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Department of Geoscience and Petroleum
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Examination paper for TPG4135 - Production Technology – Field Processing and Systems

Eksamensoppgave I emne TPG4135 – Produksjonsteknologi – Feltprosessering og systemer

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PROBLEM 1. (15 POINTS) The molar composition of separator oil (liquid) has been measured in the lab (see the table below).

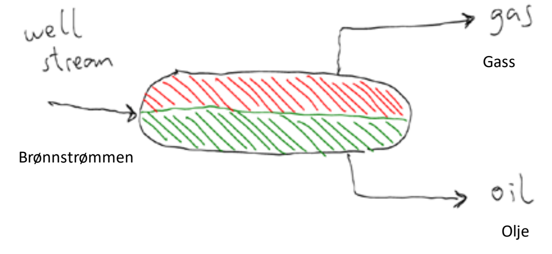
Estimate the composition of the inlet mixture.

- Assume that the vapor molar fraction (F_v) is 0.16.
- Separator pressure is 100 psia and separator temperature 120 F.
- The chart provided below shows vapor equilibrium Ki values versus pressure.

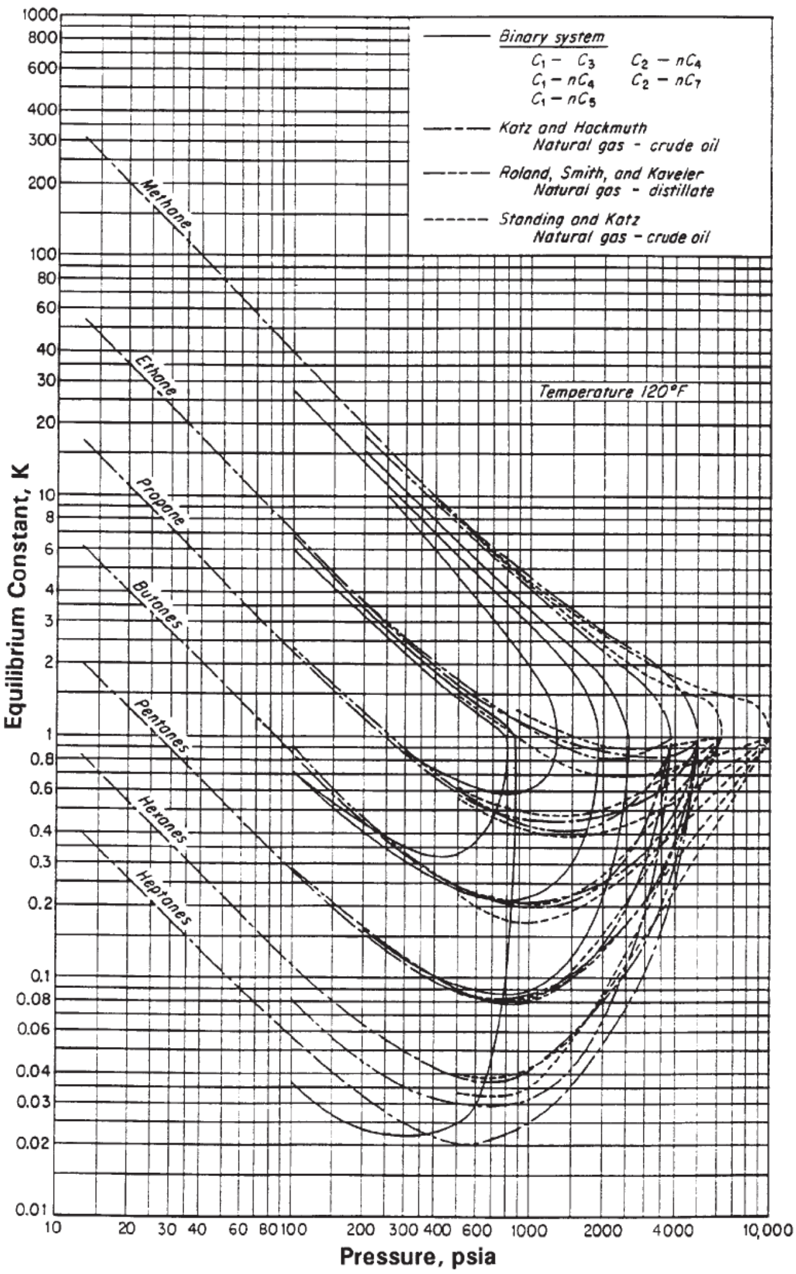
OPPGAVE 1 (15 POENGER) Molaritetene av separatorolje (væskefase) har vært målt i laboratoriet (se tabellen under)

Beregne molariteter av innløpsblandingen (olje+gass).

