Emnemodul: Advanced Process Control

01. Dec. 2017. Time: 0915 – 1200.
Answer as carefully as possible, preferably using the available space.
If possible, do not write on the backside of the exam.
You may answer in Norwegian; however, English is preferred.

Problem 1 – General Questions (15%)

a) Typically, there exists a control hierarchy in chemical plants. State the different layer of this control hierarchy.
b) What are the tasks in each layer?
c) What is the principle of self-optimizing control (SOC)?
d) In which section of the control hierarchy would you position self-optimizing control?
e) Is it possible to combine SOC with model predictive control (MPC)? Reason your answer!
f) Give two advantages and two disadvantages of MPC.
g) List two properties of good controlled variables.

Problem 2 – PID controller tuning (15%)

Consider a process given by the following process model

$$G_1(s) = \frac{300}{(100s+1)(10s+1)} e^{-5s}$$

Additionally, you will have a measurement model with time delay θ_m given by

$$G_m(s) = e^{-\theta_m s}$$

The aim in this task is to tune a controller using the SIMC rules with $\tau_c = \theta$ (effective delay) for the following two cases:

a) The time delay in the measurement function is given by $\theta_m = 1$.

b) The time delay in the measurement function is given by $\theta_m = 10$.

Consider the following arbitrary first order process

$$G_2(s) = \frac{k}{\tau_1 s + 1}$$

c) Derive and simplify (!) the closed-loop transfer function from the setpoint y_s to the measurement y $\left(T = \frac{y}{y_s}\right)$ using a PI controller tuned with the SIMC rules and $\tau_c = \tau_1$.

Problem 3 – Advanced Control Structures (15%)

The relative gain array (RGA) is a tool one can use to decide on controller pairing in multivariable systems. Additionally, it gives you information about the influence on coupling. Consider the following steady state RGA:

$$RGA = \begin{bmatrix} -0.08 & 1.18 & -0.10 \\ -0.33 & -0.46 & 1.79 \\ 1.41 & 0.28 & -0.69 \end{bmatrix}$$

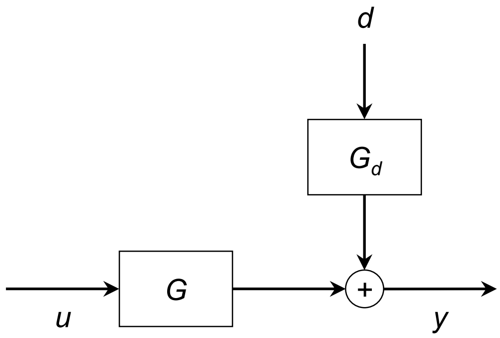
a) How would you pair the inputs with the controlled variables?

b) What are the implications if you pair on the following RGA values $\lambda_{i,j}$?

1. $\lambda_{i,j} < 0$
2. $0 < \lambda_{i,j} < 1$
3. $1 < \lambda_{i,j}$

Feedforward control is frequently used in process control. It may however lead to problems if not tuned properly.

c) Draw a feedforward control structure in the following block diagram.



d) In which situation is it advisable to incorporate a feedforward controller?

e) Why can you not always use a perfect feedforward controller?

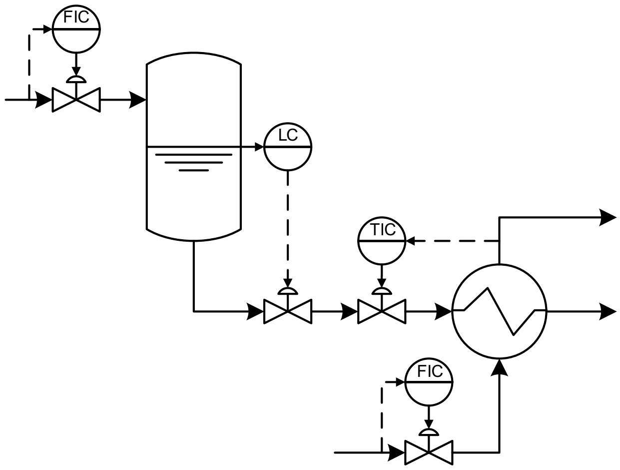
Problem 4 – Consistency (15%)

Consistency is a required property for a process in chemical industry. It should be fulfilled in all processes.

