UNIVERSITI SAINS MALAYSIA

First Semester Examination
2016/2017 Academic Session

December 2016 / January 2017

EKC 361 – Process Dynamics and Control
[Kawalan Dinamik dan Proses]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of THIRTEEN pages of printed material and FOUR pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TIGA BELAS muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

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

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

Write your index number in the space provided on the question paper to be attached to answer sheet.

[Tulis nombor angka giliran dalam ruangan yang disediakan pada kertas soalan peperiksaan untuk dikepilkan bersama kertas jawapan.]

Answer ALL questions.

1. [a] A thermometer having a time constant of 0.2 min is placed in a temperature bath, and after the thermometer comes to equilibrium with the bath, the temperature of the bath is increased linearly with time at a rate of 1°/min.

   [i] Identify the difference between the indicated temperature and the bath temperature 1.0 min after the change in temperature begins?

   [9 marks]

   [ii] Determine the maximum deviation between the indicated temperature and bath temperature, and when does it occur?

   [2 marks]

   [iii] After a long enough time, identify the time does the response lag the input?

   [1 mark]

   [b] The level in a tank shown in Figure Q.1.[b].[i] responds as a first order system with changes in the inlet flow. Figure Q.1.[b].[ii] shows the plot of level *vs.* time that was constructed from data collected after the inlet flow was increased quickly from 1.5 gal/min to 4.8 gal/min. Determine the transfer function that relates the height in the tank to the inlet flow.

   [7 marks]

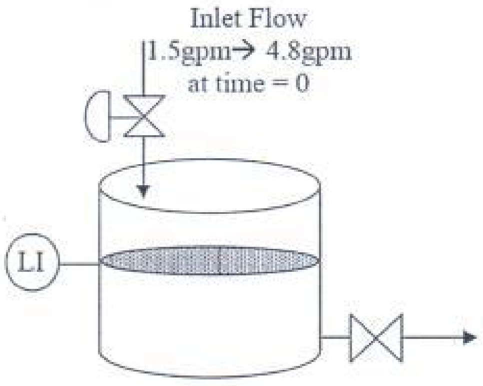


Figure Q.1.[b].[i]

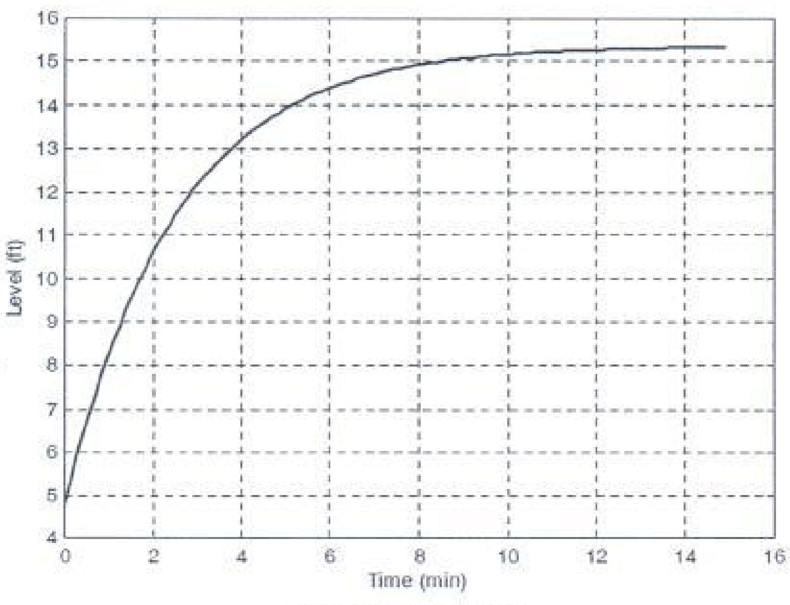


Figure Q.1.[b].[ii]

Jawab SEMUA soalan.