- Anta at dampmolefraksjonen (F_v) er 0.16.
- Separatortrykk er 100 psia og separatortemperatur 120 F.
- Grafen nedenfor viser damp-likevekt Ki-verdier versus trykk.



Component/ stoff	**Molar fraction/ Molaritet**
Methane/Metan	0.0138
Propane/Propan	0.1701
Hexane/Hexan	0.8161
Remember that/Husk at	
$Z_i = F_v \cdot y_i + (1 - F_v) \cdot x_i$	

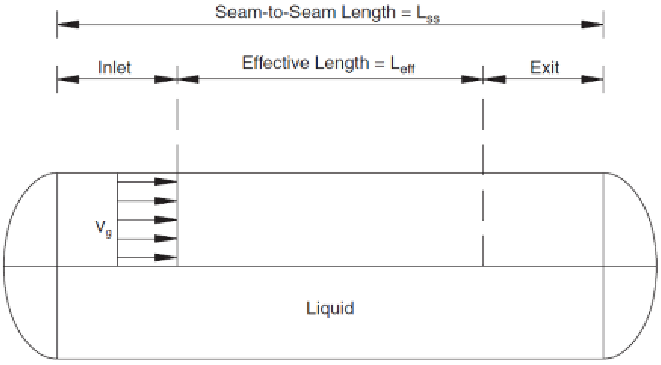


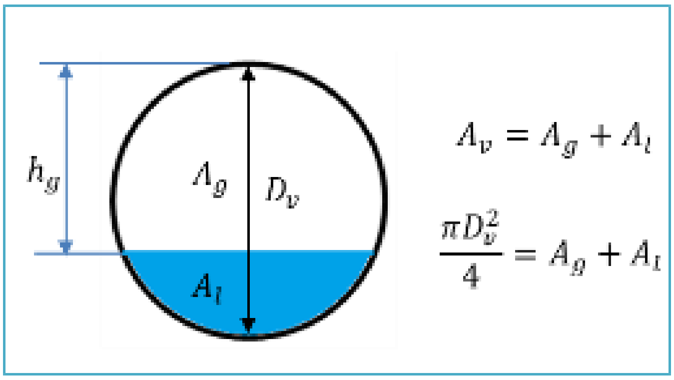
Binary system
$C_1 - C_3$
$C_2 - nC_4$
$C_1 - nC_4$
$C_2 - nC_7$
$C_1 - nC_5$
Katz and Hackmuth
Natural gas - crude oil
Roland, Smith, and Kaveler
Natural gas - distillate
Standing and Katz
Natural gas - crude oil
Temperature 120°F
Methane
Ethane
Propane
Butanes
Pentanes
Hexanes
Heptanes
Equilibrium Constant, K
Pressure, psia
1000
800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
3
2
1
0.8
0.6
0.4
0.3
0.2
0.1
0.08
0.06
0.04
0.03
0.02
0.01
10
20
30
40
60
80
100
200
300
400
600
1000
2000
4000
10,000

PROBLEM 2 (25 POINTS)
OPPGAVE 2 (25 POENGER)

1. The gas capacity of a horizontal gas/liquid separator is defined by the equation/Gass kapasitet av en væske-gass separator er gitt:

$$\frac{L_{eff} A_g}{h_g} > \frac{Q_g}{V_t}$$





Where A_g and A_l are the cross-sectional area of the gas section and liquid section respectively. Q_g is the local gas rate. / Hvor A_g og A_l er tverrsnittsareal av gass og væske lag henholdsvis. Q_g er den lokalt gassraten.

