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University of Stavanger

Faculty of Science and Technology

Date: 24th May, 2017.

Exam in: PET 540, Natural Gas Reservoir and Production Engineering.
Duration: 4 hours.
Supporting materials: Use of simple calculator is permitted.
Content: 4 exercises on 4 pages.
Annotation: Answer all questions.
Course Responsible: Yen Adams Sokama-Neuyam.

Exercise 1

1. Explain why dolomite rocks are more prolific oil/gas producers compared to pure limestone.
2. With the aid of a diagram, explain the process of petroleum migration and accumulation.
3. State two (2) evidence that support the hypothesis that petroleum is the product of the decomposition of natural organic matter.

The mole fraction of water, y_w in produced gas is given by Dalton's Law:

$$y_w = \frac{p_w(vapor)}{p(reservoir)}$$

Where $p_w(vapor)$ is the partial pressure of water vapor and $p(reservoir)$ is the reservoir pressure.

4. State the ideal gas law and show that the water molar rate, $q_{m,w}$ can be written as:

$$q_{m,w} = \frac{y_m}{1 - y_m} q_{m,g}$$

Where $q_{m,g}$ is the molar gas rate.

A gas well is producing at a rate of 2 MSm^3/day at standard conditions (15 °C and 1 atm). The reservoir pressure is 400 bar and the reservoir temperature is 100 °C.

5. From Dalton's law, calculate the mole fraction of water vapor in the gas mixture.
6. Calculate the molar gas rate, given that 1 kmol of gas at standard conditions occupy a volume of 23.664 m^3.
7. Calculate the molar water rate in m^3/day, given that the molar mass of water is 18.015 kg/kmol and the density of water is 1000 kg/m^3.

Exercise 3

The pseudo-pressure equation for infinite-acting (IA) and semi-steady state (SSS) periods are written as:

$$(m_i - m_{bh})_{IA} = \frac{q_{sc}(\mu B)_r}{2\pi kh}\frac{1}{2}\left[\ln(t) + \ln\left(\frac{D_h}{r_w^2}\right) + 0.80907 + 2(S + S_{nD})\right]$$

$$(m_i - m_{bh})_{SSS} = \frac{q_{sc}(\mu B)_r}{2\pi kh}\left[\frac{2D_h}{r_e^2} + \ln\left(\frac{r_e}{r_w}\right) - \frac{3}{4} + S + S_{nD}\right]$$

Where $(m_i - m_{bh})$ is the difference between the initial reservoir pseudo-pressure and the bottom-hole pseudo-pressure, q_{sc} is the flow rate at standard conditions, kh is the permeability-thickness product, $(\mu B)_r$ is the viscosity-formation volume factor product evaluated at a reference pressure p_r, t is time, D_h is the hydraulic diffusivity, r_e is the extent of the reservoir, r_w is the wellbore radius, S and S_{nD} are the skin factor associated with formation damage and non-Darcy flow, respectively.

Mathematically, the transition time, t_{ss} is defined as the time when:

$$\frac{d}{dt}\left|(m_i - m_{bh})_{SSS} - (m_i - m_{bh})_{IA}\right| = 0$$

1. Show that the transition time can be expressed as:

$$t_{ss} = \frac{r_e^2}{4D_h}$$

2. What is the practical purpose of t_{ss}?
3. Make a plot of $(m_i - m_{bh})$ as a function of t for the infinite-acting and pseudo-steady state periods and indicate the t_{ss}.

Given the following reservoir and fluid data:

$$k = 200\ mD \qquad \mu = 0.04\ mPa.s \qquad \phi = 0.25$$

$$c = 0.01\ bar^{-1} \qquad r_w = 15\ cm \qquad r_e = 800\ m$$

4. Calculate the transition time t_{ss} given that the hydraulic diffusivity, $D_h = \frac{k}{\phi c \mu}$.
5. Explain why the transition period is delayed in a rectangular shaped reservoir.