1. [a] *Satu termometer mempunyai pemalar masa 0.2 min diletakkan di dalam rendaman suhu. Selepas termometer mencapai keseimbangan dengan rendaman tersebut, suhu rendaman meningkat secara lelurus dengan masa pada kadar 1°/min.*

[i] *Kenal pasti perbezaan antara suhu tertunjuk dan suhu rendaman selepas 1.0 min perubahan suhu bermula?*

[9 markah]

[ii] *Tentukan sisihan maksimum antara suhu tertunjuk dan suhu rendaman dan bilakah ia berlaku?*

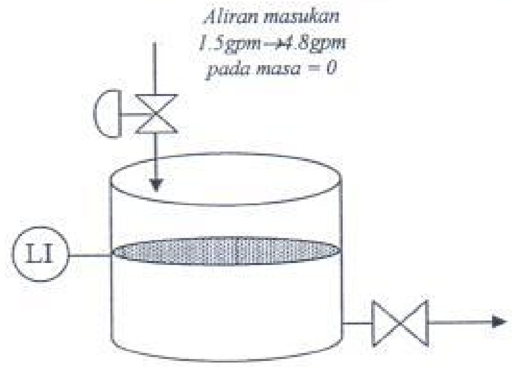
[2 markah]

[iii] *Selepas suatu masa yang panjang, kenal pasti masa sambutan lengah dari masukan?*

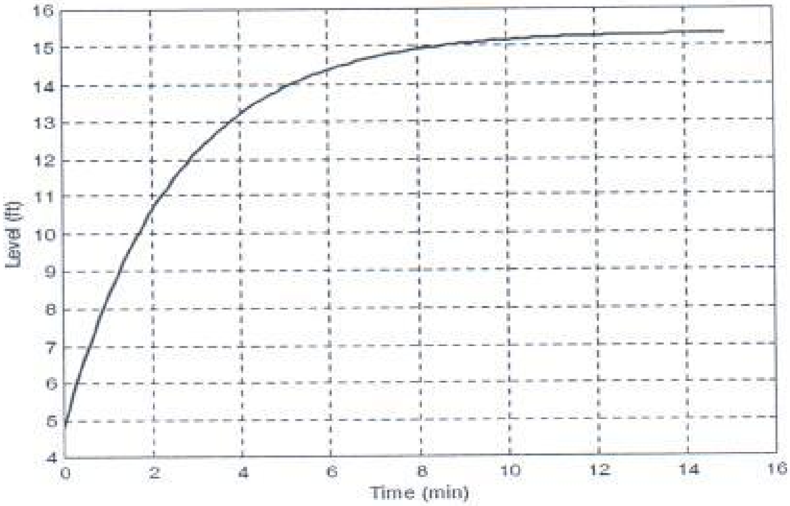
[1 markah]

[b] *Aras satu tangki ditunjukkan dalam Rajah S.1.[b].[i] memberi sambutan sebagai sistem tertib pertama terhadap perubahan pada aliran masukan. Rajah S.1.[b].[ii] menunjukkan plot aras melawan masa yang dibina daripada data terkumpul selepas aliran masukan ditambah secara cepat daripada 1.5 gal/min kepada 4.8 gal/min. Tentukan rangkap pindah yang menghubungkan antara ketinggian aras dalam tangki dengan aliran masukan.*

[7 markah]



Rajah S.1.[b].[i]



Rajah S.1.[b].[ii]

[c] Construct the block diagram representing the following transfer functions. In each case, do not conduct any algebraic manipulations to simplify the transfer functions, but use the rules of block diagram algebra to simplify the diagram if possible.

$$Y(s) = \frac{K_1}{(\tau_1 s + 1)} X(s) + \frac{K_2}{(\tau_2 s + 1)} X(s)$$

$$Y(s) = \frac{1}{(\tau s + 1)} [K_1 F_1(s) - K_2 F_2(s)]$$

$$Y_1(s) = G_1(s) X(s) + G_3(s) Y_2(s)\ ;\ Y_2(s) = G_2(s) Y_1(s)$$

[6 marks]

2. [a] Develop the transfer function $H(s)/Q(s)$ for the liquid-level system shown in Figure Q.2.[a] when the tank level operates about the steady-state value of :

[i] $h_s = 1\ ft$
[ii] $h_s = 3\ ft$

The pump removes water at a constant rate of 10 ft^3/min (cfm), this rate is independent of head. The cross-sectional area of the tank is 1.0 ft^2 and the resistance R is 0.5 $ft/(ft^3.min^{-1})$.