Explain how is this equation derived (step by step) /Forklare hvordan er ligningen avled (steg for steg)

2. In the expression presented earlier, what does V_t represent and how is it derived?/ I ligningen vist tidligere, hva V_t betyr og hvordan avledes?

PROBLEM 3 (25 POINTS)

Figure 1 shows a subsea system designed to boost a mixture of water and oil from a manifold to the platform.

Figur 1 viser en undervannsproduksjonsystem som skal transportere en blanding av olje og vann fra en manifold til platformen.

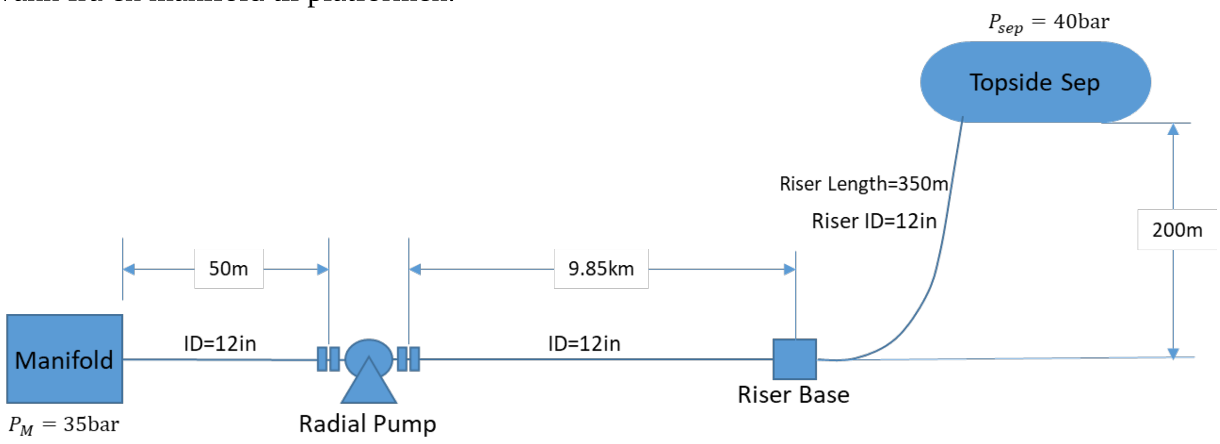


Figure 1 System description/Oversikt av systemet

The manufacturer has provided in Figure 2 the performance (head versus rate) of the pump to be installed. There are 5 impeller sizes available for the same pump casing. Based on your system characteristics you must decide which impeller size is the most suitable option to provide a rate of at least 350 m^3/h.

Pumpeprodusent har gitt I figur 2 pumpekurver (løftehøyde vs. Flow) av pumpen som skal installeres. Det finnes 5 forskjellige rotorstørrelser tilgjengelige til samme pumpehus. Basert på systemytelsen, du må bestemme hvilket rotor er mer passende for å gi en væskerate av minst 350 m^3/t

