English text in black

Norsktekst i blå

PROBLEM 1 (60 POINTS) / OPPGAVE 1 (60 POENG)

Oil will be transported from offshore platform to an onshore plant, illustrated by figure 1.

Oil skal transporteres fra en platform til en proseseringsanlegg på land, som illustrert i Figur 1.

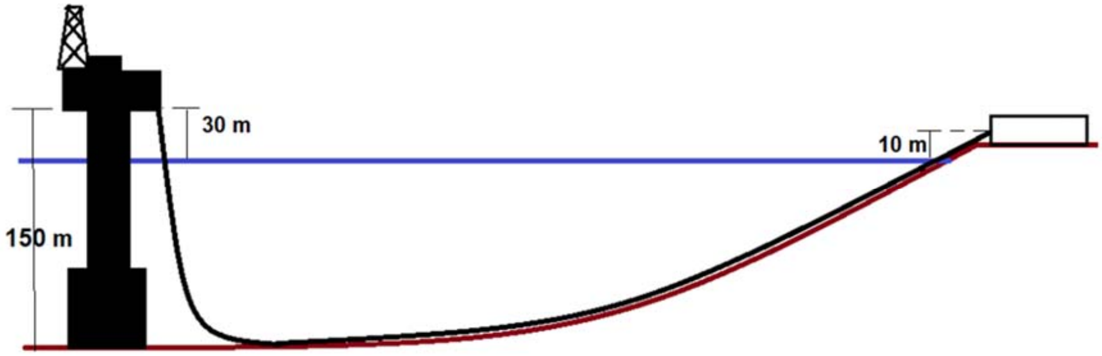


Figure 1: Transport pipe / Figur 1: Transportrør

Pipeline data / rørledning data
Inner diameter / Indre diameter : 0.2 m
Length / Lengde : 20 000m
Oil density / Olje tethet : 800 kg/m^3
Viscosity/ viscositet : 2cP
Pipe wall roughness / rørvegg ruhet : 0.046 mm

Figure 2 provides characteristics of the centrifugal pump considered,

Figur 2 gir karakteristikk-kurven av pumpen som planlegges til å bruke

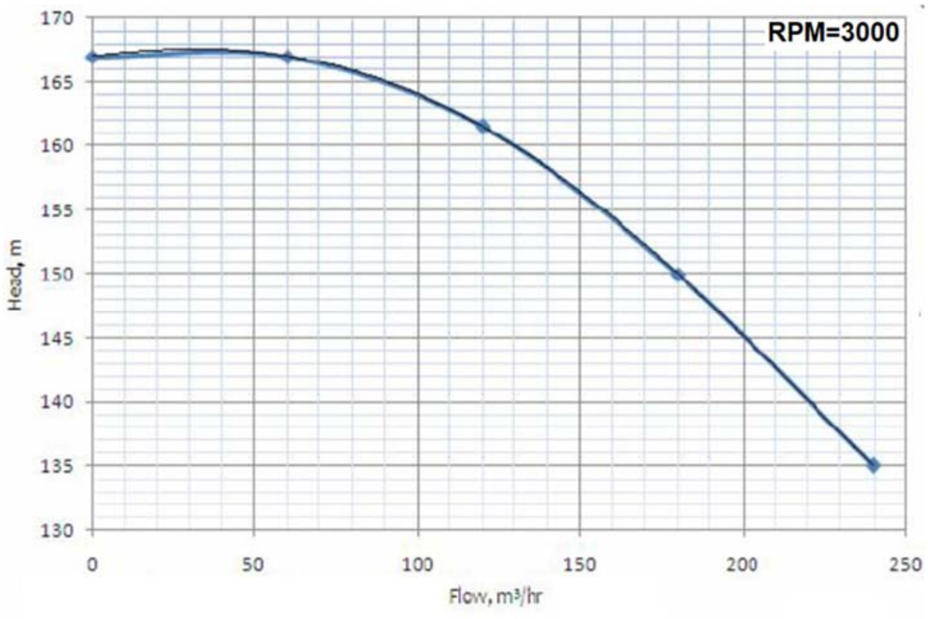


Figure 2 Pump characteristics/ Figur 2 pumpe karakteristikk-kurven

a) Estimate oil flow rate using 1 pump (at RPM 3000). Estimer produksjon (strømning i røret) ved bruk av en pumpe (på RPM 3000).

b) Consider coupling 2 pumps in series, and alternatively in parallel. Select the coupling scheme that provides highest flow rate, according to your calculations. Vurder å bruke to pumper I serier eller I parallel. Velg system som gir høyest mulig strømning, i følge dine kalkuleringer.

c) Your selected pumping system should be able to operate for production rates varying between 100 and 200 m^3/hr. Chose pump control and estimate parameters relevant your recommended control system (piping, frequency, valves, or whatever may relevant). Din pumpesystem skulle tillate operasjon med produksjonsrater mellom 100 og 200 m^3/hr. Velg pumpkontrol og estimer parameterne relevant til din anbefalt kontrolsystem (rør, frekvens, ventiler, osv.)