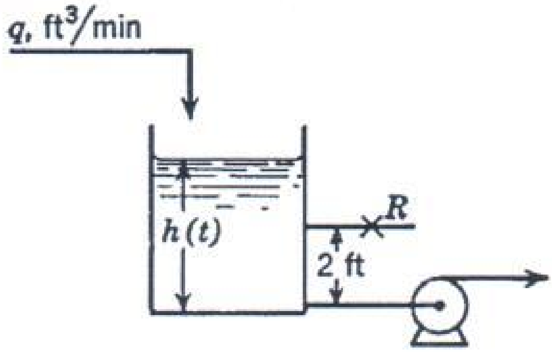


Figure Q.2.[a].: Liquid-level system

[10 marks]

[b] Process wastewater (density = 1000 kg/m^3) flows at 500,000 kg/h into a holding pond with a volume of 5000 m^3 and then flows from the pond to a river. Initially, the pond is at steady state with a negligible concentration of pollutants. Because of a malfunction in the wastewater treating process, the concentration of pollutants in the inlet stream suddenly increases to 500 mass ppm (kg of pollutant per million kg of water) and stays constant at that value.

[i] Assuming a perfectly mixed pond, develop the transfer function of the pollutant concentration in the outlet stream to the concentration of the inlet stream. Also determine for how long the process malfunction can go undetected before the outlet concentration of pollutants exceeds the regulated maximum value of 350 ppm.

[6 marks]

[ii] Repeat part [i], assuming that the water flows in plug flow (without mixing) through the pond. Note that this means the pond behaves as a pipe and the response of the concentration is a pure transportation lag.

[3 marks]

[c] *Bina gambarajah blok yang mewakili rangkap-rangkap pindah berikut. Dalam setiap kes, jangan lakukan sebarang manipulasi algebra untuk memudahkan rangkap pindah tersebut, sebaliknya gunakan peraturan algebra bagi gambarajah blok untuk meringkaskan gambarajah tersebut jika boleh.*

$$Y(s) = \frac{K_1}{(\tau_1 s+1)} X(s) + \frac{K_2}{(\tau_2 s+1)} X(s)$$

$$Y(s) = \frac{1}{(\tau s+1)} [K_1 F_1(s) - K_2 F_2(s)]$$

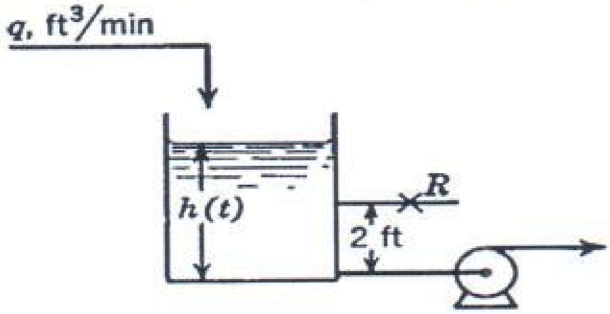
$$Y_1(s) = G_1(s)X(s) + G_3(s)Y_2(s)\,;\; Y_2(s) = G_2(s)Y_1(s)$$

[6 markah]

2. [a] *Bina rangkap pindah H(s)/Q(s) bagi sistem aras-cecair seperti yang ditunjukkan dalam Rajah S.2.[a] tersebut apabila aras tangki beroperasi pada keadaan keseimbangan:*

(i) $h_s = 1$ *kaki*
(ii) $h_s = 3$ *kaki*

Pam tersebut memindahkan air pada kadar malar 10 kaki^3*/min; kadar ini tidak bergantung kepada turus. Luas keratan rentas tangki tersebut ialah 1.0 kaki*^{2} *dan rintangan R ialah 0.5 kaki/(kaki*^{3} *min*$^{-1}$*).*



Rajah S.2.[a].: Sistem aras air

[10 markah]