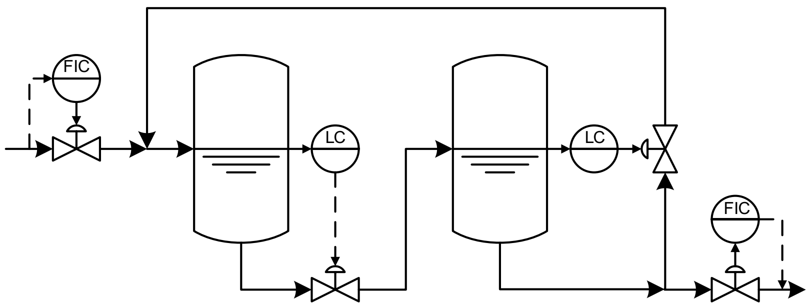
a) What is the definition of consistency and the more stringent local consistency?
b) What is the "so-called" throughput manipulator (TPM)?
c) What does the radiation rule say?

d) Are the following control structure consistent and what is (are) the TPM(s)? Justify your answers for global consistency. Do not consider gas hold-up!

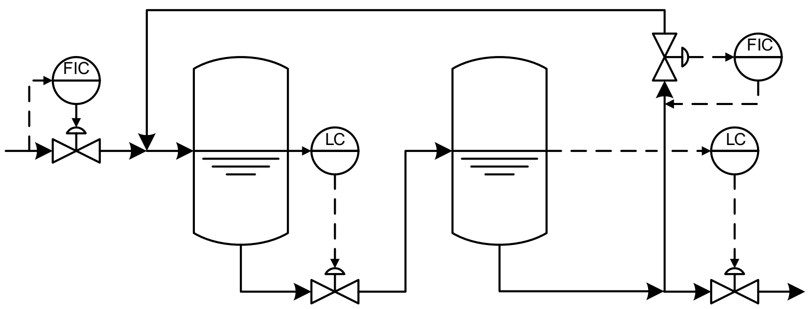
i)



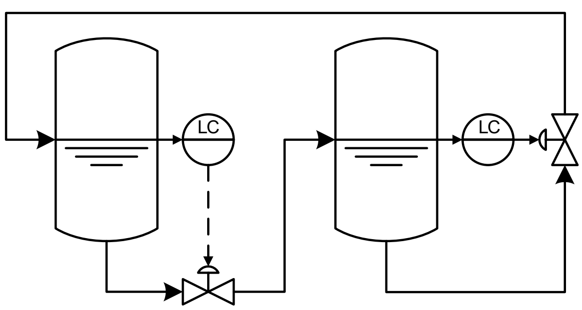
ii)



iii)

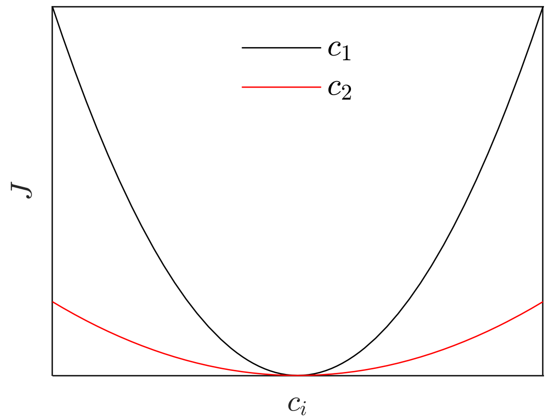


iv)



Problem 5 – Self–Optimizing Control (20%)

a) Consider the following plot showing the cost function *J* as a function of two different controlled variables c_i. Which of the two controlled variables would you implement? Why?



b) The nullspace method is one method, which can be used in the calculation of a selection matrix **H**. For this method, answer the following questions:

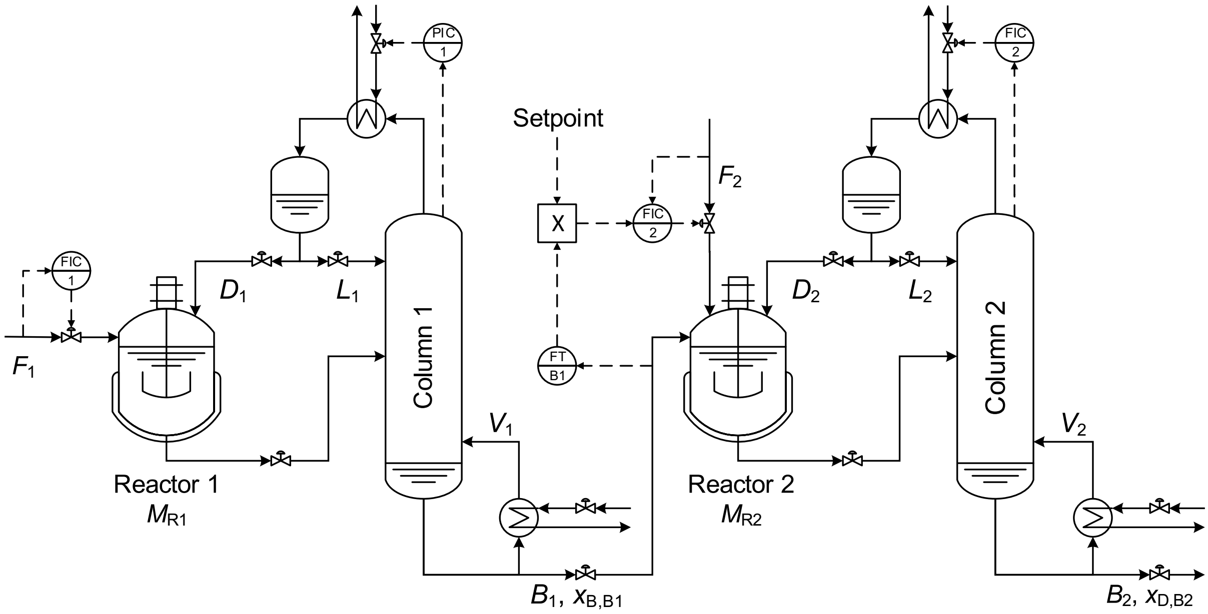
1. How many measurements are required for the nullspace method?
2. How do you calculate the selection matrix **H**?
3. In which situation is the nullspace method optimal, *i.e.* it has zero loss? Derive an expression showing this optimality.

c) The exact local method is generalization of the nullspace method and a second method to calculate the selection matrix **H**.

1. How is the selection matrix **H** calculated in this method?
2. What is the advantage of the exact local method compared to the nullspace method?

Problem 6 – Applied Plantwide Control (20%)

Consider the following process with two serial reactor and distillation columns.



In Reactor 1 (with hold-up M_{R1}), chemical A (fed through F_1) reacts to chemical B according to the following reversible reaction:

2A B

Chemical A is then separated from chemical B in Distillation column 1 and refed to Reactor 1 through D_1. The separated chemical B (stream B_1) is then fed together with a fresh stream F_2 containing chemical C in excess of chemical B to Reactor 2. Chemical B and chemical C react then to chemical D in Reactor 2 (with hold-up M_{R2}) according to

$$B+C \rightarrow D$$

Chemical D is then separated in column 2 and chemical B and C recycled to Reactor 2 through the distillate D_2.

As unwanted side reaction,

$$A+C \rightarrow E$$

Is simultaneously occurring in Reactor 2 for conversion of remaining chemical A.

This process was running now for several years and due to increased competition in the market, our objective is now to minimize the operating costs, which are given by:

$$J = -\text{Profit} = p_{F_1}F_1 + p_{F_2}F_2 + p_V\left(V_1 + V_2\right) - \; p_{B2}B_2$$

Where p_X denotes the price for quantity X, and the capital letters denote the streams.

The values for the prices are:

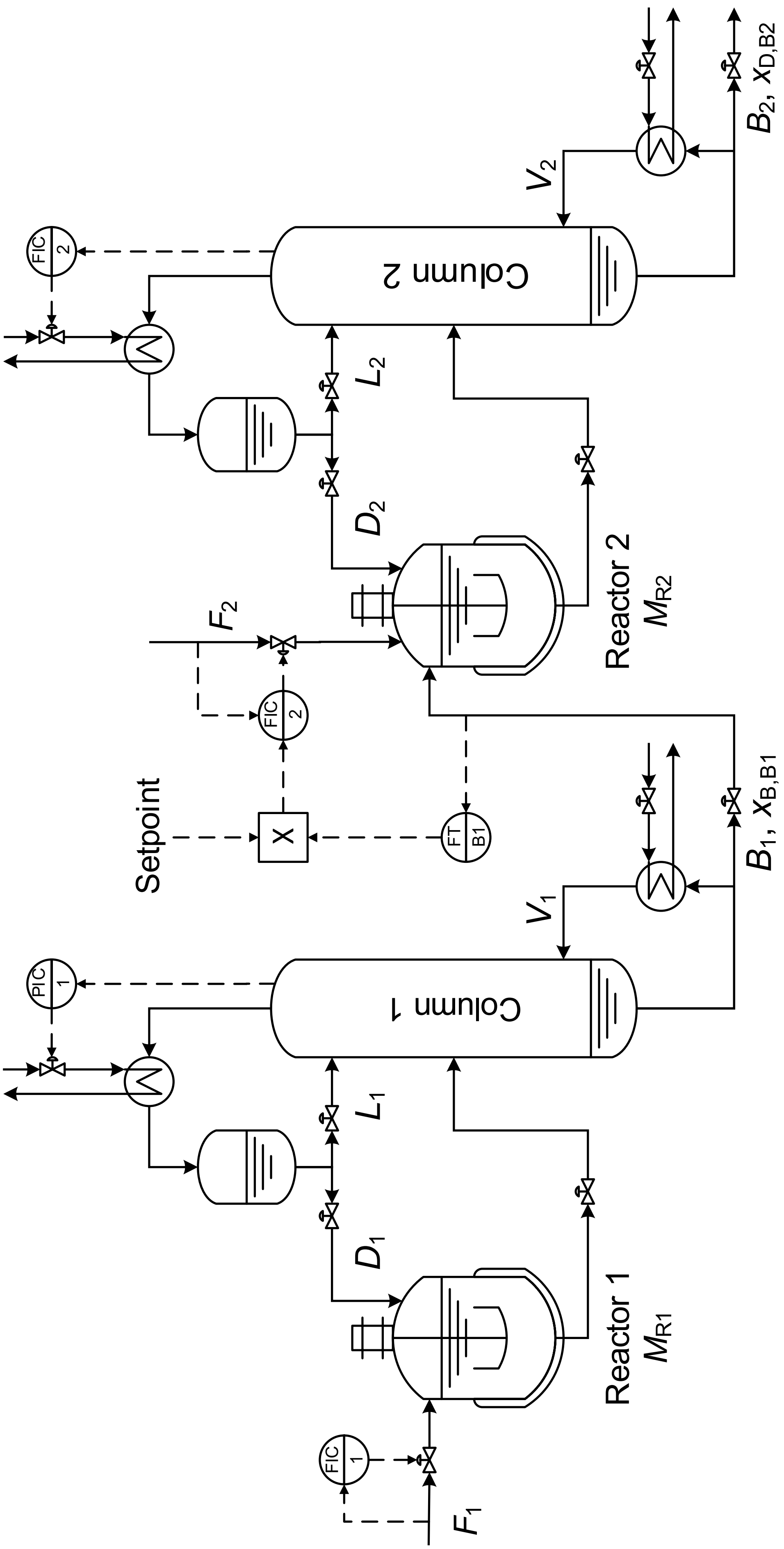
$$p_{F_1} = 1\ \$/mol$$
$$p_{F_2} = 0.5\ \$/mol$$
$$p_{B_2} = 5\ \$/mol$$
$$p_V = 0.001\ \$/mol$$

The price for energy can herby be considered as very low as the plant is located in Iceland with cheap, geothermal energy. In addition, several constraints have to be held during operation. These are given by

$$V_1 \leq 4\ \text{mol}/s$$
$$V_2 \leq 8\ \text{mol}/s$$
$$x_{B_1,B} \geq 95\%\ \text{B}$$
$$x_{B_2,D} \geq 98\%\ \text{D}$$
$$M_{R_1} \leq 2000\,\text{kmol}$$
$$M_{R_2} \leq 3000\,\text{kmol}$$

Do not change any of the controllers (FIC and PIC) drawn in the flowsheet!

a) Give the number of dynamic and steady state degree of freedom.
b) Which operational constraints will be most likely active based on your engineering experience? Reason your answer.
c) Add the missing controllers in the flowsheet on the following page such that you obtain a consistent control structure for the active constraints and inventory control. If you have any degrees of freedom left, propose a possible way to utilize them.
d) What is snowballing? Can it occur in this system and if yes, where can it occur?
e) What is the control structure controlling the feed flow rate to Reactor 2 (F_2) called?


Column 1
Column 2
Reactor 1
M_{R1}
Reactor 2
M_{R2}
F_1
F_2
D_1
D_2
L_1
L_2
V_1
V_2
B_1, $x_{B,B1}$
B_2, $x_{D,B2}$
Setpoint
FIC 1
FIC 2
PIC 1
FIC 2
FT B1
X