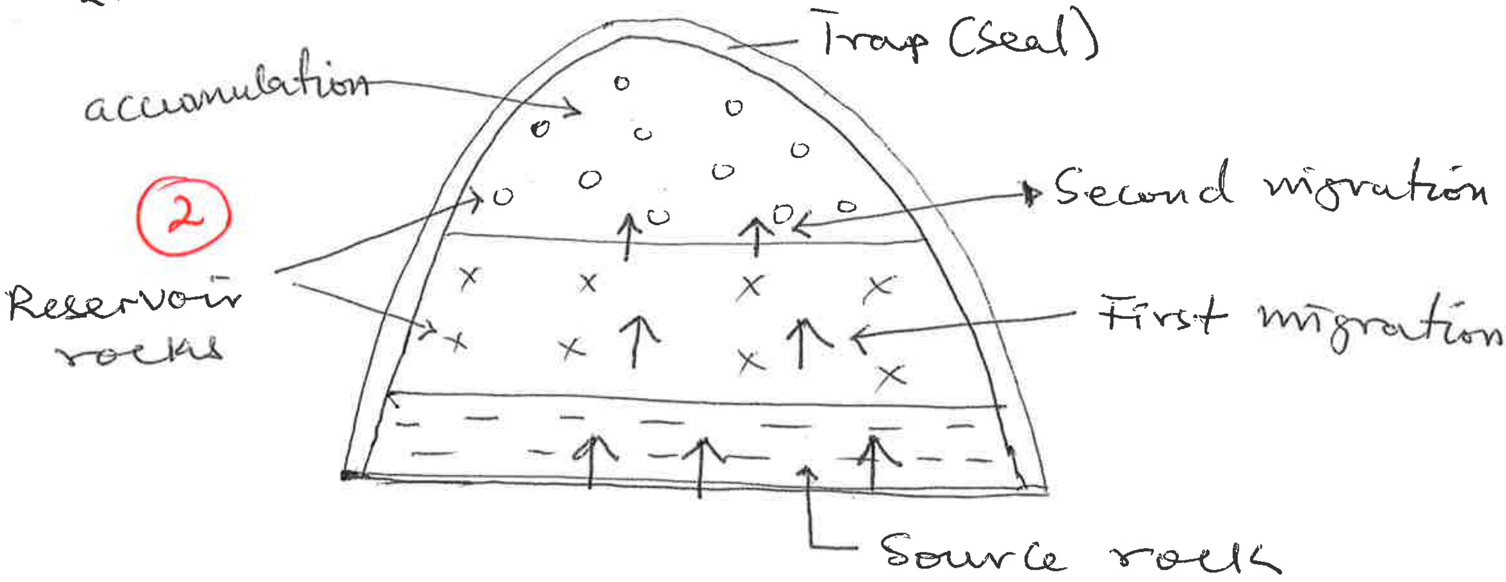
PET540
Proposed Solution to Exam Exercises — May, 2017.

Exercise I.

② 1. Dolomite rocks have higher porosity.

2.

②



- At T > 70 °c, quartz precipitation and mica/illite formation within the pore spaces reduces the pore spaces and increase the pore pressure. ②

- When the pore pressure exceed the overburden pressure in the cap rock, the gas will hydraulically fracture the rock and penetrate upward into layers above.

- The cycle will continue until the gas reaches a depth at which $T < 70°C$ where if a trap exist it may accumulate.

3. ① Oil has the optical properties of hydrocarbons that are known only to derive from organic matter. ①

② Oil contains nitrogen and certain other compounds ~~that~~ are known to originate from living organic matter only. ①

⊛ 4. Ideal gas Law: $pV_m = RT$ ①

Dalton's law: $y_w = \frac{p_w}{p}$

The water molar rate ~~q_m~~ $q_{m,w}$ is the relative molar fraction of water vapor to gas:

Thus, for a total molar flow rate, q_m, we may write from Dalton's law:

② $q_{m,w} = y_w q_m$ and $q_{m,g} = (1-y_w) q_m$

where $y_w + y_g = 1$. ①

Combining the two expressions yields:

⊛ $$q_{m,w} = \frac{y_w}{1 - y_w} q_{m,g}$$ ①

5. Given:

$$P_w(\text{Vapor}) = 1 \text{ atm} = 1.01325 \text{ bar}$$

$$P(\text{reservoir}) = 400 \text{ bar}$$

$$y_w = \frac{1.01325}{400} \simeq \underline{\underline{1/400}}$$ ②

6. The molar volume of the gas

$$V_m = 23.664 \text{ m}^3/\text{Kmol}$$
$$= 23664 \text{ cm}^3/\text{g mol}$$

The molar gas rate:

