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Process Dynamics – CPN321

Exam

Chemical Engineering
Engineering and the Built Environment

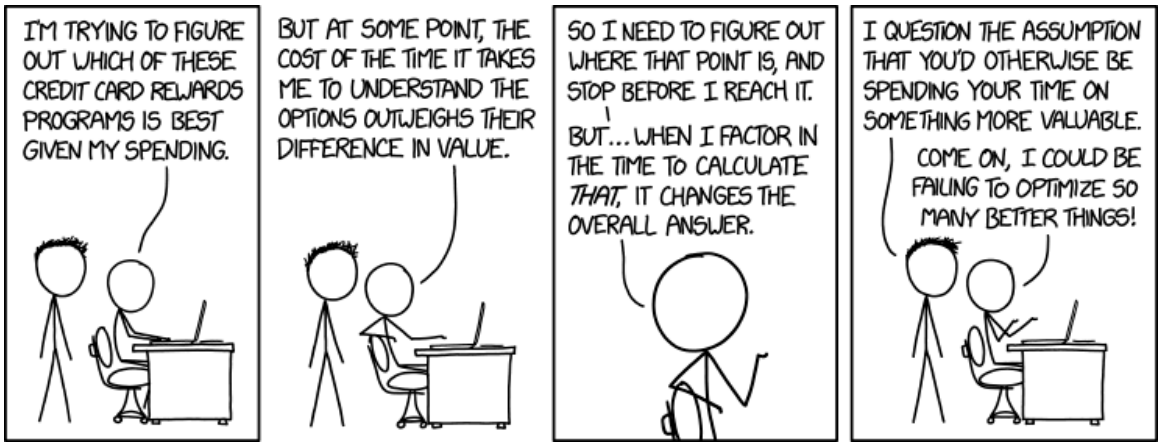
Examiner: Carl Sandrock External examiner: PL de Vaal

Date: November 2017

Duration: 180 minutes Total: 150 Total Pages: 7

Instructions – Read carefully

• This is an open book test. You may bring any information you need into the exam venue. • Answer the multiple choice questions on side 1 of the multiple choice form. • No marks will be awarded for unsubstantiated answers. • Write I claim my bonus on the first page of your answer book to receive an extra five marks.



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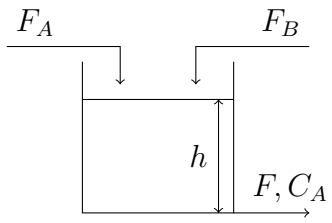
1 Multiple choice

Answer this section on side 1 of the multiple choice form. Each question counts 5 marks.

1.1. In the following process (a well-mixed tank mixing two substances) choose a reasonable assignment of controlled, manipulated and disturbance variable:



	CV	MV	DV
a.	h	F_B	C_A
b.	F_A	F	F
c.	F_B	h	F
d.	F	C_A	F_A
e.	C_A	F_A	F_B

1.2. Choose a correct statement about solving algebraic equations

a. Any set of equations can always be solved by using a numeric method like Newton's method

b. Any set of linear equations can be solved by solving for one variable at a time and substituting into the other equations until no unknowns remain

c. Any set of equations can be solved by solving for one variable at a time and substituting into the other equations until no unknowns remain

d. A set of linear equations can be solved if the number of unknowns is equal to the number of equations

e. There is no general method to solve all sets of algebraic equations.

1.3. Select a true statement about transfer functions

a. Any dynamic system with one input and one output can be represented by a rational transfer function as long as there is no time delay.

b. Systems with time delays must be approximated by Padé approximations to be represented by transfer functions

c. A rational transfer function can always be converted to a system of linear differential equations.

d. Only linear differential equations can be represented by transfer functions.

e. Systems with time delays cannot be represented by transfer functions.

