UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2011/2012 Academic Session

June 2012

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 SIX printed pages and ONE printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM muka surat yang bercetak dan SATU 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].

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] Compare the response of the following process using IMC and IMC-based PID. Discuss the effect of λ on the closed-loop stability for both systems.

Bandingkan sambutan bagi proses berikut dengan menggunakan IMC dan PID berasaskan IMC. Bincang kesan λ terhadap kestabilan gelung tertutup bagi kedua-dua sistem.

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

Is there a minimum λ required for the stability of the IMC and IMC-based PID strategy?

Adakah nilai minima λ diperlukan bagi kestabilan strategi IMC dan PID berasaskan IMC tersebut?

[18 marks/markah]

[b] A waste stream (dilute nitric acid) is neutralized by adding a base stream (sodium hydroxide) of known concentration to a stirred neutralization tank, as shown in Figure Q.1.[b]. The concentration and the flow rate of the waste acid stream vary unpredictably. The flow rates of the waste stream and base stream can be measured. The effluent stream pH can be measured, but a significant time delay occurs due to the downstream location of the pH probe. Past experience has indicated that it is not possible to tune a standard PID controller so that satisfactory control occurs over the full range of operating conditions. As a process control specialist, you have been requested to recommend an advanced control strategy that has the potential of greatly improved control. Justify your proposed method, being as specific as possible. Also, cite any additional information that you will need.

Satu alur sisa (asid nitrik cair) dineutralkan dengan menambahkan satu alur bes (kalium hidroksida) yang diketahui kepekatannya ke tangki peneutralan seperti yang ditunjukkan dalam Rajah S.1.[b]. Kepekatan dan kadar aliran bagi alur sisa berubah secara tak teramal. Kedua-dua kadar aliran alur sisa dan alur bes boleh diukur. pH bagi alur keluar boleh diukur tetapi menyebabkan berlakunya masa lengah yang bererti disebabkan kedudukan di hilir kuar pH. Pengalaman lepas menunjukkan, tidak mungkin untuk menala pengawal PID untuk mendapat kawalan yang memuaskan sepanjang keadaan operasi. Sebagai seorang pakar proses kawalan, anda diminta untuk mencadangkan strategi kawalan termaju yang berpotensi untuk menambahbaik kawalan tersebut. Berikan justifikasi terhadap kaedah yang dicadangkan dengan secara khusus. Juga, nyatakan maklumat tambahan yang anda perlukan.

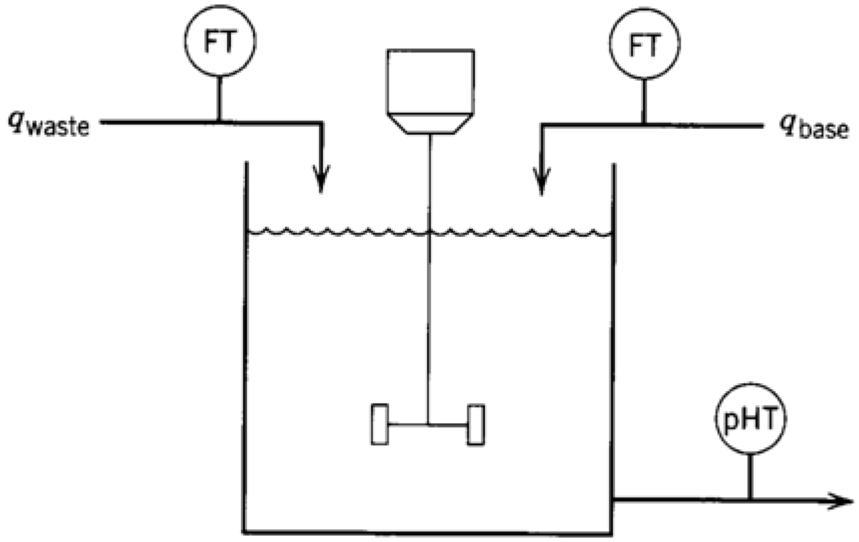

Figure Q.1.[b]: Stirred Neutralization Tank
Rajah S.1.[b]: Tangki Peneutralan Teraduk

[7 marks/markah]

2. [a] Smith predictor is to be used with an integrator-plus-time-delay process.
Pemampas Smith digunakan bersama proses dengan pengamir dan masa-lengah seperti berikut:

$$g_p(s) = \frac{2}{s}e^{-3s}$$

[i] Derive the closed-loop disturbance transfer function, Y/D.
Terbitkan rangkap gelung tertutup bagi gangguan, Y/D.