① $$q_{m,g} = \frac{q}{V_m}$$, $q \rightarrow$ well rate

$$q = 2 \text{ MSm}^3/\text{day}$$

② $$q_{m,g} = (2 \text{ MSm}^3/\text{day})/(23.664 \text{ m}^3/\text{Kmol})$$
$$= \underline{\underline{84516.57}} \text{ Kmol/day}$$

7. The molar water rate:

$$q_{m,w} = \frac{y_w}{1-y_w}\, q_{m,g}$$

$$= \left(\frac{1/400}{1-1/400}\right) \cdot 84516.57 \text{ Kmol/da}$$

① $q_{m,w} = 211.821$ Kmol/day

Given that:

$$M_w = 18.015 \text{ Kg/mol}$$

$$\rho_w = 1000 \text{ Kg/m}^3$$

$$q_{m,w}\left(\frac{m^3}{day}\right) = \frac{q_{m,w}\left(\frac{Kmol}{day}\right) \cdot M_w\left(Kg/Kmol\right)}{\rho_w\left(Kg/m^3\right)}$$

$$= \frac{211.821 \cdot 18.015}{1000}$$

② $q_{m,w} = \underline{\underline{3.816}}$ m^3/day

Exercise 2.

1. Given that

$$dG = -S\,dT + V\,dp + \sum_{i=1}^{n} \mu_i\,dn_i$$

① At chemical equilibrium:

$$dG = 0$$

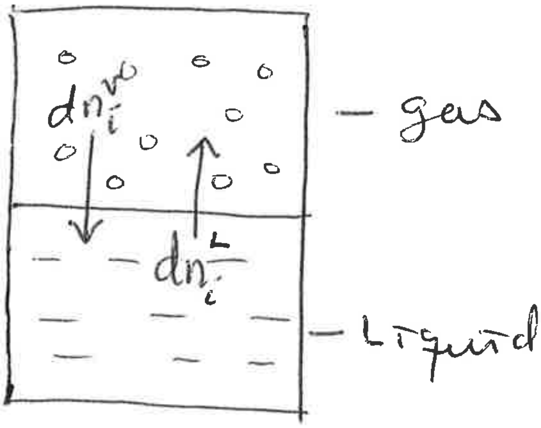
① For constant pressure and temperature

$$dp = 0 \qquad dT = 0$$

$$\Rightarrow \quad \sum_{i=1}^{n} \mu_i\,dn_i = 0$$

In a closed system containing n^V moles of gas and n^L moles of liquid in equilibrium at constant pressure and temperature:

①



$$\sum_{i=1}^{n} \left(\mu_i^L\,dn_i^L + \mu_i^V\,dn_i^V\right) = 0$$

At equilibrium:

$$dn_i^L + dn_i^V = 0$$

Thus $$\sum_{i=1}^{N} (\mu_i^L - \mu_i^V)\, dn_i = 0$$ ①

For the Sum to become zero

$$\mu_i^L = \mu_i^V$$ ①

Since the number of Vaporizing and condensing moles will vary between the different components and will never turn to zero.

2. Given that:

$$\left(\frac{\partial \mu_i}{\partial p}\right)_{T,n} = \left(\frac{\partial (V)}{\partial n_i}\right)_{T,p,n_i}$$

For ideal gas:

$$\frac{\partial V}{\partial n_i} = \frac{RT}{p}$$ ②

Thus we may write:

$$d\mu_i = \frac{RT}{p}\, dp$$ ①

By integration :