1.4. Select a true statement about second order systems

a. Two first order systems in series have the same response as a second order system with $\zeta > 1$

b. Overdamped dynamics never arise in chemical systems

c. If the poles of a second order system are complex, there will always be an overshoot in the step response

d. Underdamped dynamics never arise in chemical systems

e. When $t = \tau$, the step response of a second order system reaches approximately 68% of the final value

1.5. Select a true statement about inverse response. Inverse response is ...

a. ... associated with poles with positive real parts

b. ... associated with zeros with positive real parts

c. ... associated with a negative gain

d. ... a mathematical fiction and cannot occur in real system

e. ... only found when using a Padé approximation

1.6. Choose a correct statement regarding state space models:

a. Every transfer function model has a state space equivalent

b. The states of state space models are always related to conservation laws in the system

c. Every state space model has a transfer function equivalent

d. No two state space models have the same transfer function representation

e. The only way to check for stability of a state space model is to convert it to a transfer function model

1.7. Choose a correct statement regarding discrete time models. Discrete time models ...

a. ... can exactly predict the output of a continuous system at the sampling intervals only if the input is smooth

b. ... can only approximate the step response of continuous time models at the sampling intervals

c. ... must be simulated with small time steps to avoid errors

d. ... can exactly predict the output of a continuous system at the sampling intervals only if the input is piecewise constant

e. None of the above

1.8. Why is the sum of squares frequently used for fitting?

a. It is the best measure of error of fit

b. It is arbitrary, but widely used

c. It is mathematically convenient

d. It is an accident of history

e. It can be calculated efficiently by computers

1.9. Select a true statement about the frequency domain

a. Because real inputs are not band limited, the frequency domain can only approximate system behaviour

b. Because the frequency domain describes a system's response to pure sinusoids, it can not be used to characterise input signals

c. Since the frequency domain is a subset of the Laplace domain, some information about linear systems is always lost when looking only at frequency behaviour

d. Since the frequency domain describes a system's response to pure sinusoids, it can only be used to analyse responses to periodic inputs

e. None of the above

1.10. Select a true statement about linear discrete systems.

a. Sampled signals are carried inside the digital device by impulse signals ($\delta(t)$)

b. Analog filters are not required anymore since modern computers can simulate them

c. Every continuous linear system has a linear discrete equivalent

d. Discrete systems can represent calculations which have no continuous equivalent

e. Digital systems require less processing power than analog systems

Total for question 1: $\boxed{50}$

System description

Acid mine drainage is a severe problem in disused mines in South Africa, especially in Johannesburg. Your company has been hired to develop a neutralisation plant which will make use of lime to increase the pH of $10\,\mathrm{m}^3 \cdot \mathrm{h}^{-1}$ of acid drainage to safe levels. The system consists of two constant cross-section stirred tanks where lime is added to the acidic stream in two stages.

The system is shown in Figure 1. The questions in this paper will all be on this system. For the purposes of the paper, we will assume that the acid mine runoff contains only water and H_2SO_4 and that the lime additions are pure quicklime (CaO). The neutralisation reaction follows first order elementary kinetics and can be written as

$$H_2SO_4 + CaO \longrightarrow CaSO_4 + H_2O$$

The insoluble $CaSO_4$ can be assumed to be carried along in suspension between the tanks. You may assume that the concentrations of all the substances in the solution is low enough that the density of the liquid is the same throughout the system. Concentrations are in $\mathrm{kmol/m}^3$. To keep things simple, the tanks have been designed with restrictions in the output which are sized such that the level in each tank is maintained 1 m, with a design volume of $2\,\mathrm{m}^3$

We will ignore any temperature effects in this paper.

