UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2012/2013 Academic Session

June 2013

EKC 561 – Model Based Process Control

Duration : 3 hours

Please ensure that this examination paper contains SEVEN printed pages and ONE printed page of Appendix before you begin the examination.

Instruction: Answer **ALL** questions.

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1. [a] The catalyst in catalytic reactors undergoes deactivation as the reaction proceeds, due to carbonaceous deposits on it. It can be regenerated by burning off these deposits with air or oxygen. To avoid destruction of the catalyst, due to excessive temperature during the combustion of the deposits, we can use an auctioneering system which:

   [i] to take the temperature measurement from the various thermocouples along the length of the reactor.

   [ii] select the highest temperature that corresponds to the combustion front as it moves through the bed.

   [iii] control approximately the amount of air.

   Draw the auctioneering control system for a tubular catalytic reactor for this exercise.

[10 marks]

   [b] Usually, the steam pressure in a boiler is controlled through the use of a pressure control loop line. At the same time the water level in the boiler should NOT fall below a lower limit which is necessary to keep the heating coil immersed in water and thus prevent its burning out. According to this system, whenever the liquid level falls below the allowable limit, the controller switches the control action and closes the valve on the discharge line. Draw the appropriate control system to illustrate the issue here.

[10 marks]

2. Consider the following Internal Model Controller (IMC) block diagram as shown in Figure Q.2. Find the closed loop transfer function relating the load [l(s)] and the set point [r(s)] to the output [y(s)]. Assume that the model is not perfect. If that so, how the model uncertainty will be handled? If the model is perfect, the resulting transfer is similar to open loop control formulation? Explain your reasons.

[20 marks]

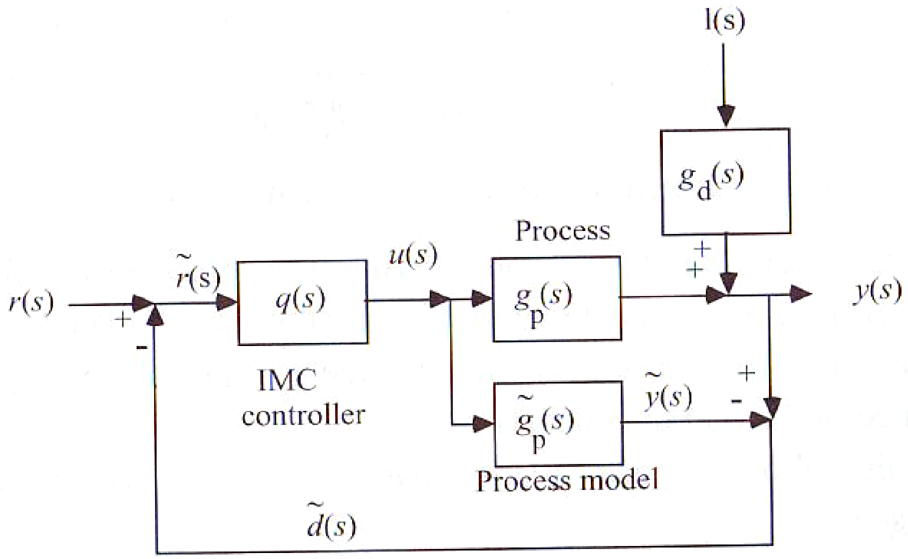


Figure Q.2.

3. [a] A plant owned by a public listed company has a problem of high ammonium in its waste water with current standard B DOE regulation of 20 mg/l. This issue has been solved using prepared concentration of magnesium chloride and sodium dihydrogen phosphate as reactants to react with the ammonium to form magnesium ammonium phosphate (MAP). Nevertheless, 10% of ammonium is remained un-reacted. The reaction is conducted in a stirred tank reactor with three streams entering the reaction tank which are the waste water, and sodium dihydrogen phosphate and the magnesium chloride respectively. The stream of sodium dihydrogen phosphate is maintained constant based on two reasons of economic aspect and less effect of it in the reaction. The other two streams can be manipulated with two controlled valves. The objectives of the operation are (1) to maintain the level of ammonium below the DOE standard limit and (2) to control the exit flow rate from the reaction tank. Since the reaction produces solid precipitation of MAP, a centrifuge is placed downstream to separate the solid and the liquid with maximum capability of 2 m^3/h. The process is equipped with controllers, ammonium "software sensor", and a flowmeter located downstream.