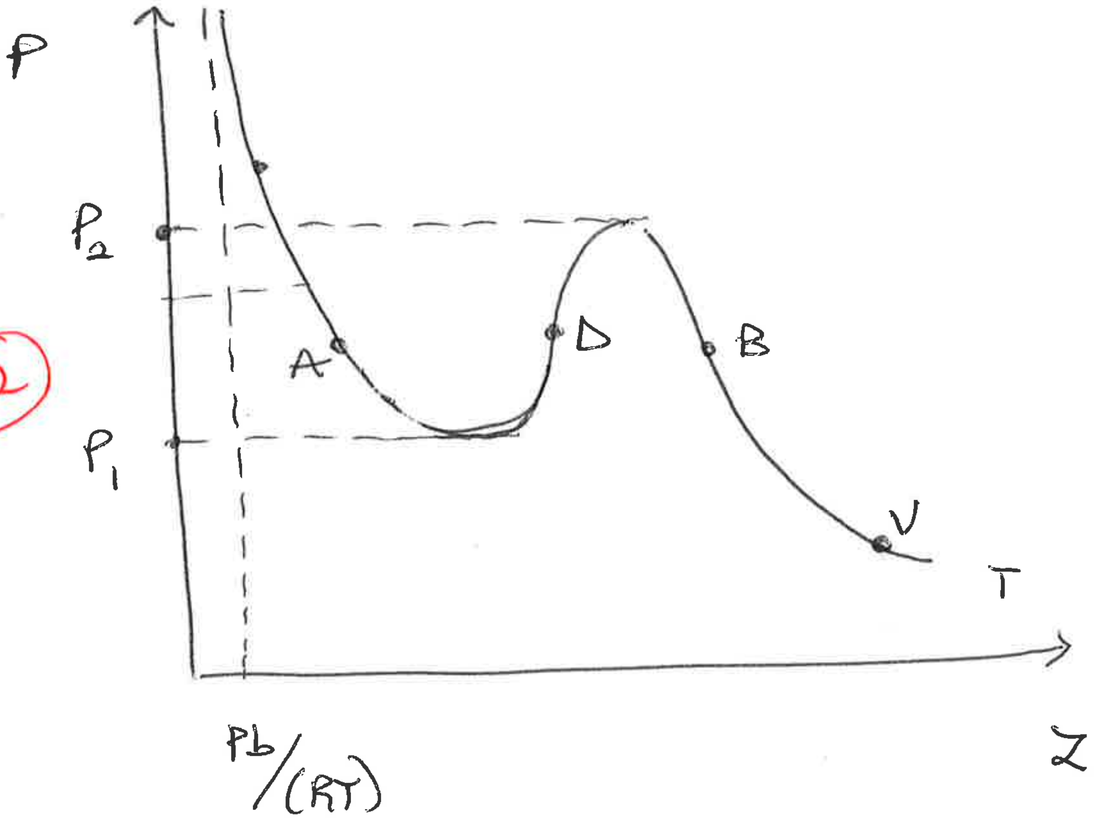
$$\int_{\mu_0}^{\mu} d\mu_i = RT\int_{p_0}^{p}\frac{dp}{p}$$ ①

$$\mu - \mu_0 = RT\ln\left(\frac{p}{p_0}\right)$$

$$\mu = \mu^\circ(T) + RT\ln(p/p_0)$$ ①

3.

②



when $V > b$, $Z > pb/RT$

① $\Rightarrow$ $P_2 < P$ or $P < P_1$ $\rightarrow$ a liquid or vapor not exist.