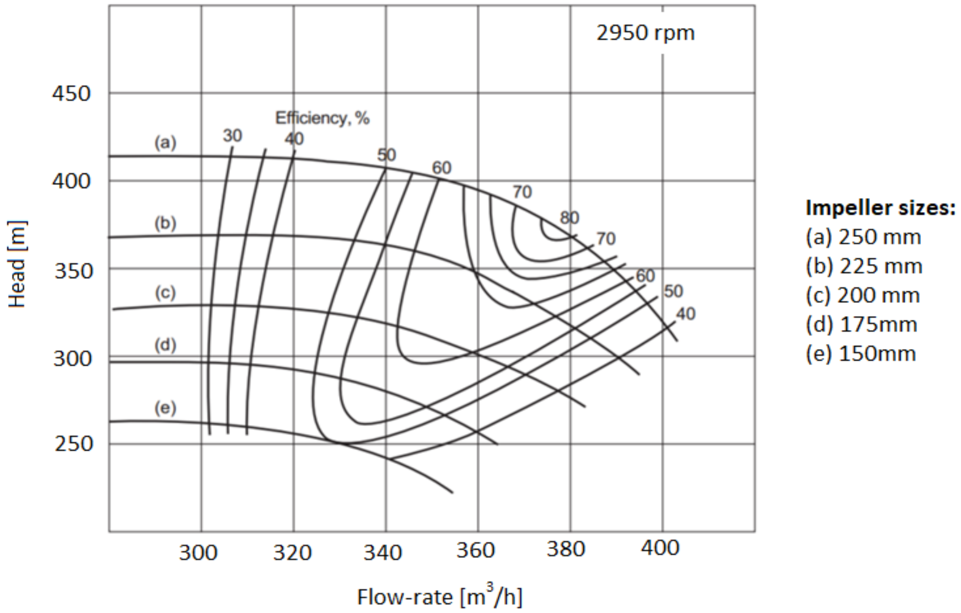


Figure 2 Performance curve of the radial pump

Task/Oppgave:

1. Select an appropriate impeller diameter of the radial pump to provide the desired rate. Calculate the operating point (flow rate and head) for your selection.

1. Velg en passende rotorstørrelse av pumpen for å gi ønsket raten. Beregne rate og løftehøyde for din valg.

Additional considerations/supplerende informasjon:

- *Consider the change in kinetic energy is negligible of fluid in the suction and discharge piping. /Neglisjere endringer I kinetisk energi I systemet nedstrøm og oppstrøm pumpen*
- *Consider constant Darcy friction factor of 0.023 and neglect the minor loses (accessories) in the pipe/ Antar at Darcys friksjonsfaktor er konstakt og har en Verdi av 0.023. Neglisjere mindre tap I restriksjoner*
- *Gravity acceleration/Tyngdeakselerasjon:* $9.81\, m/s^2$
- *Density of oil-water mixture/ densitet av olje-vann blanding:* $\rho_l = 940\ \ kg/m^3$

PROBLEM 4 (35 POINTS)

Prosessen for Statfjord A er illustrert i figur 6.1 nedenfor. Figur 6.2 angir adiabatisk eksponent for alifatiske naturgasser (metan, etan, osv.)

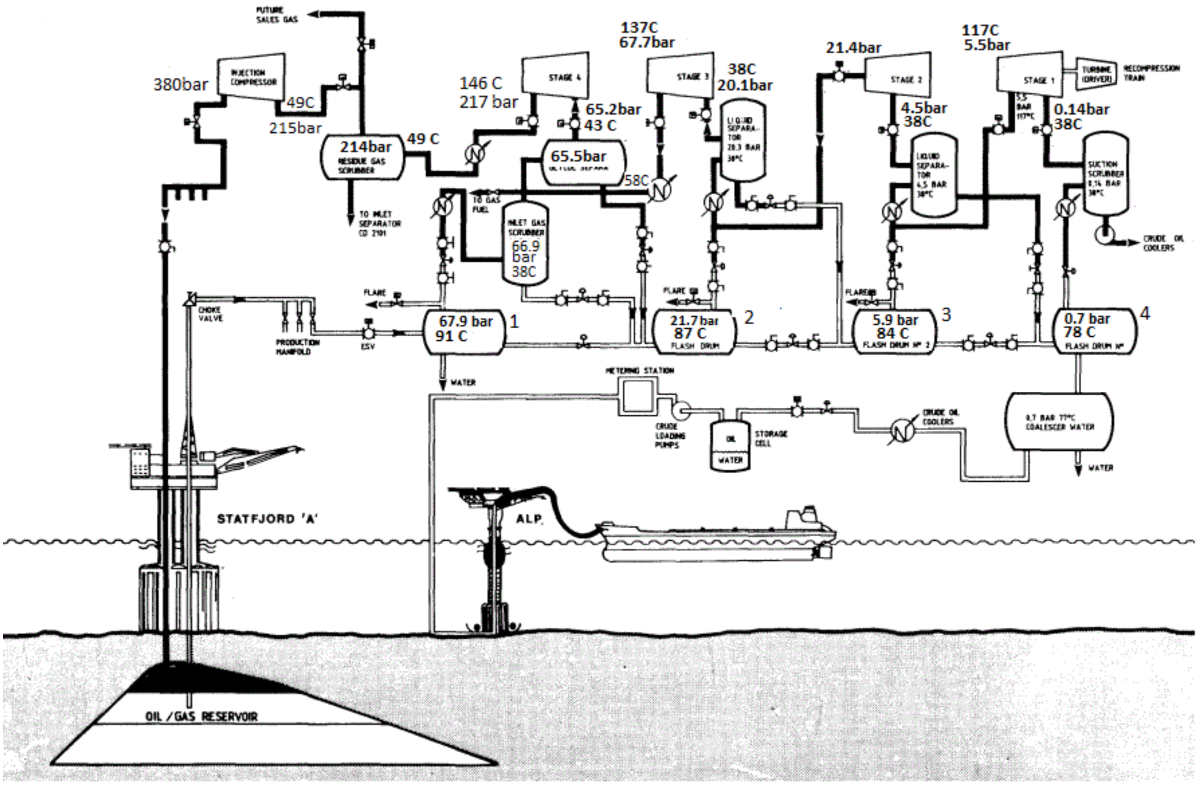
The process for Statfjord A is illustrated in figure 6.1 below. Figure 6.2 indicates adiabatic exponent for aliphatic natural gases (methane, ethane, etc.)