LECTURER: HARALD ASHEIM

Solution Exercise 12

a) Flow rate with 1 pump

For numerical calculations it simplifies to fit the pump characteristics to a polynomial:

$$H_p = a_o + a_1 Q + a_2 Q^2$$

The figure below shows fit for : $a_o = 167$, $a_1 = 0.0460$, $a_2 = -0.000754$

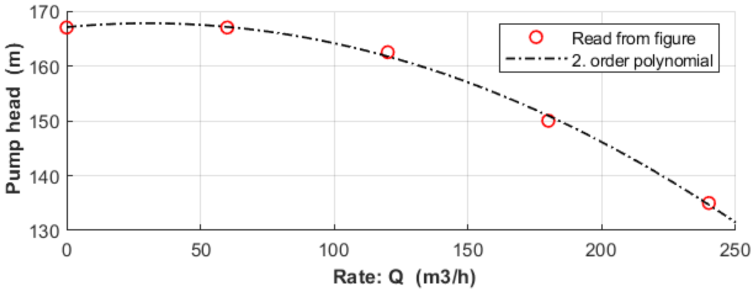


Figure 1

Pipe pressure drop calculated, neglecting acceleration: $\Delta p = \rho g_x \Delta h + \frac{1}{2} f \frac{\rho}{d} v^2 L$

Using friction factor by Haalands formula: $1/\sqrt{f} = -1.8\log_{10}\left((\varepsilon/3.7d)^{1.11} + 6.9/\mathrm{Re}\right)$

Expressed by hydraulic potential: $\Delta H = \frac{\Delta p}{\rho g_x}$

Script 1 calculates hydraulic potential provided by the pump, and hydraulic potential needed at pipe inlet, plotted below. Solution (equality) at flow rate: 179 m^3/hr.

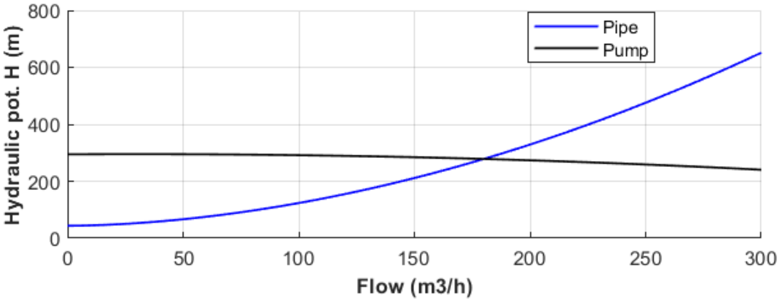


Figure 2

b) Pumps coupled together

2 pumps in series doubles the potential. In the script, this implies multiplying the single-pump head by 2.

$$H_p = 2\left(a_o + a_1 Q + a_2 Q^2\right)$$

Implemented in the script and illustrated below. Provides rate estimate : 227 m^3/hr.

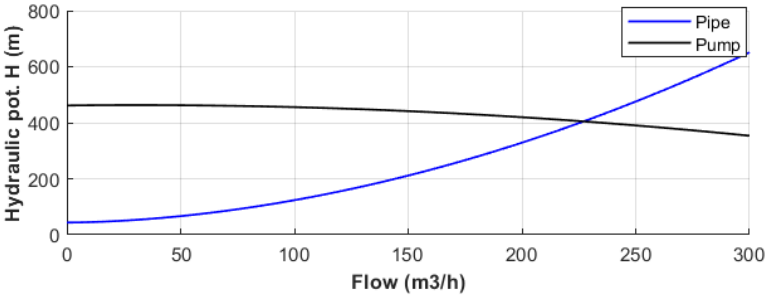


Figure 3

2 pumps in parallel splits the total flowrate into half through each pump, providing:

$$H_p = a_o + a_1\left(Q/2\right) + a_2\left(Q/2\right)^2$$

Implemented in the script and illustrated below. Provides rate estimate: 185 m^3/hr.

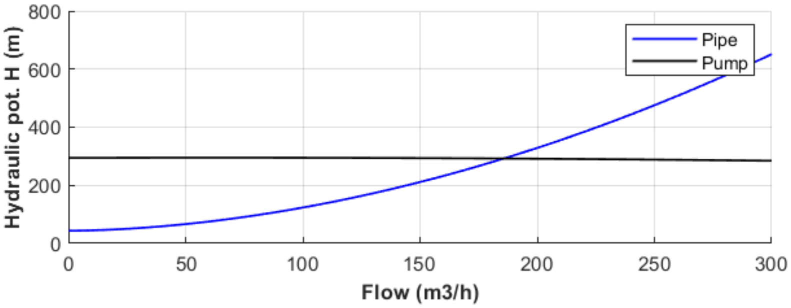


Figure 4

Thus, pumps coupled in series provides higher rate capacity.

c) Regulation

Choking to rate reduced to 100 m^3/hr requires head reduction around 200 m, pressure drop around 20 bar. This may cause erosion/cavitation and implies high energy loss. Limited space on an offshore platform makes piping arrangement for bypassing unattractive. Frequency control appears the obvious choice.