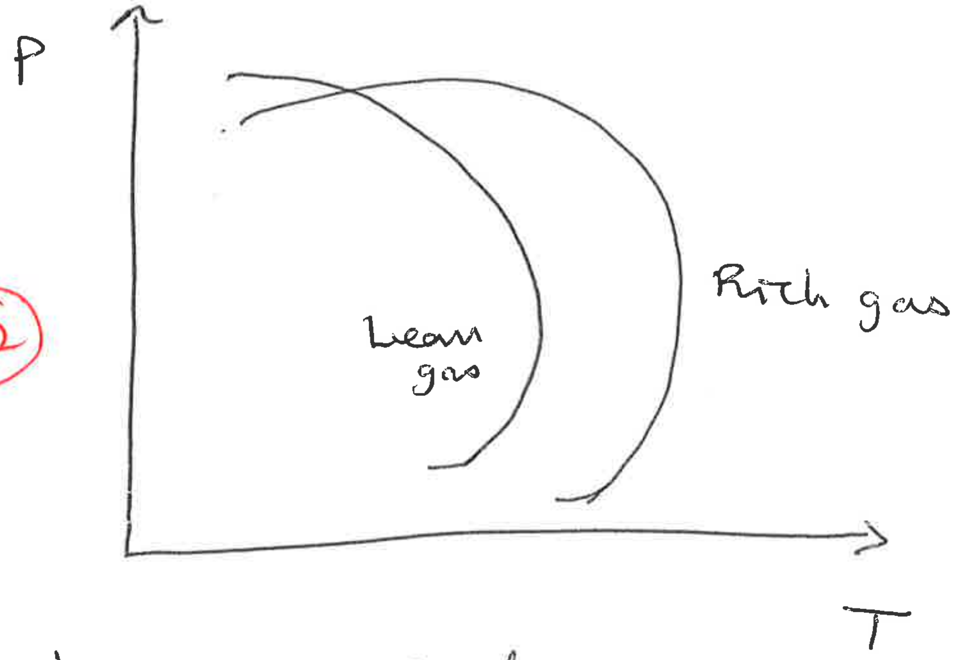
and

$P_1 < P < P_2 \longrightarrow$ three roots exist:

$Z_A < Z_D < Z_B$

4.

②



The Lean gas contains less oil than the rich gas, therefore it has a high vapor fraction.

5.

②

① The deviation from ideal behaviour is

Exercise 3

1. $$\frac{d}{dt}\left|\Delta m_{sss} - \Delta m_{IA}\right| = \frac{d}{dt}\left[\frac{q_{sc}(\mu B)_r}{2\pi kh}\left(\frac{2D_h}{r_e^2}t + \cdots + \right.\right.$$

②
$$\left.\left. - \frac{1}{2}\ln(t) + \cdots + \cdots\right]\right. = 0$$

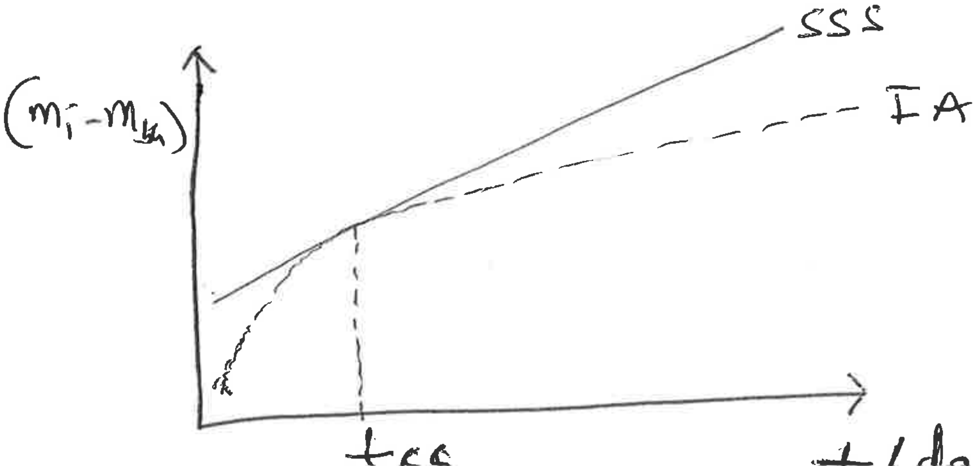
$$= \frac{q_{sc}(\mu B)_r}{2\pi kh}\left(\frac{2D_h \cancel{t}}{r_e^2} - \frac{1}{2}\cdot\frac{1}{t_{ss}}\right) = 0$$

$$\Rightarrow \frac{2D_h}{r_e^2} = \frac{1}{2}\frac{1}{t_{ss}}$$ ②

$$\therefore t_{ss} = \frac{r_e^2}{4D_h}$$ ①

2. t_{ss} is used as the time-marker for switching from infinite-acting solution to semi-steady-state pressure solution.
②

3.



