{\frac{m_b}{1000}} = k_f \frac{m_o \cdot 1000}{m_b \cdot M_o} \Rightarrow$$

$$\boxed{M_o = k_f \frac{m_o \cdot 1000}{\Delta T \cdot m_b}}$$

2.2 Molecular weight of plus fraction based on 100g STO

$$\frac{100}{M_{STO}} = \sum_{i=1}^{n-1} \frac{(wt\%)_i}{M_i} + \frac{(wt\%)_{n+}}{M_{n+}} \Rightarrow$$

$$\frac{(wt\%)_{n+}}{M_{n+}} = \frac{100}{M_{STO}} - \sum_{i=1}^{n-1} \frac{(wt\%)_i}{M_i} \Rightarrow$$

$$M_{n+} = \frac{(wt\%)_{n+}}{\frac{100}{M_{STO}} - \sum_{i=1}^{n-1} \frac{(wt\%)_i}{M_i}} \cdot \left| \frac{M_{STO}}{M_{STO}} \right| \Rightarrow$$

$$\boxed{M_{n+} = \frac{M_{STO} \cdot (wt\%)_{n+}}{100 - M_{STO} \cdot \sum_{i=1}^{n-1} \frac{(wt\%)_i}{M_i}}}$$

2.3 Density of plus fraction

$$\rho_{STO} = \frac{M_{STO}}{\sum_{i=1}^{n-1} \frac{x_i M_i}{\rho_i} + \frac{x_{n+} M_{n+}}{\rho_{n+}}} \Rightarrow$$

$$\frac{M_{STO}}{\rho_{STO}} = \sum_{i=1}^{n-1} \frac{x_i M_i}{\rho_i} + \frac{x_{n+} M_{n+}}{\rho_{n+}} \Rightarrow$$

$$\frac{x_{n+} M_{n+}}{\rho_{n+}} = \frac{M_{STO}}{\rho_{STO}} - \sum_{i=1}^{n-1} \frac{x_i M_i}{\rho_i} \Rightarrow$$

$$\rho_{n+} = \frac{x_{n+} M_{n+}}{\frac{M_{STO}}{\rho_{STO}} - \sum_{i=1}^{n-1} \frac{x_i M_i}{\rho_i}} \cdot \left| \frac{\rho_{STO}}{\rho_{STO}} \right| \Rightarrow$$

$$\boxed{\rho_{n+} = \frac{\rho_{STO} x_{n+} M_{n+}}{M_{STO} - \rho_{STO} \sum_{i=1}^{n-1} \frac{x_i M_i}{\rho_i}}}$$

2.4 Recombination of fluid

Based on $V_{STO} = 1.0\ Sm^3$

$$n_g = \frac{GOR}{V_m},\ \ n_{STO} = \frac{\rho_{STO} V_{STO}}{M_{STO}} = \frac{\rho_{STO}}{M_{STO}}$$

$$GOR_{corr} = GOR_{rig} \cdot \sqrt{\frac{(\gamma_g Z_g)_{rig}}{(\gamma_g Z_g)_{lab}}}$$

$$z_i' = n_g y_i + n_{STO} x_i = \frac{GOR}{V_m} y_i + \frac{\rho_{STO}}{M_{STO}} x_i \Rightarrow$$

$$z_i'' = z_i' + \frac{GOR}{V_m} y_i' \Rightarrow$$

$$z_i = \frac{z_i''}{\sum z_i''}$$

2.5 Y-function for CME process

$$Y = \frac{P_b - P}{P\left(\frac{V_t}{V_b} - 1\right)}$$

2.6 Hydrocarbon Pore volume ($HCPV$) and formulas for finding the Z-factor

$$HCPV = V_b \cdot \phi \cdot (1 - S_w)$$

$$pP_c = \sum y_i P_{ci},\ \ pT_c = \sum y_i T_{ci}$$

$$pP_R = \frac{P}{pP_c},\ \ pT_R = \frac{T}{pT_c}$$

$$Z - factor = f(pP_R, pT_R)$$

To use the chart, the units **must** be in oil field units! (P, T) = (psia, R).