Gitt/given :

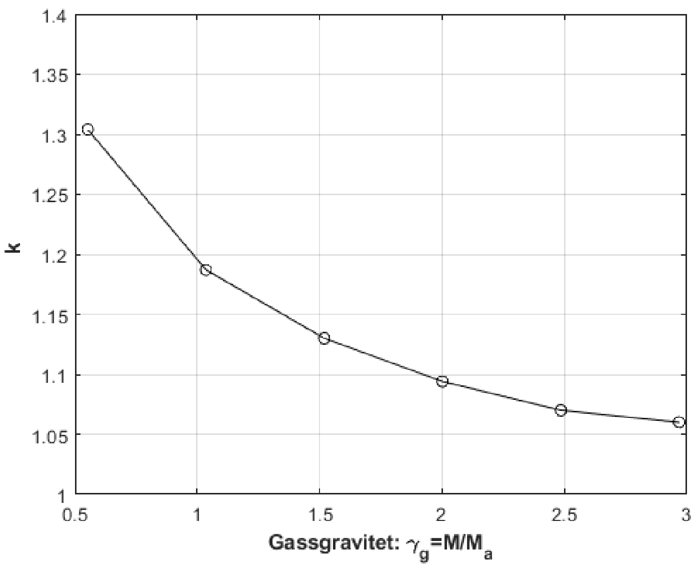
- Produksjon olje/Oil production: 20 000 Sm^3/d
- Gassproduksjon/ gas production $40 \cdot 10^5\, Sm^3 / d$
- Vann/oljeforhold/ WOR: R_W=0.01
- Spesifikk tettheter/gravity olje: 0.825, gass: 0.7, vann: 1

a) Estimer utløpstemperatur for injeksjons-kompressoren.
b) Estimer effektbehov for injeksjons-kompressoren
c) Basert på svartoljemodell, estimer gass-strøm (kg/s) gjennom kompressor 2 .
d) Estimer utløpstemperatur kompressor 2. Vurder/diskuter eventuelt avvik mellom ditt estimat og utløpstemperaturen 126 C, estimert ved komposisjonell simulering.

a) Estimate outlet temperature from the injection compressor.
b) Estimate power requirements of the injection compressor
c) Based on black oil model, estimate gas flow (kg / s) through compressor stage 2
d) Estimate the outlet temperature compressor 2. Evaluate / discuss any deviation between your estimate and the temperature estimated by compositional simulation: 126 C.