Affinity laws for frequency change:

Lifting height change: $H = H_1 \left(f / f_1 \right)^2$

where: H_1 = lifting height at reference frequency: f_1=50 Hz (RPM=3000)

Flow rate change: $Q = Q_1 \left(f / f_1 \right)$, where: Q_1 = flow rate at reference frequency: f_1

This is implemented in script2. Figure 5 shows performance curves for frequency: f=30.5 Hz (chosen after some trial-and-error) Rate predicted close to 100 m^3/hr

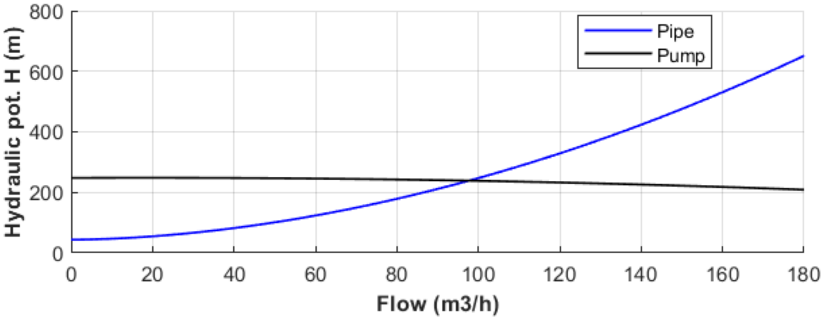


Figure 5

Script 1: Pump and system characteristics

```
% pumpekarakteristikk
clear
clf
Qp= [0 60 120 180 240];   % avlest (m3/h)
Hp=[167 167 162.5 150 135];   % avlest (m)
% tilpasning 2.grads polynom
par=polyfit(Qp,Hp,2);
a0=par(3);
a1=par(2);
a2=par(1);
disp('----------------- Pump characteristics--------------------- ')
disp([' H(Q)=',num2str(a0),' + ' ,num2str(a1),' *Q   ',num2str(a2),'*Q^2'])
Q=linspace(0,max(Qp)+10);
H=polyval(par,Q);
subplot(2,1,1)
hold on
plot(Qp,Hp,'ro','LineWidth',1)
plot(Q,H,'k-.','LineWidth',1)
hold off
legend('Read from figure','2. order polynomial')
grid
xlabel('\bf Rate: Q  (m3/h)')
ylabel('\bf Pump head  (m)')
%
disp(' ------  Pump-pipline system------------------')
pipeo=5e5;     % pipe outlet pressure
pumpi=10e5;    % pump inlet pressure
% pipe parameters
d=0.2;
h=-20;
```

```
L=20000;
rho=800;
vis=2e-3;
eps=0.046/1000;      % pipewall roughness
g=9.81;
% ---------------------------------------------
%
n=100;
qh=linspace(0,300,n);   % strømning m3/h
q=qh/3600;      % m3/s
for i=1:n
v(i)=q(i)/(pi*d^2/4);
Re=rho*v(i)*d/vis;
% Haalands formel
a=-1.8*log10((eps/3.7/d)^1.11+6.9/Re);
f=1/a^2;
p(i)=pipeo+rho*g*h+0.5*f*rho/d*v(i)^2*L;
end
Hpump=a0+a1*(qh) +a2*(qh).^2; % pump outlet head
Hi=pumpi/(rho*g);
Hpipe=p/(rho*g);              % pipe inlet head
subplot(2,1,2)
hold on
plot(qh,Hpipe,'b','LineWidth',1)
plot(qh,Hpump+Hi,'k','LineWidth',1)
hold off
legend('Pipe','Pump')
grid
xlabel('\bfFlow (m3/h)')
ylabel('\bfHydraulic pot. H (m)')
% flow rate predicted
y2=(Hpump+Hi-Hpipe).^2;
[m,im]=min(y2);
disp([' Flow rate predicted: ',num2str(qh(im)),' m3/hr'])
```