[b] *Air sisa proses (kepadatan = 1000 kg/m*^{3}*) mengalir pada 500 m*^{3}*/jam ke dalam satu kolam penahan yang berisipadu 5000 m*^{3} *dan kemudiannya mangalir dari kolam ke sebuah sungai. Pada awalnya, kolam tersebut berada pada keadaan mantap dengan kepekatan pencemar boleh diabaikan. Disebabkan kegagalan proses perawatan air sisa, kepekatan pencemar dalam aliran masukan meningkat secara tiba-tiba kepada 500 ppm (kg pencemar per juta kg air) dan kekal pada nilai tersebut.*

[i] *Anggap kolam bercampur secara sempurna, dapatkan rangkap pindah bagi kepekatan pencemar dalam aliran keluar terhadap kepekatan pencemar pada aliran masuk. Juga, tentukan berapa lamakah masa diambil dari mula kegagalan proses sehingga kepekatan keluaran melebih nilai maksimum 350 ppm.*

[6 markah]

[ii] *Ulangi bahagian [i], anggap air mengalir dalam aliran palam (tanpa bercampur) melalui kolam tersebut. Ini bermaksud, kolam bertindak seperti satu paip dan sambutan terhadap kepekatan adalah masa lengah tulen.*

[3 markah]

[iii] In both parts [i] and [ii], it is assumed that the entire volume of the pond is active. How the answers will be affected if portions of the pond were stagnant and were not affected by the flow of water in and out?

[1 mark]

[c] Match the transfer functions with the responses to a unit step input, shown in Figure Q.2.[c].