Figur 6.1 Prosessdiagram Statfjord A



Figur 6.2 Adiabatisk eksponent

Oppgitt /Given

γ_o : oljegravitet, $\gamma_o = \rho_o/\rho_w$

γ_g: gassgravitet, $\gamma_g = \rho_g^o/\rho_a = M_g/28.97$

General gas constant: 8314 J/(kmol K) Mole weight air : 28.97 kg/kmole

Flow in pipes:

$$\frac{\partial p}{\partial x} + \rho v \frac{\partial v}{\partial x} + \rho g_x + \frac{1}{2} f \frac{\rho}{d} v^2 = 0$$

General gas equation: $pV = znRT$

Adiabatic model:

$$pV^k = p_i V_i^k$$

$$T_2 = T_1 \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}}$$

Heat transfer, Heat exchanger

$$dq = -U \left(T - T_a \right) \pi D dx$$

$$dq = c_p \dot{m} dT$$

Mean temperature drop: $\Delta T_m = \dfrac{\Delta T_1 - \Delta T_2}{\ln\left(\Delta T_1 / \Delta T_2 \right)}$

$$\Delta T_1 = T_{a,2} - T_{i,1}$$

$$\Delta T_2 = T_{a,1} - T_{i,2}$$

Black oil model relations

$$Q_g = q_o \left(R_t - R_s \right) B_g$$

$$Q_l = q_o \left(B_o + R_w B_w \right)$$

$$R_s = 0.00590\ \gamma_g\, 10^{2.14/\gamma_o} 10^{-0.00198\,T} \left(0.797 \cdot 10^{-5}\ p + 1.4 \right)^{1.205}$$

$$B_o = 0.9759 + 0.952 \cdot 10^{-3} \left(\left(\gamma_g / \gamma_o \right)^{0.5} R_s + 0.401\, T - 103 \right)^{1.2}$$

$$B_g = \frac{p^o}{p} \frac{T}{T^o} z$$

Gas compression

$$w = p_1 V_1 \frac{k}{k-1} \left(\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right)$$

$$\dot{m} w = \dot{m} \frac{R T_1}{M z_1} \frac{k}{k-1} \left(\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right) \frac{z_1 + z_2}{2}$$

TPG4135 – SPRING 2019 – Exam solution

Problem 1:

Reading from the chart, for separator pressure and temperature:

$K_{C1} = 40$

$K_{C3} = 2.1$

$K_{C6} = 0.11$

Now, x_i is given, with $K_i = y_i / x_i$ this gives:

$y_{C1} = 0.553$

$y_{C3} = 0.357$

$y_{C6} = 0.089$

then, using the expression with the mole vapor fraction provided:

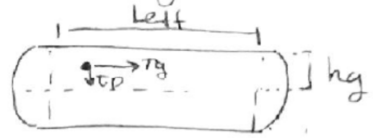
$z_{C1} = 0.1$

$z_{C3} = 0.2$

$z_{C6} = 0.7$

Problem 2.1:

For a horizontal tank



$\tau_p < \tau_g$ The time that take the particle to to Travel vertically a "hg" distance. Should be less than the time that The gas take to travel horizonta towards the outlet

$$t = \frac{L}{V} \quad \frac{[m]}{[m/s]}$$

$$\frac{hg}{Vt} < \frac{Leff}{Vg}$$

where hg : is the height of gas
Vt : terminal velocity
Vg : gas velocity
Leff : tank effective length

$$Vg = \frac{Qg}{Ag} \quad \frac{[m^3/s]}{[m^2]}$$

$$\frac{hg}{Vt} < \frac{Leff\,Ag}{Qg} \rightarrow \frac{Qg}{Vt} < \frac{Leff\,Ag}{hg}$$

Problem 2.2

Vt represents the terminal velocity of the droplet and it is the vertical velocity at which the droplet travels in the gas towards the gas-liquid interface. It is usually derived by performing a force balance on the droplet considering weight, drag and buoyancy.

Problem 3

1.- Define the system curve:

Applying Bernoulli between Manifold and Suction, and between discharge and the topside.

Manifold → Suction

$$\frac{P_H}{\rho g} + \frac{V_H^2}{2g}^{\nearrow 0} + Z_H = \frac{P_S}{\rho g} + \frac{V_S^2}{2g} + Z_S + h_L^s$$

$$H_S = \frac{P_S}{\rho g} = \frac{P_H}{\rho g} - \frac{V_S^2}{2g} + (Z_H - Z_S)^{\nearrow 0} - h_L^s \qquad Z_H = Z_S$$