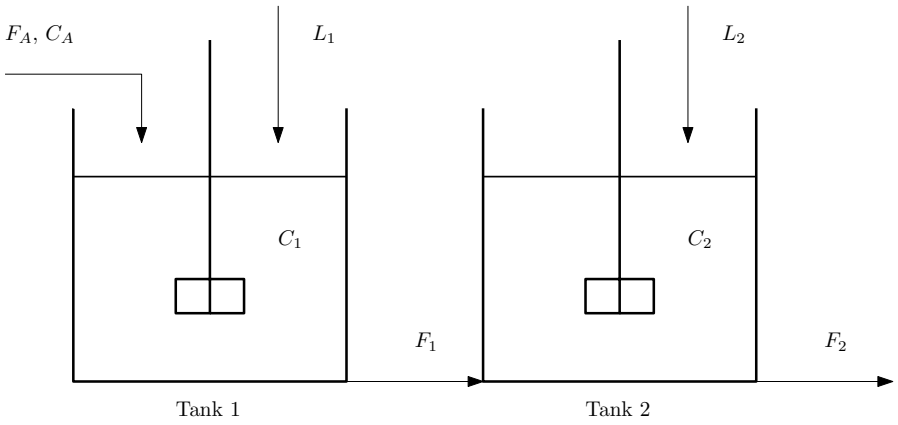


Figure 1: Neutralisation system

2 Design

2.1. Develop a dynamic model for a single tank which could be used to predict how the concentration of acid exiting the tank will respond to changes in the input streams. Make sure you check the degrees of freedom. [15]

2.2. Assume that the output flowrate F_2 responds to changes in the input flowrate according to a critically damped second order transfer function with a time constant of 20 minutes. If F_A varied approximately sinusoidally with an amplitude of $0.5\,\mathrm{m}^3 \cdot \mathrm{h}^{-1}$ at a frequency of 0.3 Hz due to a positive displacement pump being used to pump it from the mine, calculate the amplitude of the flow variation of F_2. Is it significant? [10]

2.3. How would the time constants of the transfer functions in the system respond if the tank size were halved? [5]

Total for question 2: [*30*]

3 System concepts

3.1. Draw a block diagram for the system featuring all the symbols shown in Figure 1 [10]

3.2. How many states would a state space description of this system have? Motivate. [5]

Total for question 3: *15*

4 Measurement

A colleague has been working on designing the control system for the plant but has been called away and you need to resume their work. You find the following bode diagram in their notes. They have written "Note: measurement dynamics included" in the margin of their notebook.