②

4. Given $D_h = \dfrac{K}{\phi c \mu}$

$$t_{ss} = \frac{r_e^2}{4D_h} = \frac{r_e^2 \phi \mu c}{4K} \quad ①$$

$$① \quad t_{ss} = \frac{(800)^2 m^2 \cdot 0.25 \cdot 0.04\ mPa\cdot s \cdot 0.01\ bar^{-1}}{4 \cdot 200\ mD}$$

$$① \quad = 810537\,s \simeq \underline{\underline{9}}\ days$$

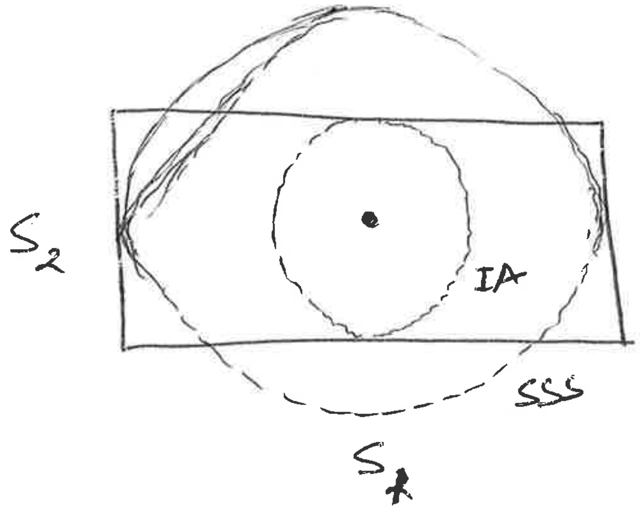
We have used the following conversions:

1 Darcy $= 9.87 \times 10^{-13}\ m^2$

1 mPa.s $= 10^{-3}$ Pa.s

1 bar^{-1} $= 10^{-5}$ Pa^{-1}

5.



②

The rectangular reservoir with the well at the centre is defined by

the two sides S_1 and S_2, where
$S_1 > S_2$.

The infinite acting period (IA) does not end when the pressure wave has reached the nearest boundary (S_1) and the Simi-steady-state period does not start when the pressure wave has reached the outer boundary. Thus, the semi-steady-state time does not coincide with the end of infinite acting period.

②

Exercise 4

1. Given $dp - \left(K_1 \frac{P}{T} + K_2 \frac{T}{P}\right) dT = 0$

Let $s = \frac{P}{T}$

Taking differentials:

$dp = d(sT) = s\,dT + T\,ds$ ①

By substitution:

$s\,dT + T\,ds - \left(K_1 s + K_2/s\right) dT = 0$ ①

Rearranging the equation:

$$\frac{dT}{T} = \frac{-ds}{\left(s - K_1 s - \frac{K_2}{s}\right)}$$

① Given $K_3 = \frac{K_2}{K_1 - 1} \Rightarrow K_2 = K_3(K_1 - 1)$

Substituting for K_2:

$$\frac{dT}{T} = \frac{-ds}{s - K_1 s - \frac{1}{s} K_3 (K_1 - 1)}$$

Factorizing the equation

① $$\frac{dT}{T} = \frac{-s\,ds}{-(s^2 + K_3)(K_1 - 1)}$$

$$\Rightarrow \frac{dT}{T} = \frac{1}{K_1 - 1} \frac{s\,ds}{s^2 + K_3}$$ ①

as required.

2. Given that

$$U_{min} = 3.6 \left(\frac{\Delta \rho g \sigma}{\rho_g^{2}} \right)^{\frac{1}{4}}$$