[i] Construct a schematic diagram of the process.

[4 marks]

[ii] Construct a block diagram of multivariable process.

[4marks]

[iii] What is source of disturbance?

[1 mark]

[b] Due to improper control tuning parameters, when there is a disturbance, the results of controlled variables can be shown in the Figure Q.3. [a]. and Figure Q.3.[b].

[i] What is implication of result in Figure Q.3.[b].[i]?

[3 marks]

[ii] What is implication of result in Figure Q.3.[b].[ii]?

[3 marks]

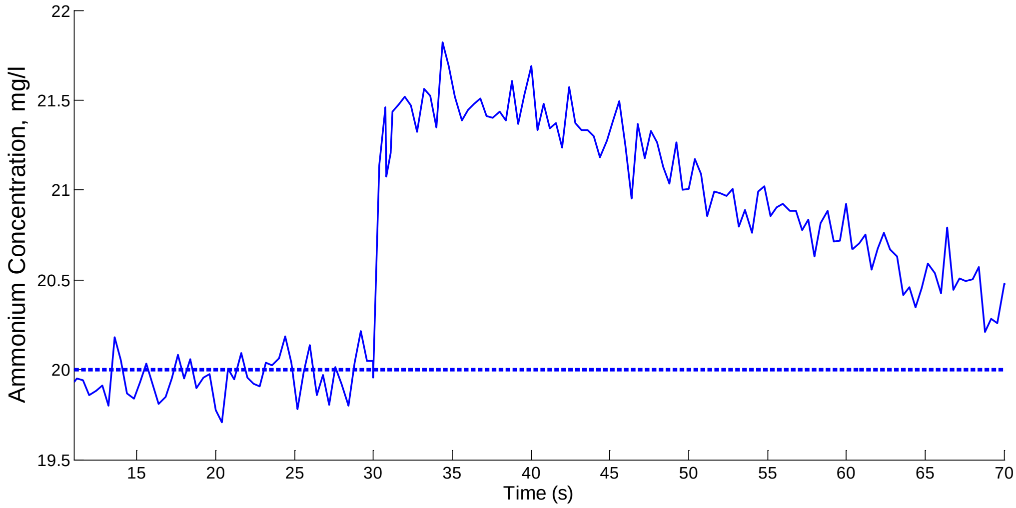


Figure Q.3.[b].[i]. Concentration at the outlet

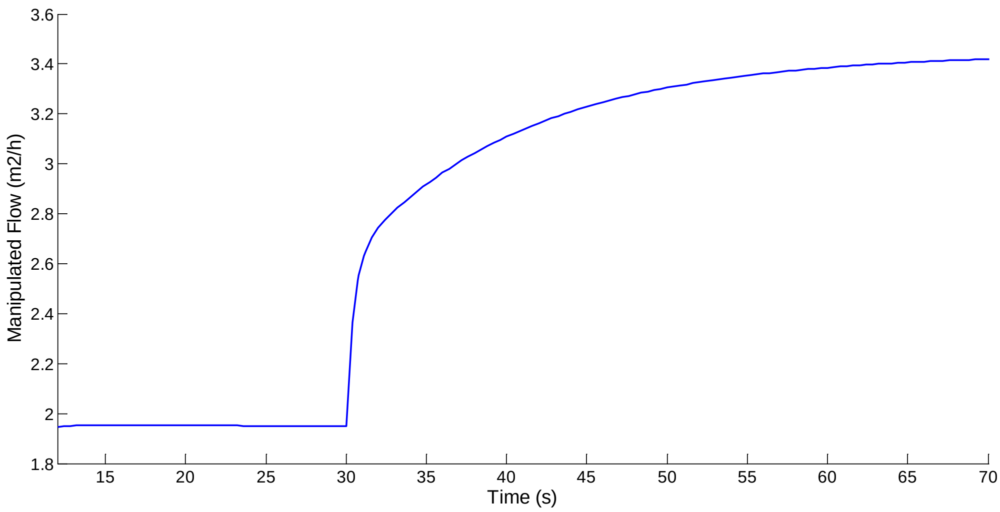


Figure Q.3.[b].[ii]. Manipulated response due to disturbance

[c] Due to the problem mentioned above, the plant experiences non compliance of DOE regulation in which the company can be compounded up to RM 2000 per day until the standard is obliged. The plant manager proposes to the management that they just pay the fine since there is nothing they can do to solve the issue.