Discharge → topside

$$\frac{P_D}{\rho g} + \frac{V_D^2}{2g} + Z_D = \frac{P_T}{\rho g} + \frac{V_T^2}{2g}^{\nearrow 0} + Z_T + h_L^d$$

$$H_D = \frac{P_D}{\rho g} = \frac{P_T}{\rho g} - \frac{V_D^2}{2g} + (Z_T - Z_D) + h_L^d$$

The differential head required is: $\Delta H = H_D - H_S$

$$\Delta H = \frac{P_T - P_H}{\rho g} + \frac{V_S^2 - V_d^2}{2g}^{\nearrow 0} + (Z_T - Z_D) + \Sigma h_L$$

Diameter at suction = Diameter discharge. $V_S = V_d$

$$\Delta H = \frac{P_T - P_H}{\rho g} + (Z_T - Z_D) + \Sigma h_L$$

$$\Sigma h_L : \frac{f \cdot V_D^2 \cdot L_D}{2Dg} + \frac{f \cdot V_S^2 \cdot L_S}{2Dg}$$

$$V_D = V_S = V$$

$$V = \frac{Q}{A}$$

$$A = \frac{\pi D^2}{4}$$

$$\Sigma h_L = \frac{f \cdot Q^2}{2Dg A^2} (L_D + L_S)$$

$$L_{TOTAL} = L_D + L_S = 50m + 9.85\ Km + 350m = \underline{10\ 250\ m}$$

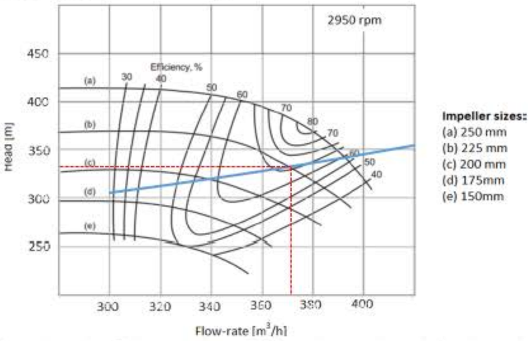
$$\Delta H = \underbrace{\frac{P_T - P_H}{\rho g}}_{54.3m} + \underbrace{(z_T - z_D)}_{200m} + \underbrace{\frac{f\ L_{TOTAL}}{2 \cdot D \cdot g A^2}}_{7404.5} \cdot Q^2$$

$$\boxed{\Delta H = 254.3m + 7404.5\ Q^2}$$

Q : m^3/sec
H : m.

from the Pump Curve we can evaluate 3 Q

Q (m^3/h)	H (m)
320	312.7
360	328.3
400	345.6



Ploting Thus over The performance curve The operating point is :

$$Q \approx 370\ \frac{m^3}{s} \qquad H \approx 330\ m$$

The impeller size selelected is the one that gives the higher efficiency:

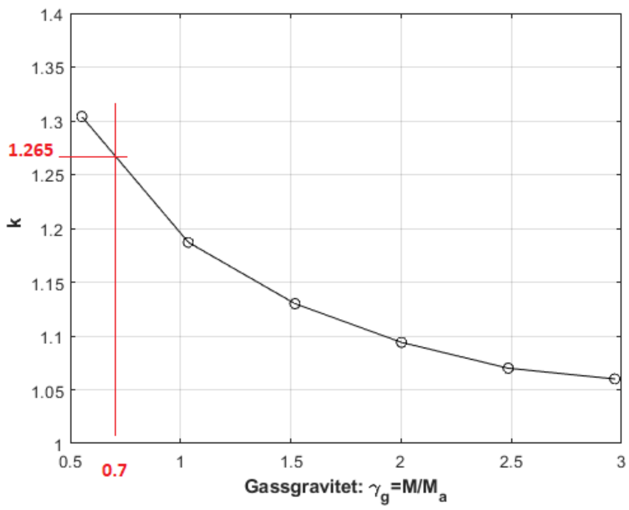
The impeller diameter is 225 mm

$\eta \approx 65\%$

Løysingsforslag PROBLEM 4

a) Utløpstemperatur

Adiabatisk eksponent, estimert for gassgravitet: 0.7



$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} = (49+273)\left(\frac{380}{215}\right)^{\frac{1.265-1}{1.265}} = 362.8K \quad \rightarrow t_2=89.8C$$