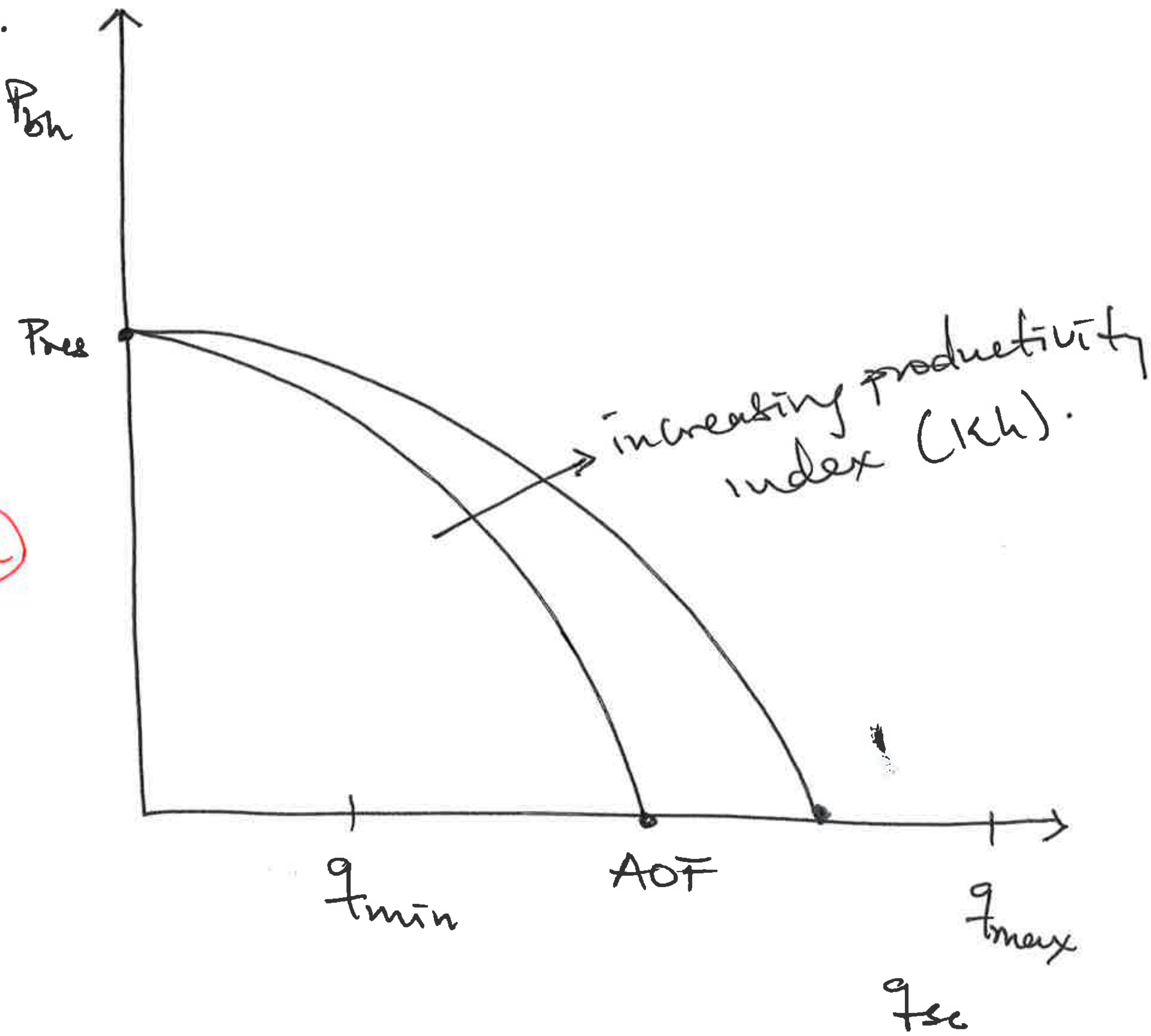
$$\Rightarrow \quad q_{min} = 3.6\, A \frac{\sqrt{\rho_g}}{\rho_{sc}} (\Delta \rho g \sigma)^{\frac{1}{4}}$$

which is the minimum unloading volumetric rate.

③ From the equation, the minimum unloading rate increases with increasing gas density. Therefore, a lighter gas is able to lift relatively more liquids than a denser gas.

3. The unloading rates for water and condensates are different mainly because ③ of the different interfacial tension (σ) and the differences in density.

4.



②

5. Given

$$P_{bh} \simeq P_{wh}\sqrt{e^{2N_{gp}} + \frac{\bar{f}\, q_{sc}^2}{A^2 d_n}\cdot \text{Constant.}}$$

At extremely low rates:

① $q_{sc} \simeq 0$

$$\Rightarrow P_{bh} \simeq P_{wh}\sqrt{e^{2N_{gp}}}$$

$$P_{bh} \simeq P_{wh}\cdot e^{2N_{gp}\cdot\frac{1}{2}}$$

$$\Rightarrow P_{bh} \simeq P_{wh}\cdot e^{N_{gp}}$$ ①