UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2010/2011 Academic Session

April/May 2011

EKC 462 – Advanced Process Control For Industrial Processes
[Sistem Kawalan Lanjutan untuk Proses Industri]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan DUA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

1. [a] Use the Skogestad's half rule to obtain a first-order-plus-time-delay approximation for the following transfer function:

Gunakan peraturan separuh Skogestad untuk mendapatkan anggaran rangkap pindah tertib pertama dengan masa lengah bagi rangkap pindah berikut:

$$g_0(s) = \frac{7(1.5 - s)e^{-2s}}{(3s+1)(10s+1)(0.2s+1)(0.05s+1)^2}$$

Design PID controller using IMC-Based PID procedure using the reduced model.

Rekabentukkan pengawal PID dengan menggunakan kaedah IMC-asas PID dengan menggunakan model terturun tersebut.

Given:
Diberi:

$$\frac{T_0 s+1}{(\tau_0 s+1)} \approx \begin{cases} T_0/\tau_0 & \text{for } T_0 \ge \tau_0 \ge \theta & (Rule\ T1) \\ T_0/\theta & \text{for } T_0 \ge \theta \ge \tau_0 & (Rule\ T1a) \\ 1 & \text{for } \theta \ge T_0 \ge \tau_0 & (Rule\ T1b) \\ T_0/\tau_0 & \text{for } \tau_0 \ge T_0 \ge 5\theta & (Rule\ T2) \\ \dfrac{\tilde{\tau}_0/\tau_0}{(\tilde{\tau}_0 - T_0)s+1} & \text{for } \tilde{\tau}_0 \overset{def}{=} \min(\tau_0, 5\theta) \ge T_0 & (Rule\ T3) \end{cases}$$

[17 marks/markah]

[b] Derive a closed loop transfer function, Y/Y_{sp} for the Smith predictor when $G_p(s) \neq \tilde{G}_p(s)$. What is the characteristic equation?

Terbitkan rangkap pindah gelung tertutup, Y/Y_{sp} bagi peramal Smith apabila $G_p(s) \neq \tilde{G}_p(s)$. Apakah persamaan cirinya?

[8 marks/markah]

2. [a] Figure Q.2.[a] shows a step response behavior for a packed-bed reactor. A step decrease in steam valve position was made at t = 5 minutes.

Rajah S.2.[a] menunjukkan kelakuan satu sambutan langkah bagi reaktor lapisan terpadat. Satu pengurangan langkah bagi kedudukan injap stim telah dibuat pada masa t = 5 minit.