[i] What will be the consequences of this proposal to stakeholders?

[3 marks]

[ii] Discuss the ethic of the issue.

[2 marks]

4. [a] A system has the following open loop input-output relationships:

$$y_1(s) = G_{11}(s)u_1(s) + G_{12}(s)u_2(s)$$
$$y_2(s) = G_{21}(s)u_1(s) + G_{22}(s)u_2(s)$$

The process transfer function are shown in the Table Q.4.:

Table Q.4.

$G_{11} = \dfrac{K}{3s+1}$	$G_{12} = \dfrac{5}{(s+1)(2s+1)}$
$G_{21} = \dfrac{1.5}{s+1}$	$G_{22} = \dfrac{2.55}{2s+1}$

[i] Find the gain for G_{11} based on the Figure Q.4.[a].

[2 marks]

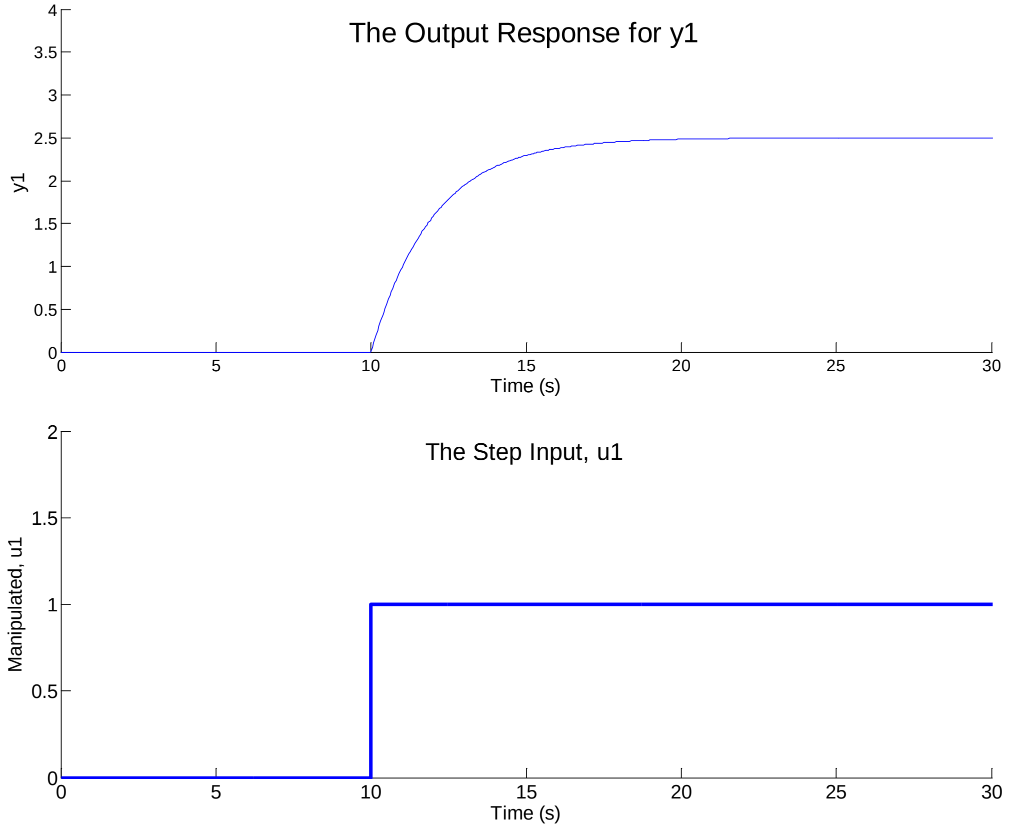
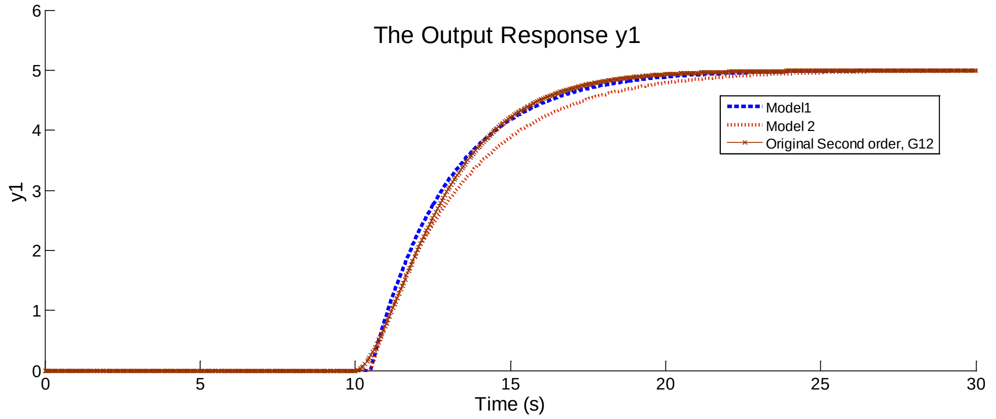