Script 2 Pump control

```
disp('-------------Frequency control------------')
clear
clf
%  pumpekarakteristikk
a0=167.0714;
a1=0.045952;
a2=-0.00075397;
disp('----------------- Pump characteristics--------------------- ')
disp([' H(Q)=',num2str(a0),' + ' ,num2str(a1),' *Q   ',num2str(a2),'*Q^2'])

disp(' ------  Pump-pipline system------------------')
pipeo=5e5;     % pipe outlet pressure
pumpi=10e5;    % pump inlet pressure
% pipe parameters
d=0.2;
h=-20;
L=20000;
rho=800;
```

```
vis=2e-3;
eps=0.046/1000;      % pipewall roughness
g=9.81;
% ---------------------------------------------
%
n=100;
qh=linspace(0,300,n);   % strømning m3/h
q=qh/3600;      % m3/s
for i=1:n
v(i)=q(i)/(pi*d^2/4);
Re=rho*v(i)*d/vis;
% Haalands formel
a=-1.8*log10((eps/3.7/d)^1.11+6.9/Re);
f=1/a^2;
p(i)=pipeo+rho*g*h+0.5*f*rho/d*v(i)^2*L;
end
 % frequency scaling
fref=50;  % reference frequency
Hpump=a0+a1*(qh) +a2*(qh).^2; % pump outlet head
% new frequency
f= 30.5;
qh=qh*(f/fref);
Hpump=Hpump*(f/fref)^2;
Hpump=2*Hpump;
Hi=pumpi/(rho*g);
Hpipe=p/(rho*g);              % pipe inlet head
subplot(2,1,2)
hold on
plot(qh,Hpipe,'b','LineWidth',1)
plot(qh,Hpump+Hi,'k','LineWidth',1)
hold off
legend('Pipe','Pump')
grid
xlabel('\bfFlow (m3/h)')
ylabel('\bfHydraulic pot. H (m)')
% flow rate predicted
y2=(Hpump+Hi-Hpipe).^2;
[m,im]=min(y2);
disp([' Pump frequency: ',num2str(f),'  Hz  (1/s)'])
disp([' Flow rate predicted: ',num2str(qh(im)),' m3/hr'])
```

LECTURER: AUDUN FAANES

Exam Spring 2021

Problems Gas Liquid Separation Oil water separation Subsea Factory and Process Control with suggested solutions

Problem 1 Gas liquid separation

a) Separator trains

Explain why gas liquid separation at a production platform at the Norwegian Continental Shelf normally takes place in several stages.

Audun's suggested solution: All the gas needs to be compressed for transportation from the production platform to a gas processing facility at the coast. When the gas is separated at high pressure, medium pressure and low pressure in a series of separators the total energy required for this compression is lower. The gas separated at elevated pressure keeps its enthalpy and does not have to be compressed "all the way up". Compression is also more energy efficient from a higher inlet pressure. Separation at low pressure is required in order to get a stable oil for transportation.

Milan's solution: The gas-liquid separation is done in several stages because this promotes a higher percentage of light components to move into the oil, rather than remaining in the gas. For example, for the same inlet composition a multi-stage separation will give a lower gas-oil ratio GOR than a single-stage separation. This means that more of the reservoir fluids will end up in the oil, and therefore will have a higher market value (the same mole of the component is worth more money in the oil than in the gas). Although separating at higher pressures (first stage separator pressure) usually gives a lower GOR and reduces the compression power required for gas transportation downstream, it also gives lower rates from the reservoir (because the pressure against which the reservoir is producing is higher). Therefore, it is important to pick a first stage separator pressure and number of stages that gives both high reservoir production rates and low GOR.

b) Flash calculations

Give examples for when we use "flash calculations" and which values are calculated

Audun's suggested solution: Expected production rates for a field is estimated by reservoir models as the flow rates locally in the reservoir and flow into the wells. From this flash calculations are used to determine the volumetric production rates given at standard conditions for simple comparison with other fields, and for the oil product it also is the export rate out of the field. From the flowrates at standard conditions – or possibly form the production flowrates in the well, the volumetric flow rates in each of the processing units and pipes are calculated in order to design these, both equipment subsea and topside. Example processing units are separators, heaters, pumps and compressors. Simplified flash calculations are also used in the calculation of flow and pressure in the pipelines and risers.

Values being calculated are volumetric flow rates of each phase and the components in each phase and thus physical properties such as density.

The reason for this being necessary (not actually a question) is that due to compressibility the volumetric rates increases at lower pressures (especially this influences the gas rates), and at lower pressures the lighter hydrocarbon components evaporate.

Milan's solution: Flash calculations are used wherever fluid properties of oil gas or water are needed, e.g. for reservoir studies/simulation, production studies/simulation, processing facilities studies/simulation, to compute black oil properties, etc. Flash calculations are used to determine if a given composition will partition into oil and gas and, if they do, to determine the vapor mole fraction of the mixture and compositions of the resulting oil and gas. With these equilibrium compositions, and the equation of state one can then compute fluid properties such as densities, viscosities, enthalpies, etc.