[i] $\dfrac{3(-2s+1)}{s^2+0.5s+1}$

[ii] $\dfrac{-2e^{-3s}}{3s+1}$

[iii] $\dfrac{2}{-5s+1}$

[iv] $\dfrac{1}{s(5s+1)}$

[v] $\dfrac{4s+1}{2s+1}$

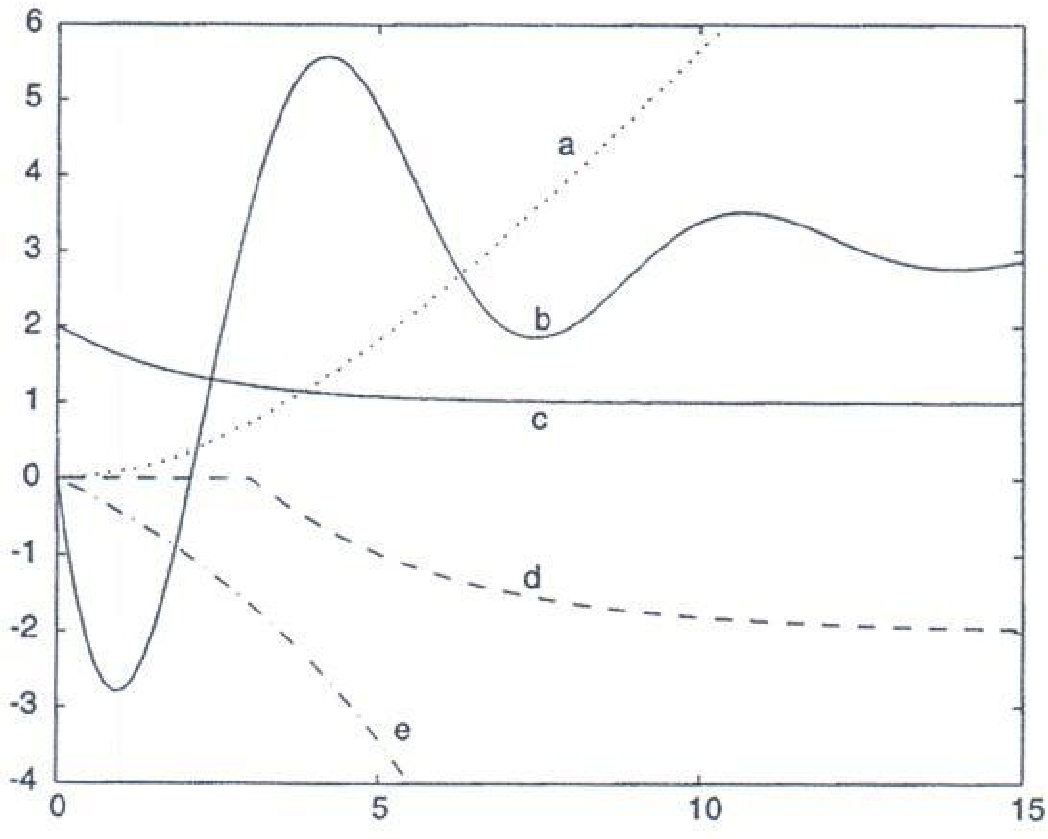


Figure Q.2.[c]

[5 marks]

[iii] *Dalam kedua-dua bahagian [i] dan [ii], kesemua isipadu kolam dianggap aktif. Bagaimanakah kesan terhadap jawapan tersebut jika sebahagian daripada kolam tersebut adalah tidak aktif dan tidak dipengaruhi oleh aliran air masuk dan keluar?*

[1 markah]

[c] *Padankan rangkap-rangkap pindah dengan sambutan-sambutan terhadap satu unit langkah masukan seperti ditunjukkan dalan Rajah S.2.[c].*

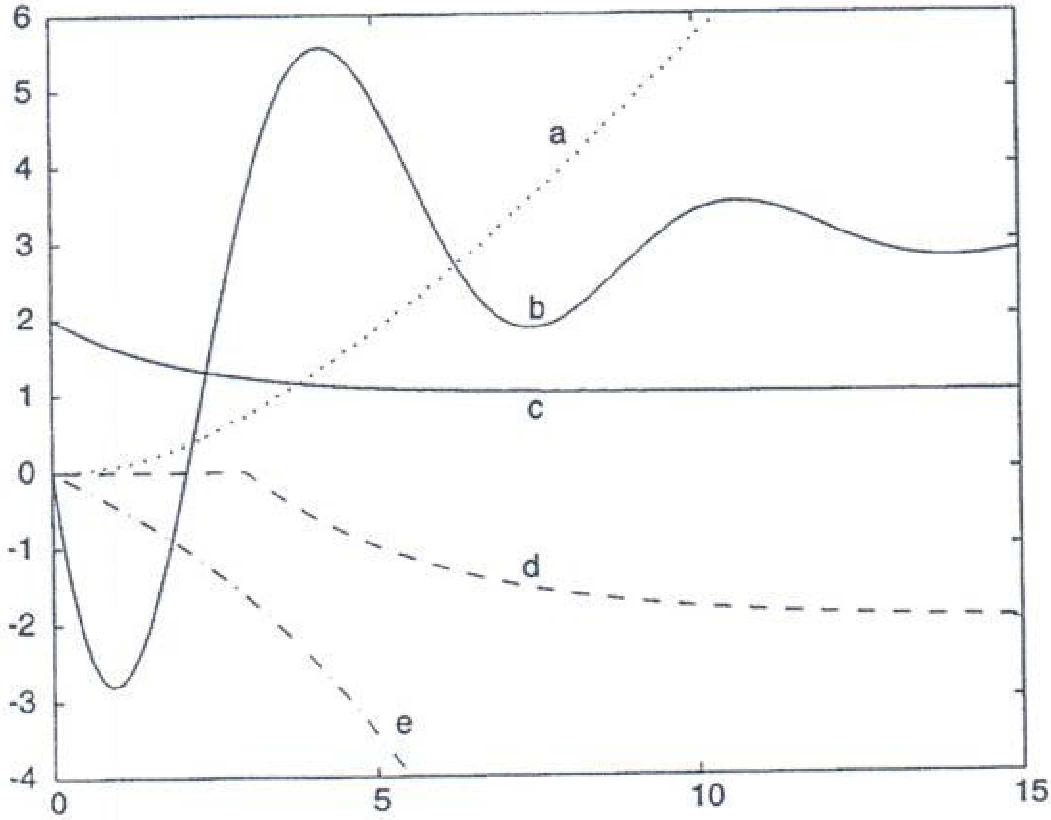
[i] $\dfrac{3(-2s+1)}{s^2+0.5s+1}$

[ii] $\dfrac{-2e^{-3s}}{3s+1}$

[iii] $\dfrac{2}{-5s+1}$

[iv] $\dfrac{1}{s(5s+1)}$

[v] $\dfrac{4s+1}{2s+1}$



Rajah S.2.[c]