[ii] For a unit step disturbance and $g_d = g$, shows that PI control will not eliminate offset even when the model is known perfectly.
Bagi gangguan satu unit langkah dan $g_d = g$, tunjukkan bahawa pengawal PI tidak akan menghapuskan ofset walaupun model adalah sempurna.

Given:

L'Hopital's Rules:
If $\lim_{x\to c} f(x) = 0$ *and* $\lim_{x\to c} g(x) = 0$ or $\lim_{x\to c} f(x) = \infty$ *and* $\lim_{x\to c} g(x) = \infty$, then

$\lim_{x\to c}\frac{f(x)}{g(x)} = \lim_{x\to c}\frac{f'(x)}{g'(x)}$, c is either a finite number or ∞.

Diberi:
Peraturan L'Hopital':
Jika $\lim_{x\to c} f(x) = 0$ *dan* $\lim_{x\to c} g(x) = 0$ *atau* $\lim_{x\to c} f(x) = \infty$ *dan* $\lim_{x\to c} g(x) = \infty$
maka

$\lim_{x\to c} \frac{f(x)}{g(x)} = \lim_{x\to c} \frac{f'(x)}{g'(x)}$, *c samada nombor terhingga atau* ∞.

[16 marks/markah]

[b] Design an IMC controller for each of the following process model using all pass factorization. Keep you final answer in *s* domain.

Rekabentukkan pengawal IMC bagi setiap proses model berikut dengan menggunakan pemfaktoran semua lulus. Kekalkan jawapan akhir anda dalam domain s.

[i] $$\frac{s^2 - s - 2}{s^4 + 6.5s^3 + 15s^2 + 14s + 4}$$

[ii] $$\frac{10(s-1)e^{-s}}{s^2 + s - 2}$$

[iii] $$\frac{d^2y}{dt^2} - \frac{2dy}{dt} - 3y(t) = u(t) - \frac{d}{dt}u(t)$$

[9 marks/markah]

3. [a] The cooling water enters the jacket of reactor then exits the jacket. A flow controller is provided for the cooling water flow. It is determined to use model predictive control to control the reactor temperature. A finite step response model will be developed for this process.

Air penyejuk memasuki jaket reaktor dan kemudian keluar darinya. Pengawal aliran disediakan untuk aliran air penyejuk itu. Kawalan ramalan model ditentukan untuk mengawal suhu reaktor itu. Satu model sambutan langkah terhingga akan dibina untuk proses tersebut.

[i] Table Q.3.[a]. shows the data of step response of the reactor. Complete the table Q.3.[a].
Jadual S.3[a]. menunjukkan data sambutan langkah reaktor itu. Lengkapkan Jadual S.3.[a].

Table Q.3.[a].: Based on the finite step response model for a jacketed reactor.
Jadual S.3.[a].: Berdasarkan model sambutan langkah terhingga bagi reaktor berjaket.

Time, T (min)	Actual cooling water flow (lb/min)	Change in cooling water flow	Actual reactor temperature (^{o}F)	Change in reactor temperature	Step response (^{o}F/(lb/min))	Impulse response (^{o}F/(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			

[3 marks/markah]

[ii] Formulate the controller for the reactor temperature with the low dimension configuration of horizon R = 4 and number of control moves L = 2. Show the final control moves using the data of Table Q.3.[a].
Formulasikan kawalan suhu reaktor dengan konfigurasi dimensi rendah pada ufuk R = 4 dan bilangan gerakan kawalan L = 2. Tunjukkan langkah kawalan akhir dengan menggunakan data Jadual S.3.[a].

[7 marks/markah]

[b] You are given a task to propose model predictive control scheme (MPC) for a continuous stirred tank blending system as shown in Figure Q.3.[b]. The control objective is to blend the inlet streams to produce an outlet stream that has the desired composition. Stream 1 is a mixture of two chemical species, *A* and *B*. It is assumed that its mass flow rate w_1 is constant, but the mass fraction of A, x_1, varies with time. Stream 2 consists of pure A and thus x_2 = 1. The mass flow rate of stream 2, w_2 can be manipulated using a control valve. The mass fraction of A in the exit stream is denoted by x, and the desired value (setpoint) by x_{sp}. Thus for this issue, the controlled variable is x, the manipulated variable is w_2 and the disturbance variable is x_1. Write in details of your proposal report of control design from the beginning of mass balance until the proposed MPC control scheme algorithm.