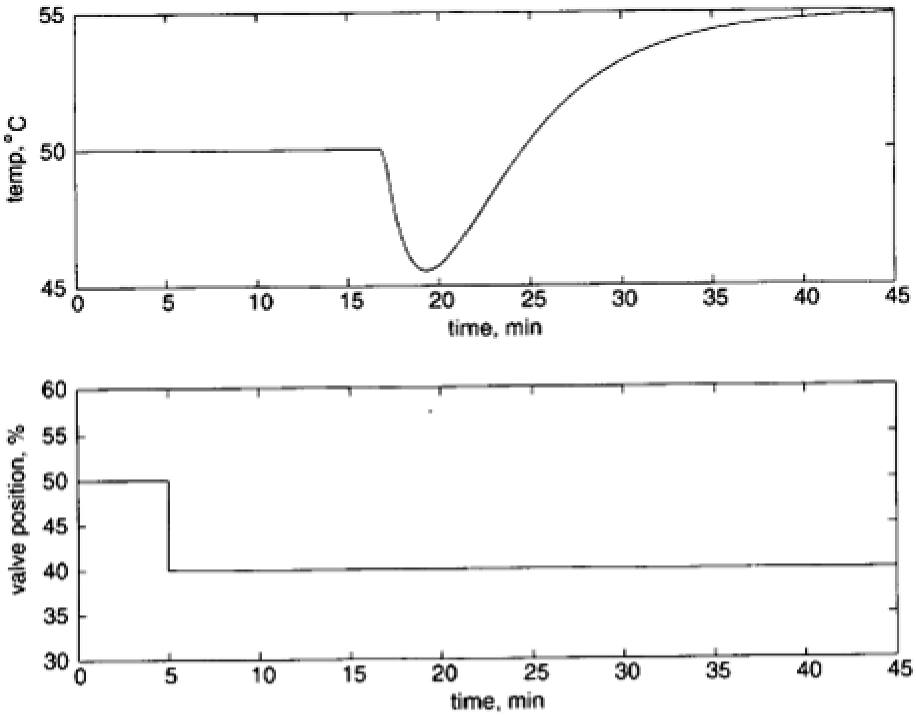

Figure Q.2.[a]: Step Response Behavior for a Packed-Bed Reactor
Rajah S.2.[a]: Kelakuan Sambutan Langkah bagi Satu Reaktor Lapisan Terpadat

The process model (the time unit is minutes) that representing the process is given as:

Proses model (unit masa ialah minit) yang mewakili proses tersebut telah dibina seperti berikut:

$$\tilde{g}_p(s) = \frac{K(-10s+1)\,e^{-\theta s}}{(5s+1)(3s+1)}$$

[i] From Figure Q.2.[a], calculate the value of K and θ. What are the units for both values?

Dari Rajah S.2.[a], kirakan nilai K dan θ. Apakah unit bagi bagi kedua-dua nilai tersebut?

[ii] Design an Internal Model Control (IMC) for this process. Use the all-pass factorization and assume that q(s) is semiproper.

Rekabentukkan Kawalan Model Dalam (IMC) bagi proses ini. Gunakan pemfaktoran lulus-semua bagi RHP sifar dan andaikan bahawa q(s) adalah separa wajar.

[iii] Assuming a perfect model, plot qualitatively how the temperature will respond to a step change of 1°C.

Dengan mengandaikan model adalah sempurna, plot secara kualitatif bagaimana suhu berubah terhadap perubahan langkah titik set 1°C

[18 marks/markah]

[b] Selectors are normally used in combustion control systems to prevent unsafe situations from occurring. Figure Q.2 [b] shows the typical configuration for high and low selectors that are applied to air and fuel flow rates. The energy demand signal comes from the steam pressure controller. Discuss how the selectors operate in this control scheme when the furnace temperature drops suddenly.

Pemilih biasanya digunakan dalam sistem kawalan pembakaran untuk menghalang situasi tidak selamat daripada berlaku. Rajah S.2. [b] menunjukkan konfigurasi biasa bagi pemilih tinggi dan rendah yang digunakan kepada kadar aliran udara dan bahan api. Isyarat pemintaan tenaga datang dari pengawal tekanan wap. Bincangkan bagaimanakah pemilih beroperasi dalam skim kawalan ini apabila suhu relau jatuh secara mendadak.

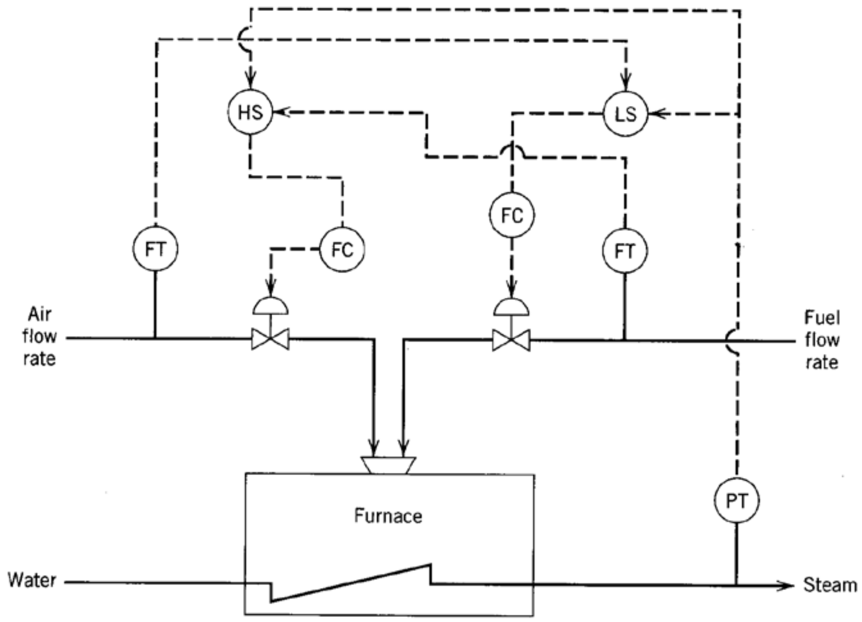

Figure Q.2. [b]: Combustion Control System
Rajah S.2. [b]: Sistem Kawalan Pembakaran

[7 marks/markah]

…5/-

3. [a] Discuss the principle of model predictive control (MPC) scheme based on the receding horizon approach. In addition, assist your explanation with diagram. Discuss the advantages and disadvantages of the MPC.