Nærmere temperaturen oppgitt: 90C, enn vi kan forvente

b) Effekt, injeksjonskompressor

Massestrøm: $\dot{m}_g = \rho_g^o q_g = (0.7\cdot 1.23)\cdot(40\cdot 10^5/86400) = 39.9kg/s$

$$\dot{w} = \dot{m}_g \frac{RT_i}{M}\frac{k}{k-1}\left(\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} - 1\right) = 39.9\frac{8314\cdot(49+273)}{0.7\cdot 1.23}\frac{1.265}{0.265}\left(\left(\frac{380}{215}\right)^{\frac{0.265}{1.265}} - 1\right) = \underline{\underline{3.59\cdot 10^6 w}}$$

c) Kompressor 2

Kompressor 2 håndterer gass fra separator 3 og 4. Gass-strømmen tilsvarer gass som frigis mellom separator 2 (21.7 bar, 87C) og 4 (0.7 bar, 78 C). Med svartoljekorrelasjon

$$R_{s2} = 0.00590\,\gamma_g\,10^{2.14/\gamma_o}10^{-0.00198\,T_2}\left(0.797\cdot 10^{-5}\ p_2 + 1.4\right)^{1.205} = 10.7$$

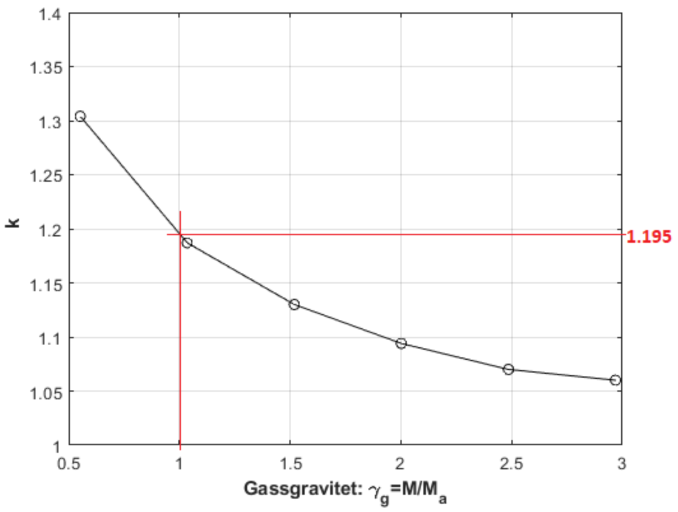
$$R_{s4} = 0.00590\,\gamma_g\,10^{2.14/\gamma_o}10^{-0.00198\,T_4}\left(0.797\cdot 10^{-5}\ p_4 + 1.4\right)^{1.205} = 0.73$$

$$\dot{m}_{g2} = \rho_g^o q_{g2} = \rho_g^o\left(R_{s2} - R_{s4}\right)q_o = (0.7\cdot 1.23)\cdot(10.7-0.7)20000/86400 = \underline{\underline{2.0kg/s}}$$

d) Utløpstemperatur kompressor 2

$$\text{Estimat}: T_{2u} = T_{2i}\left(\frac{p_{2u}}{p_{2i}}\right)^{\frac{k-1}{k}} = (38+273)\left(\frac{21.4}{4.5}\right)^{\frac{1.265-1}{1.265}} = 431K \quad \rightarrow t_{2u}=158C$$

Dette er betydelig over gitt temperatur 126: En åpenbar feilkilde er at vi forutsatt gjennomsnittlig gassgravitet : 0.7, samsvar med svartoljemodellen. I realiteten vil andelen tyngre gasser som frigjøres være større ved låge trykk. Om vi for eksempel antar gravitet som for luft: γ_g=1, skulle det tilsvare adiabatisk eksponent: 1.195



Revidert temperaturestimat

$$T_{2u} = T_{2i}\left(\frac{p_{2u}}{p_{2i}}\right)^{\frac{k-1}{k}} = (38+273)\left(\frac{21.4}{4.5}\right)^{\frac{0.195}{1.195}} = 401K \quad \rightarrow \underline{\underline{t_{2u}=128C}}$$

Bringer temperaturestimatet nært oppgitt utløpstemperatur