Figure Q.4.[a]

[b] The transfer function G_{12} is in second order behaviour and this can be reduced to simple model. Two diagrams in Figure Q.4.[b]. show the result of reduction.



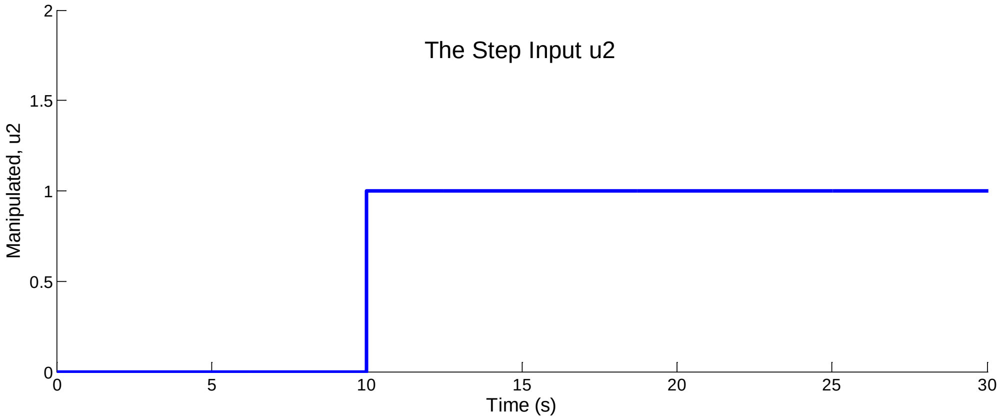


Figure Q.4.[b].

[i] Pick the correct model suitable for reduction of model G_{12} with reference to Figure Q.4.[b]. Explain your choice.

[4 marks]

[ii] Estimate the parameters of the model.

[5 marks]

[c] As for now you have completed the all the transfer function for the multiloop process. Determine how would you pair variables for your control loops? Why?

[9 marks]

5. [a] A company proposes Model Predictive Control (MPC) system for an evaporator unit in its plant as part of its modernization and migration strategy. You are selected as the Project Manager (PM) for this modernization project by your company. You are given an initial description of the unit where the implementation is going to take off. Therefore your company needs to prepare the technical specification and aspect of the project. The description is written below.

A forced circulation evaporator is used to concentrate dilute urea solution by evaporation solvent from a feed stream. Feed is mixed with circulating urea and pumped into the tube side of a vertical heat exchanger. Steam enters the shell side of the vertical heat exchanger and condenses on the outside of the tubes. The urea solution is partially vaporized as it passes through the tube side of heat exchanger and passes into the separator. Vapour from the evaporator is condensed by a cooling water exchanger, while a portion of the liquid stream from the separator is withdrawn as product and the rest is recirculated to the heat exchanger. A schematic process and instrumentation diagram is shown in Figure Q.5.