Bincangkan prinsip skema kawalan ramalan model (MPC) berdasarkan pendekatan ufuk kebelakang. Sebagai tambahan, gunakan gambarajah bagi memudahkan penjelasan anda. Bincangkan kelebihan dan kelemahan MPC.

[10 marks/markah]

[b] The cooling water enters the reactor jacket, makes a single pass, and then exits the jacket. A flow controller is provided for the cooling water flow, and the model predictive controller will output to the setpoint of this controller. The objective is to control the reactor temperature. A finite step response model will be developed for this process. Table Q.3. shows the finite step response model for the reactor with the jacket. Complete the table provided in Appendix.

Air penyejuk memasuki jaket reaktor dengan sekali lalu dan kemudian keluar dari jaket tersebut. Kawalan aliran disediakan untuk pengaliran air penyejuk tersebut dan pengawal ramalan model itu mengeluarkan tindakan ke titik set pengawal ini. Objektif proses ini adalah untuk mengawal suhu reaktor itu. Jadual S.3. menunjukkan model sambutan langkah terhingga bagi reaktor dengan jaket itu. Lengkapkan jadual yang disediakan dalam Appendik.

[5 marks/markah]

Table Q.3.
Jadual S.3.

Time, *t* *Masa*, t (min)	Actual cooling water flow *Aliran air penyeduk sebenar* (lb/min)	Change in cooling water flow *Perubahan aliran air penyejuk* (lb/min)	Actual reactor temperature *Suhu reaktor sebenar* (^oF)	Change in reactor temperature *Perubahan suhu reaktor* (^oF)	Step response *Sambutan langkah* [^oF/(lb/min)]	Impulse response *Sambutan dedenyut* [^oF/(lb/min)]
-15	108.8	0	150.0			
0	88.8	-20	150.0			
15	88.8	-20	151.0			
30	88.8	-20	151.9			
45	88.8	-20	152.5			
60	88.8	-20	153.0			
75	88.8	-20	153.4			
90	88.8	-20	153.7			
105	88.8	-20	153.9			
120	88.8	-20	154.1			
135	88.8	-20	154.2			
150	88.8	-20	154.3			
165	88.8	-20	154.4			
180	88.8	-20	154.4			
195	88.8	-20	154.5			
210	88.8	-20	154.5			
225	88.8	-20	154.5			
240	88.8	-20	154.5			

[c] With the low dimension configuration of horizon R = 4 and number of control moves L = 2, it is to formulate the controller for the reactor temperature. Show the final computation of the control moves using the data of Table Q.3.

Dengan konfigurasi dimensi rendah pada ufuk R = 4 dan bilangan pergerakan kawalan L = 2, ia adalah untuk menformulasikan pengawal untuk suhu reaktor. Tunjukkan pengiraan akhir bagi pergerakan kawalan menggunakan data dalam Jadual S.3.

[10 marks/markah]

4. Figure Q.4. shows control configuration for a purified water supply process with a variable speed drive for the pump. The designated manipulated and controlled variables are

Gambarajah S.4. menunjukkan konfigurasi bagi proses bekalan air terawat dengan pam yang berfungsi dari pemacuan laju berbeza. Pembolehubah-pembolehubah olahan dan kawalan adalah

M_1: recirculation valve opening (%)
M_2: recirculation pump speed (rpm)
C_1: recirculation pressure (psig)
C_2: recirculation flow (gpm)

M_1: bukaan injap aliran edaran semula (%)
M_2: laju pam aliran edaran semula (rpm)
C_1: tekanan aliran edaran semula (psig)
C_2: aliran edaran semula (gpm)

The process gain matrix *K* are as follows:
Matrik gandaan proses, K *adalah seperti berikut:*

$$K = \begin{bmatrix} -0.636\,psig/\% & 0.0495\,psig/rpm \\ 1.132\,gpm/\% & 0.0121\,gpm/rpm \end{bmatrix}$$

[a] Obtain the decoupler matrix G using the V-Canonical Decoupler.
Dapatkan matrik nyahgandingan G menggunakan nyahgandingan berkanun V.