2.7 CVD-analysis

$$C_1 \to iC_4 = \boxed{\text{V}}$$

$$C_5 - C_{10+} = \boxed{\text{L}}$$

$$IGIP = \frac{P_i \cdot HCPV}{Z_i R T_{res}} \cdot V \cdot V_m$$

$$IOIP = \frac{P_i \cdot HCPV}{Z_i R T_{res}} \cdot \frac{M_{STO}}{\rho_{STO}} \cdot L$$

2.7.1 For $P < P_d$

$$(\Delta G_p)_j = \frac{HCPV \cdot P_j}{(Z_g)_j RT_{res}} \cdot \frac{(\Delta V_g)_j}{V_{cell}} \cdot V_m$$

$$n_g = \frac{(\Delta G_p)_j}{V_m}$$

2.8 Flash equations

$$L + V = 1$$

$$z_i = x_i L + y_i V$$

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

$$\sum x_i = \sum y_i = \sum z_i = 1$$

Easy to derive the flash equations: (1) and (2) from the formulas above, but inserting them here anyway:

$$\sum x_i = \frac{z_i}{L + K_i V} = 1 \tag{1}$$

$$\sum y_i = \frac{z_i}{\frac{L}{K_i} + V} \tag{2}$$

2.8.1 P_b

V = 0, L = 1 ⇒

$$\sum y_i = \sum z_i K_i = 1$$

$$\sum y_i = \sum z_i K_i > 1 : \text{Two-phase region}$$

$$\sum y_i = \sum z_i K_i < 1 : \text{Liquid phase}$$

2.8.2 P_d

V = 1, L = 0 ⇒

$$\sum x_i = \sum \frac{z_i}{K_i} = 1$$

$$\sum x_i = \sum \frac{z_i}{K_i} > 1 : \text{Two-phase region}$$

$$\sum x_i = \sum \frac{z_i}{K_i} < 1 : \text{Gas phase}$$

2.9 Separator equations

Based on 1 mole of separator fluid: $z_i = 1$ mole.

$$V_g = n_g V_m, \;\; V_{STO} = \frac{n_{STO} M_{STO}}{\rho_{STO}}$$

$$n_{STO} = n_k = L_1 L_2 \cdots L_k = \Pi_{i=1}^{k} L_i, \;\; n_g = 1 - n_{STO}$$

$$(GOR)_{tot} = \frac{(V_g)_{sc}}{V_{STO}} = \frac{n_g V_m \rho_{STO}}{n_{STO} M_{STO}}$$

2.9.1 For separator step j

$$(GOR)_j = \frac{(n_g)_j V_m \rho_{STO}}{n_{STO} M_{STO}} \Rightarrow$$

$$(GOR)_j = \frac{(L_1 L_2 \cdots L_{j-1}) V_j V_m \rho_{STO}}{(L_1 L_2 \cdots L_{j-1})(L_j L_{j+1} L_{j+2} \cdots L_k) M_{STO}} \Rightarrow$$

$$(GOR)_j = \frac{(L_1 L_2 \cdots L_{j-1}) V_j V_m \rho_{STO}}{(L_1 L_2 \cdots L_{j-1})(L_j L_{j+1} L_{j+2} \cdots L_k) M_{STO}} \Rightarrow$$

$$\boxed{(GOR)_j = \frac{V_j V_m \rho_{STO}}{(L_j L_{j+1} L_{j+2} \cdots L_k) M_{STO}}}$$

2.10 Undersaturated ***oil reservoar***

$$B_o = \frac{(M_o)_{res} \rho_{STO}}{(\rho_o)_{res} n_{STO} M_{STO}}$$

2.11 ***Wet gas*** or undersaturated ***gas condensate***

$$B_o = \frac{(V_o)_{res}}{V_{STO}} = \frac{\frac{ZRT_{res}}{P_{res}}}{\frac{n_{STO} M_{STO}}{\rho_{STO}}} = \frac{ZRT_{res} \rho_{STO}}{P_{res} n_{STO} M_{STO}}$$

$$B_g = \frac{(V_g)_{res}}{(V_g)_{sc}} = \frac{\frac{ZRT_{res}}{P_{res}}}{n_g V_m} = \frac{ZRT_{res}}{P_{res} n_g V_m} = \frac{ZRT_{res}}{P_{res}(1 - n_{STO}) V_m}$$

2.12 Other important formulas

$$GE_{STO} = V_m \cdot \frac{\rho_{STO} V_{STO}}{M_{STO}}$$

$$\rho_o = \rho_{Po} + (\Delta\rho)_P - (\Delta\rho)_T$$

$$\rho_{Po} = \frac{m_g + m_{STO}}{(V_g)_{app} + V_{STO}}$$

$$V_{STO} = 1.0Sm^3 \Rightarrow m_{STO} = \rho_{STO} \cdot 1$$

$$m_g = n_g M_g = \frac{GOR}{V_m} \cdot (\gamma_g)_{avr.} \cdot M_{air}$$

$$(V_g)_{app} = \frac{m_g}{(\rho_g)app)}$$

$(\rho_g)_{app}$ is found from chart when we have $^\circ API$ and γ_g determined.

$$IGIP = \frac{HCPV}{(B_g)_i} \Leftrightarrow (B_g)_i = \frac{HCPV}{IGIP}$$

$$IOIP = \frac{HCPV}{(B_o)_i} \Leftrightarrow (B_o)_i = \frac{HCPV}{IOIP}$$

$$GOR = \frac{IGIP}{IOIP}$$