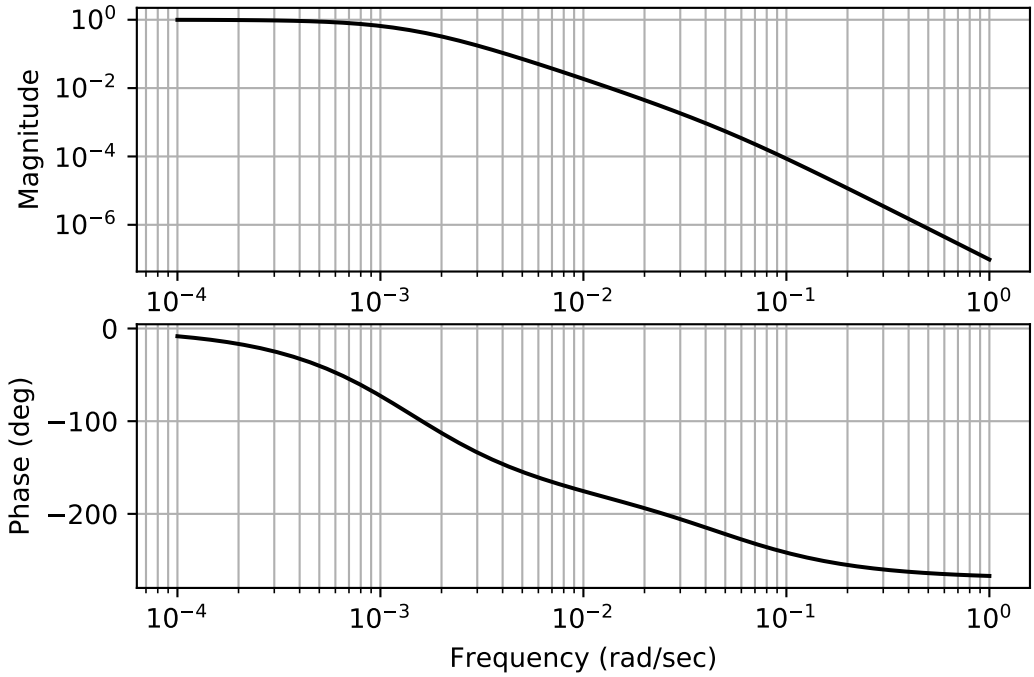


Figure 2: Bode diagram

4.1. You know the bode diagram was drawn up for F_A as the input. Identify which of the following output variables it was drawn up for: F_1, F_2, C_1, C_2. Be sure to present the evidence you used in this reasoning. [10]

4.2. What is the time constant for the measurement dynamics included in the analysis? [3]

4.3. Was there any time delay accounted for in the analysis? [2]

Total for question 4: *15*

5 Pilot data

The file `steptest.csv` contains the result of a step test on a scaled down pilot plant. C_A was changed from $0.4\,\mathrm{kmol/m^3}$ to $0.5\,\mathrm{kmol/m^3}$ at $t = 0$ and the pH of the liquid in Tank 2 was measured at intervals of 5 seconds using a pH meter.

The results are also shown in Figure 3

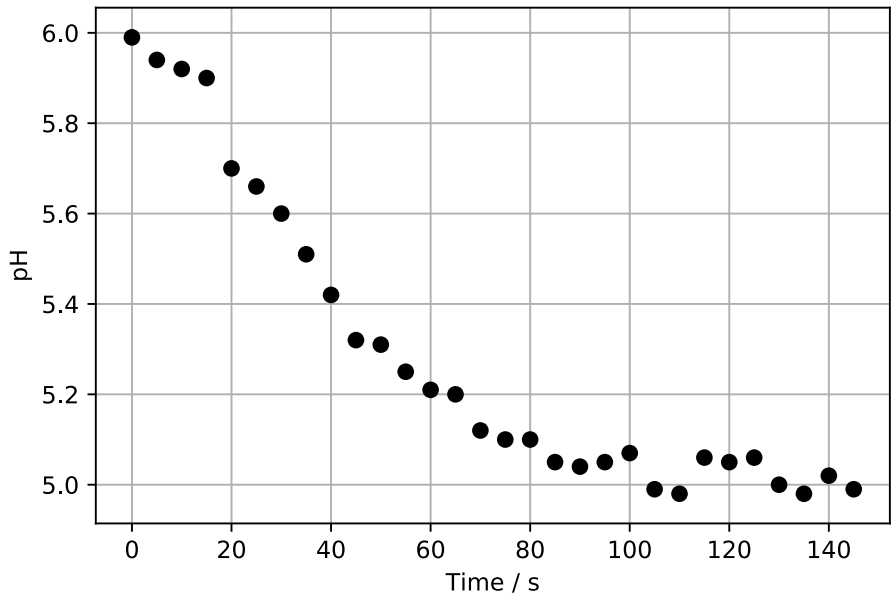


Figure 3: Step test on pilot plant

5.1. Propose an approximate transfer function relating C_A and the pH of the liquid in Tank 2. [8]

5.2. Fit a discrete model of the form $y(k) = a_1 y(k-2) + a_2 y(k-3) + b_1 u(k-1)$ to the data. Be sure to write down the first 5 rows of the matrices you construct in the process. [15]

5.3. Write the model above in transfer function form in the z domain [5]

5.4. It is clear that the measurement is quite noisy. Will accuracy of the model fit be improved by applying a moving average filter to the data before fitting? Discuss. [5]

5.5. Do you think that the models you have fitted/proposed in this section will remain valid if C_A would double? Explain why/why not. [5]

5.6. Do you think that the data have been sampled at a sufficient rate? [2]

Total for question 5: [*40*]

Full Marks [150]

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