[5 markah]

3. Consider the transfer function of a temperature control loop for a heat exchanger as follow:

Heat Exchanger: The heat exchanger outlet temperature response to the service stream flowrate has a gain of -1.20 [C/(l/min)], a time constant of 2.0 min, and a dead time constant of 0.90 min

$$G_p(s) = -\frac{1.20}{2.0s+1}e^{-0.90s}$$

Sensor/Transmitter: The sensor/transmitter has unitary gain ($^oC/^oC$)

$$G_m(s) = 1.0$$

Control valve: The control valve (linear characteristics) has capacity of 25 l/min at 50 % opening and a time constant of 0.20 min.

$$G_f(s) = \frac{0.50}{0.20s+1}$$

Controller: The controller is proportional only

$$G_c(s) = K_c$$

[a] Draw a block diagram for the closed loop system.

[4 marks]

[b] Find the characteristic equation for the closed loop system for the transfer functions defined in part [a] by assuming the servo control.

[3 marks]

[c] Analyse the stability of the system in part [b] using the Routh stability method and determine the minimum and the maximum stable gain for the controller (K_c).

Hints: use the first order Pade approximation to express the exponential term in a rational form.

[8 marks]

[d] The open loop response for the heat exchanger outlet temperature to a 5% step change on the control valve opening at t = 0 is shown in Figure Q.3 from the nominal values of 50% control valve opening. Calculate the effective dead time, time constant and gain by using process reaction curve method. Indicate the units of the dead time, time constant and the gain. Show the calculated values in Figure A.3 provided in Appendix and attached with your answer booklet.

[6 marks]

[e] Since the current *P*-only controller was expected to give undesirable offset, it is decided to implement a *PI* controller.

[i] Determine the *PI* controller using Cohen Coon tuning method by determining the values of the appropriate controller parameters using information in part [d].

[2 marks]

[ii] Write the transfer function of the new *PI* controller.

[2 marks]

...9/-

3. *Pertimbangkan gelung rangkap pindah kawalan suhu untuk penukar haba seperti berikut:*

Penukar haba: Tindak balas suhu keluaran penukar haba kepada aliran perkhidmatan kadaralir mempunyai gandaan sebanyak -1.20 [C/(l/min)], pemalar masa 2.0 min, dan masa mati 0.90 min.

$$G_p(s) = -\frac{1.20}{2.0s+1}e^{-0.90s}$$

Pengesan/Penghantar: Pengesan/penghantar mempunyai gandaan kesatuan ($^oC/^oC$).

$$G_m(s) = 1.0$$

Injap kawalan: Injap kawalan (ciri lelurus) mempunyai keupayaan 25 l/min pada bukaan 50% dan pemalar masa 0.20 min.

$$G_f(s) = \frac{0.50}{0.20s+1}$$

Pengawal: Pengawal berkadar sahaja

$$G_c(s) = K_c$$

[a] *Lukiskan gambarajah blok untuk sistem kawalan tertutup.*

[4 markah]

[b] *Cari persamaan ciri bagi sistem pemindahan fungsi gelung tertutup yang ditentukan dalam bahagian [a] dengan menganggap kawalan servo.*

[3 markah]

[c] *Analisa kestabilan sistem dalam bahagian [b] dengan menggunakan kaedah kestabilan Routh dan tentukan gandaan minimum dan maksimum yang stabil bagi pengawal (K_c).*
Petunjuk: Gunakan anggaran Pade tertib pertama untuk menyatakan terma eksponen dalam bentuk yang rasional.