Scrubber design

TABLE 1	**Value and unit**	**Comments**
Gas production	300 000 Am^3/day	At separator conditions, in total from field, the year with maximum production
Oil density	780 kg/m^3	At separator conditions
Gas density	40 kg/m^3	At separator conditions

The process engineer in a field development project would like to estimate the cost consequences for increased performance requirements for the separator. To do this, the effect of K-value requirement on the required scrubber diameter shall be studied.

c) Use the expression for the K-value for scrubber design, $u_g\sqrt{\frac{\rho_g}{\rho_l-\rho_g}} < K$, and

derive an expression for required scrubber diameter as a function of K for given densities and gas production rate (Am^3/day).

Suggested solution:

$$u_g\sqrt{\frac{\rho_g}{\rho_l-\rho_g}} < K$$

$$\frac{1}{u_g} > \frac{\sqrt{\frac{\rho_g}{\rho_l-\rho_g}}}{K}$$

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

gives

$$A = \frac{Q_{vol}}{u_g} > \frac{Q_{vol}\sqrt{\frac{\rho_g}{\rho_l-\rho_g}}}{K}$$

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

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4Q_{vol}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}}}{\pi K}}$$

$$D = B\sqrt{\frac{1}{K}}$$

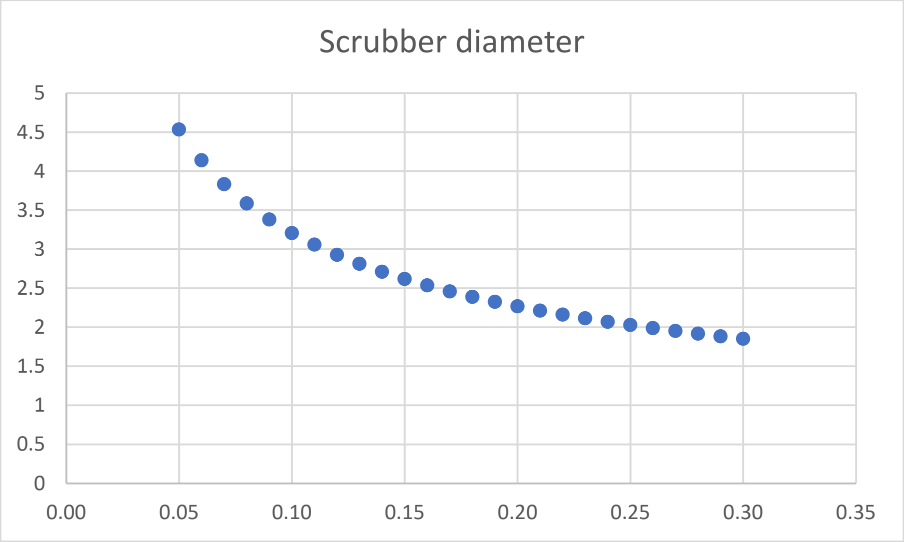
where

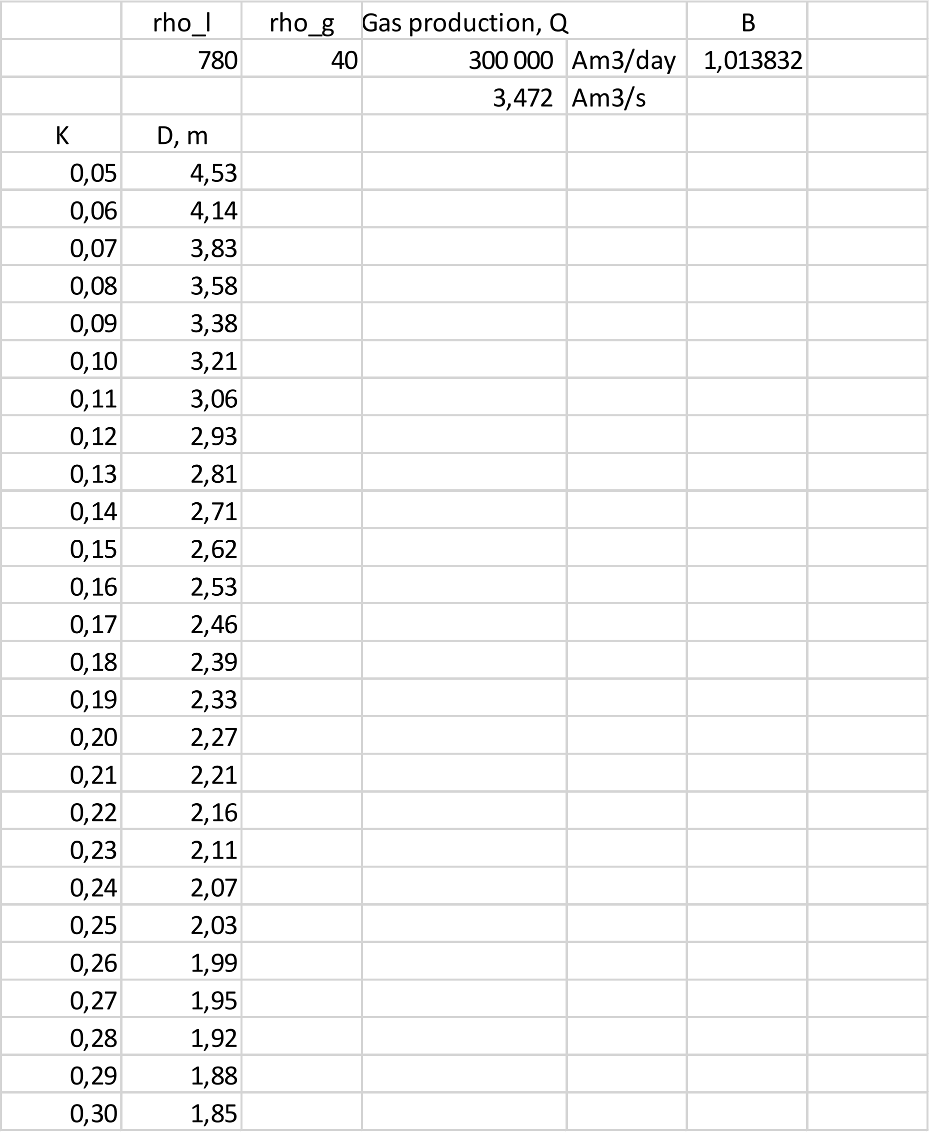
$$\boldsymbol{B} = \sqrt{\frac{\boldsymbol{4Q_{vol}}\sqrt{\frac{\boldsymbol{\rho_g}}{\boldsymbol{\rho_l - \rho_g}}}}{\boldsymbol{\pi}}}$$