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Anda diberi tugas mencadangkan skema kawalan ramalan model (MPC) untuk sistem campuran tangki teraduk berterusan seperti yang ditunjukkan dalam Rajah S.3.[b]. Objektif kawalan adalah mencampurkan aliran-aliran masukan bagi membentuk komposisi yang dikehendaki dalam aliran keluaran. Aliran 1 adalah campuran dua spesis kimia, A *dan* B*. Aliran jisim* w_1 *adalah malar tetapi pecahan jisim* A*,* x_1*, boleh berubah dengan masa. Aliran 2 mempunyai spesis* A *sahaja, dan* $x_2 = 1$*. Aliran jisim 2,* w_2 *boleh diolah menggunakan injap kawalan. Pecahan jisim A dalam aliran keluar adalah* x *dan nilai dikehendaki (titik set) adalah* x_{sp}*. Bagi isu ini, pembolehubah kawalan adalah* x*, pembolehubah olahan adalah* w_2 *dan pembolehubah gangguan adalah* x_1*. Tuliskan satu laporan cadangan untuk rekabentuk kawalan dari mula iaitu pada imbangan jisim sehingga algoritma skema kawalan MPC yang dicadangkan.*

[15 marks/markah]

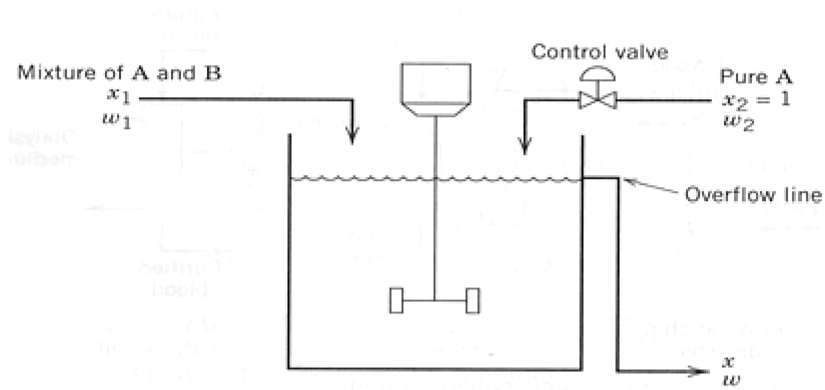

Figure Q.3.[b].: The continuous stirred tank blending system
Rajah S.3.[b].: Sistem campuran tangki teraduk berterusan

4. Composition of chemical A (mole percent) in 2 streams with flowrate F_1 and F_2 are x_1 = 80% and x_2 = 20% respectively. It is desired to apply two control loops to regulate the product compositions *x* and flow rate F. Let $F = y_1$ and $x = y_2$ be the two controlled outputs, while $F_1 = m_1$ and $F_2 = m_2$ are the two available manipulated variables. Draw the two possible control configurations with different pairings between the inputs and outputs. Determine the preferred control configuration pairing. Show how do you arrive at the preferred one. Provide two main conclusions of the chosen preferable control configuration pairings.

Komposisi bahan kimia A (peratus mol) dalam 2 aliran pada kadar alir F_1 *dan* F_2 *adalah masing-masing* x_1 *= 80% dan* x_2 *= 20%. Keadaan mengkehendaki dua gelung kawalan digunakan untuk mengatur komposisi produk,* x *dan aliran F. Biarkan* $F = y_1$ *dan* $x = y_2$ *sebagai keluaran kawalan, di mana* $F_1 = m_1$ *dan* $F_2 = m_2$ *adalah dua pembolehubah yang boleh diolah. Lukiskan dua konfigurasi kawalan yang mungkin dengan pasangan berlainan antara masukan dan keluaran. Tentukan konfigurasi pasangan kawalan yang dikehendaki. Tunjukkan bagaimana anda menentukan pasangan kawalan yang dikehendaki. Berikan dua kesimpulan penting untuk pasangan konfigurasi kawalan yang dikehendaki.*

[25 marks/markah]

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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. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0 \le \lvert\zeta\rvert < 1)$		$\frac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1 \neq \tau_2)$		$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1 \neq \tau_2)$		$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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.