[5 marks/markah]

[b] Use the calibrated range below for the manipulated variable and convert the resulting matrix into a new one.
Gunakan julat kalibrasi di bawah untuk pembolehubah olahan dan tukarkan hasil matrik ke matrik yang baru.

[3 marks/markah]

Manipulated variable *Pembolehubah olahan*	Range *Julat*
Recirculation valve opening *Bukaan injap aliran edaran semula*	0 to 100%
Recirculation pump speed *Laju pam aliran edaran semula*	0 to 4000 rpm

[c] Later provide two options in table form which must include the manipulated variable involved, process gain matrix **K**, inverse $\mathbf{K}^{-1}$ decoupler inputs and the decoupler matrix **G.**

*Kemudian, berikan dua pilihan dalam bentuk jadual di mana ia mesti mengandungi pembolehubah olahan yang berkaitan, matrik gandaan proses, **K**, masukan nyahgandingan songsang $\mathbf{K}^{-1}$ dan matrik nyahgandingan **G.***

[17 marks/markah]

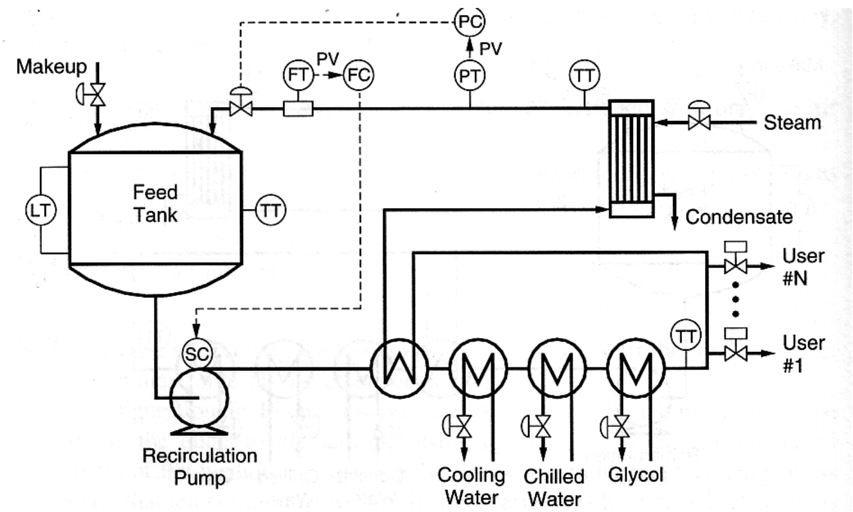

Figure Q.4.: The configuration of purified water supply
Gambarajah S.4.: Kongfigurasi bekalan air terawat

- oooOooo -

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. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\ne\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
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. $\frac{d^nf}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$	$e^{-t_0s}F(s)$

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

…2/-

Table Q.3.
Jadual S.3.

Time, *t* *Masa*, t (min)	Actual cooling water flow *Aliran air penyeduk sebenar* (lb/min)	Change in cooling water flow *Perubahan aliran air penyejuk* (lb/min)	Actual reactor temperature *Suhu reaktor sebenar* (^oF)	Change in reactor temperature *Perubahan suhu reaktor* (^oF)	Step response *Sambutan langkah* [^oF/(lb/min)]	Impulse response *Sambutan dedenyut* [^oF/(lb/min)]
-15	108.8	0	150.0			
0	88.8	-20	150.0			
15	88.8	-20	151.0			
30	88.8	-20	151.9			
45	88.8	-20	152.5			
60	88.8	-20	153.0			
75	88.8	-20	153.4			
90	88.8	-20	153.7			
105	88.8	-20	153.9			
120	88.8	-20	154.1			
135	88.8	-20	154.2			
150	88.8	-20	154.3			
165	88.8	-20	154.4			
180	88.8	-20	154.4			
195	88.8	-20	154.5			
210	88.8	-20	154.5			
225	88.8	-20	154.5			
240	88.8	-20	154.5			