d) Data for the field is given in Table 1 above. For this field, plot/sketch a graph for the required scrubber diameter for K between 0.05 and 0.3.

Suggested solution:

The formulas from c) are implemented in Excel below, and the graph becomes:



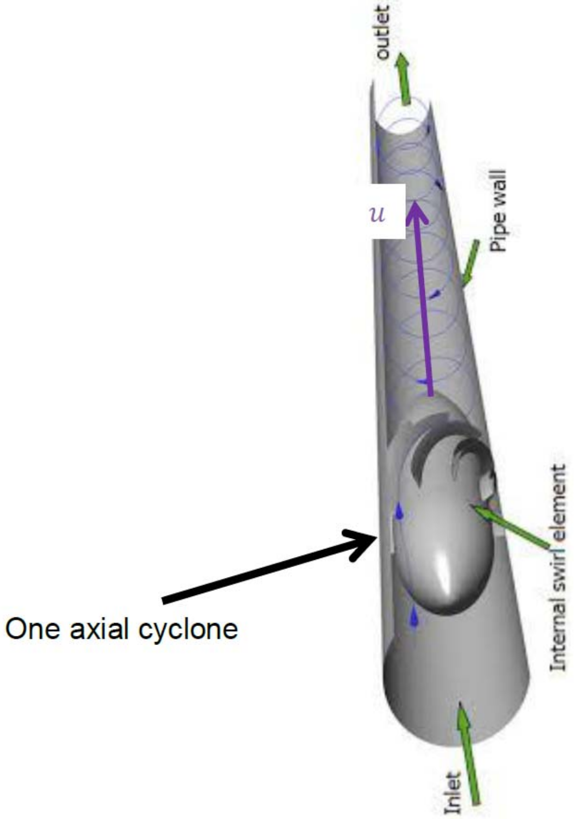


	rho_l	rho_g	Gas production, Q		B	
	780	40	300 000	Am3/day	1,013832	
			3,472	Am3/s		
K	D, m					
0,05	4,53					
0,06	4,14					
0,07	3,83					
0,08	3,58					
0,09	3,38					
0,10	3,21					
0,11	3,06					
0,12	2,93					
0,13	2,81					
0,14	2,71					
0,15	2,62					
0,16	2,53					
0,17	2,46					
0,18	2,39					
0,19	2,33					
0,20	2,27					
0,21	2,21					
0,22	2,16					
0,23	2,11					
0,24	2,07					
0,25	2,03					
0,26	1,99					
0,27	1,95					
0,28	1,92					
0,29	1,88					
0,30	1,85					

e) In the demister section, the velocity parallel with the cyclones, u, (see the figure below) shall be limited by the gas flow momentum:

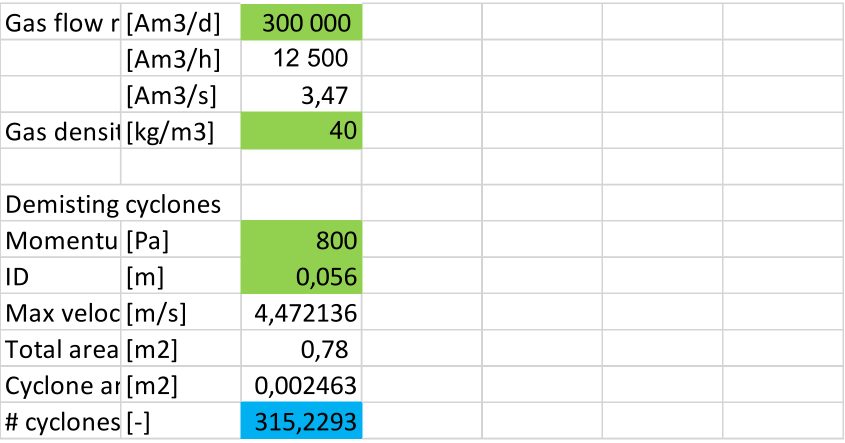
$$\rho_g u^2 < 800 kg/(ms^2)$$

For 56 mm ID axial cyclones: What is the minimum number of cyclones required in the demister section to stay below the required gas flow momentum?



Suggested solution:

$$u < \sqrt{800/\rho_g}$$



Gas flow r	[Am3/d]	300 000				
	[Am3/h]	12 500				
	[Am3/s]	3,47				
Gas densit	[kg/m3]	40				
Demisting	cyclones					
Momentu	[Pa]	800				
ID	[m]	0,056				
Max veloc	[m/s]	4,472136				
Total area	[m2]	0,78				
Cyclone ar	[m2]	0,002463				
# cyclones	[-]	315,2293				

The required number of cyclones is 316.

Problem 2 Process control of subsea compressor station

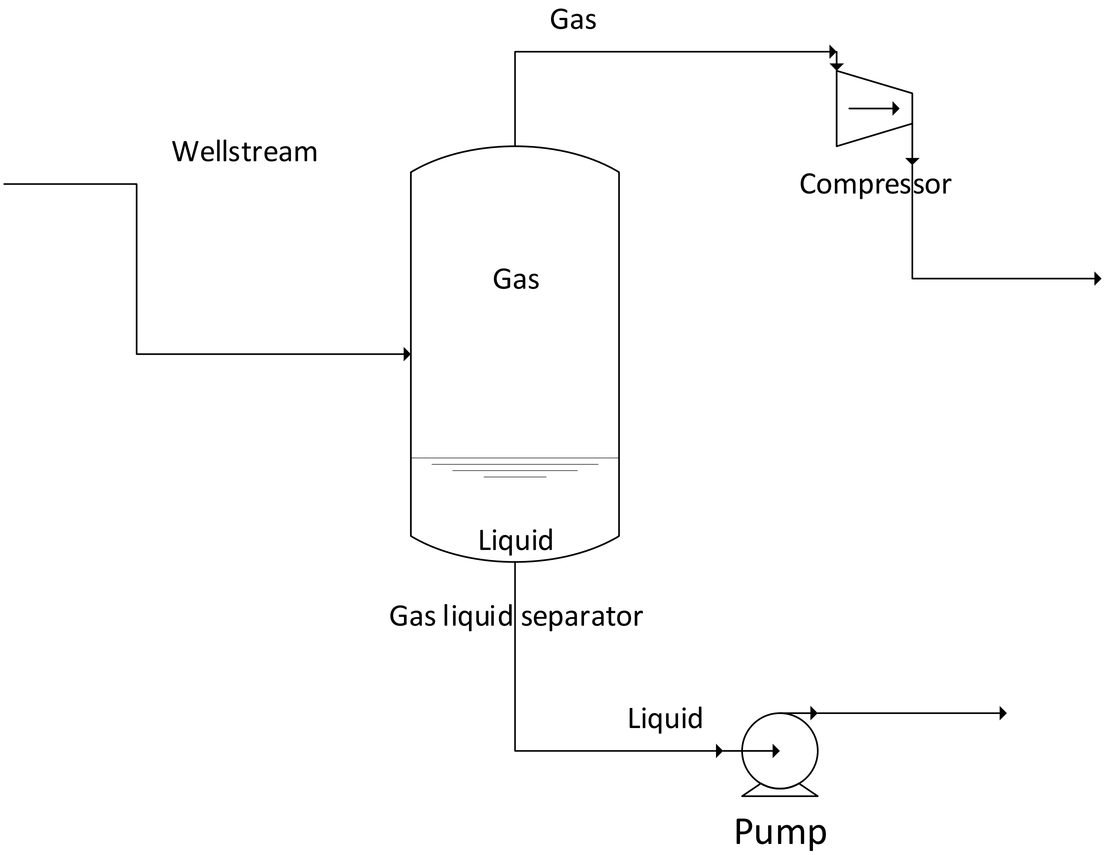


Figure 1: Subsea compressor

In Figure 1 a subsea compression station, is shown.

a) Which instruments would you need to control this process? Explain and add the instruments in the figure.