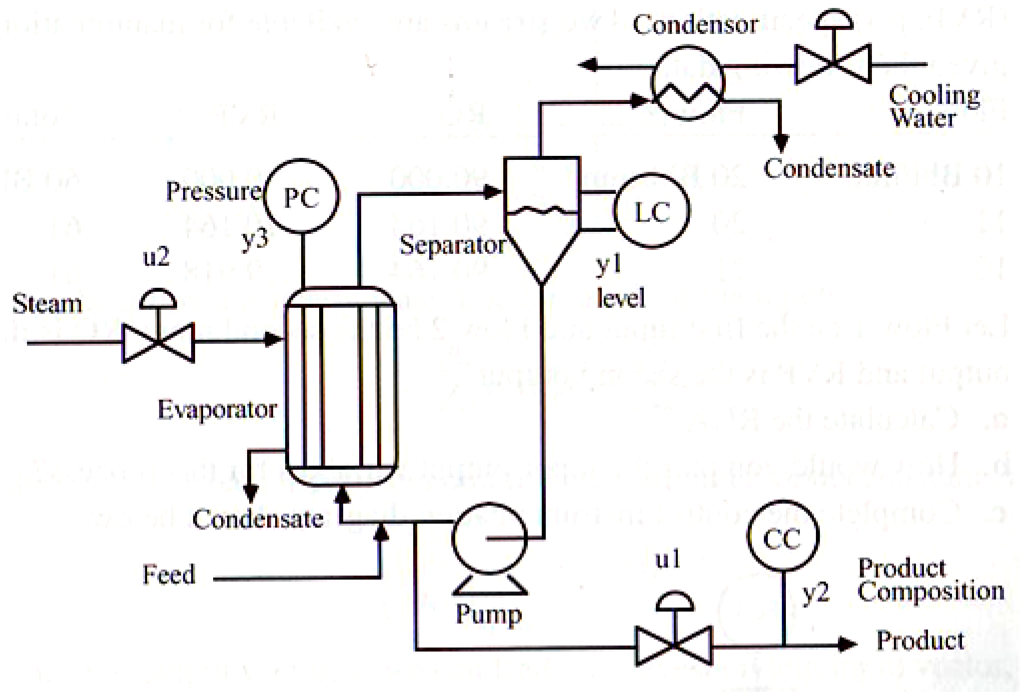


Figure Q.5.

[i] Provide the needed information for the project.

[4 marks]

[ii] Arrange the information and data with the procedure for the project to take off.

[4 marks]

[iii] Formulates action plan and timetable.

[3 marks]

[b] On the later stage of project, the company agrees to engage the proposal of Model Predictive Control (MPC), therefore your company need to prepare the technical specification and aspect of the project.

[i] Explain how to investigate the functional relationship for variables.

[3 marks]

[ii] Describe how to formulate the model for MPC.

[3 marks]

[iii] Describe how to validate the model.

[3 marks]

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Appendix

Table Laplace Transforms for Various Time-Domain Functions[a]

$f(t)$	$F(s)$
1. $\delta(t)$ (unit impulse)	1
2. $S(t)$ (unit step)	$\frac{1}{s}$
3. t (ramp)	$\frac{1}{s^2}$
4. t^{n-1}	$\frac{(n-1)!}{s^n}$
5. e^{-bt}	$\frac{1}{s+b}$
6. $\frac{1}{\tau}e^{-t/\tau}$	$\frac{1}{\tau s+1}$
7. $\frac{t^{n-1}e^{-bt}}{(n-1)!}$ $(n>0)$	$\frac{1}{(s+b)^n}$
8. $\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$	$\frac{1}{(\tau s+1)^n}$
9. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$	$\frac{1}{(s+b_1)(s+b_2)}$
10. $\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
11. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2t}$	$\frac{s+b_3}{(s+b_1)(s+b_2)}$
12. $\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$	$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$
13. $1-e^{-t/\tau}$	$\frac{1}{s(\tau s+1)}$
14. $\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$
15. $\cos\omega t$	$\frac{s}{s^2+\omega^2}$
16. $\sin(\omega t+\phi)$	$\frac{\omega\cos\phi+s\sin\phi}{s^2+\omega^2}$
17. $e^{-bt}\sin\omega t$ } b, ω real	$\frac{\omega}{(s+b)^2+\omega^2}$
18. $e^{-bt}\cos\omega t$ } b, ω real	$\frac{s+b}{(s+b)^2+\omega^2}$
19. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{\tau^2 s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1\ne\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
23. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1\ne\tau_2)$	$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$	$sF(s)-f(0)$
25. $\frac{d^n f}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$	$e^{-t_0 s}F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t\ge 0$ only.