Suggested solution:

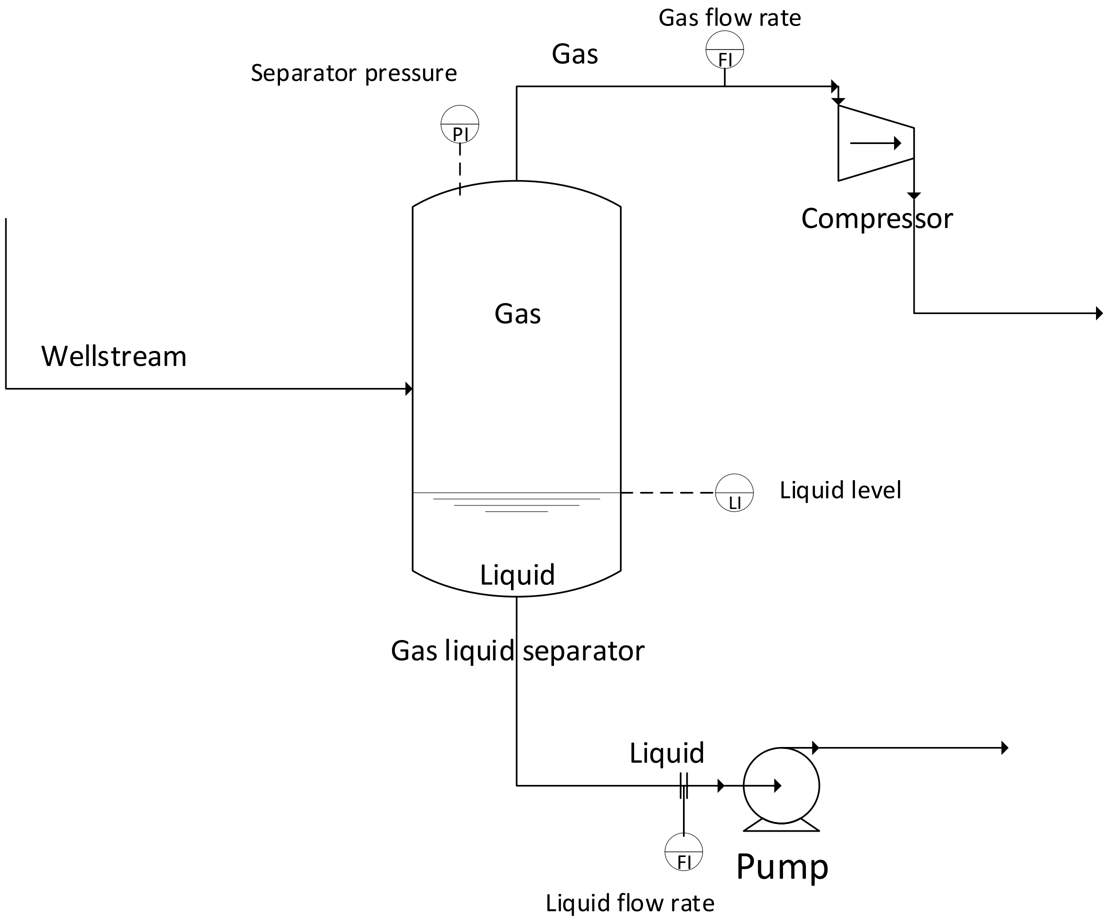
Instruments:

Pressure sensor in the separator – to be installed in the gas phase

Liquid level instrument, for example a level profiler

Possibly also:

Gas and liquid flow rates



b) Explain shortly how the electronics in the instruments must be prepared for installation in sea water

Suggested solution:

The electronics must be protected from sea water and thus encapsulated into a metal can that is made in sea water resistant material. To get power and communication lines in to the electronics, so called penetrators are used (metal wires and optic fibres that are melted in glass).

May also say that the instruments are connected to with special subsea connectors, and that the signals are transferred through a long umbilical to the production platform.

c) Which feedback control loops would you select?

Suggested solution:

Separator pressure controlled with compressor speed

Separator liquid level is controlled with liquid pump speed

Alternatively:

Separator pressure controlled with gas flow rate

Separator liquid level is controlled with liquid flow rate

Gas flow rate controlled with compressor speed

Level flow rate is controlled with liquid pump speed

d) For a dynamic model of the process, select states (x's), disturbances (d's), control variables (u's) and variables to control (y's)?

Suggested solution:

States (x's, some examples)

Separator pressure and liquid level or

Mass of gas and liquid or

Total mass and gas fraction

Disturbances (d's): (some examples)

Total inlet flow rates and gas volume fraction at actual conditions or

Gas volumetric flow rate and liquid volumetric flow rate at actual conditions or

Mole flow of each component or

Mass flow for gas and liquid phases

Control variables (u's)

Compressor speed and pump speed or

Compressor speed and pump speed and gas flow rate and liquid flow rate

Variables to control (y's)

Separator pressure and liquid level