[8 markah]

[d] *Tindak balas gelung terbuka untuk suhu keluar penukar haba kepada perubahan langkah 5% pembukaan injap kawalan pada $t = 0$ adalah ditunjukkan dalam Rajah S.3 daripada nilai nominal 50% pembukaan kawalan injap. Kira masa mati, pemalar masa dan gandaan yang berkesan menggunakan kaedah proses reaksi lengkung. Sila nyatakan unit untuk masa mati, pemalar masa dan gandaan. Sila tunjukkan nilai yang dikira dalam Rajah A.3 yang dilampirkan dan kepilkan bersama buku jawapan.*

[6 markah]

[e] *Oleh kerana pengawal P sahaja dijangka memberi ofset yang tidak diingini, anda memutuskan untuk menggunakan pengawal PI.*

[i] *Tentukan pengawal PI menggunakan kaedah penalaan Cohen Coon dengan menentukan nilai-nilai parameter pengawal yang sesuai berdasarkan maklumat dalam bahagian [d].*

[2 markah]

[ii] *Tulis rangkap pindah pengawal PI yang baru.*

[2 markah]

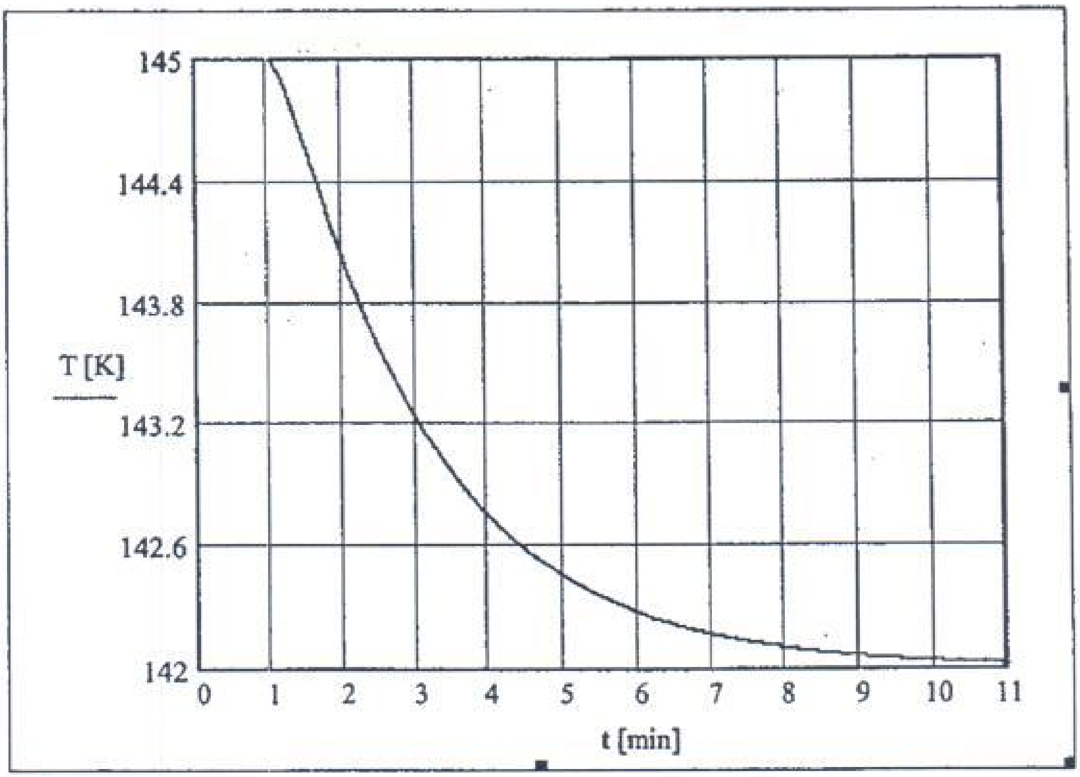


Figure Q.3. : Open loop response for heat exchanger.

4. The reactor temperature in an exothermic reactor is controlled by varying the cooling water flow into the reactor jacket as shown in Figure Q.4.

[a] Why would such a control scheme be used for this system?

[5 marks]

[b] Draw a closed loop block diagram for the reactor temperature control system implemented in part [a].

[7 marks]

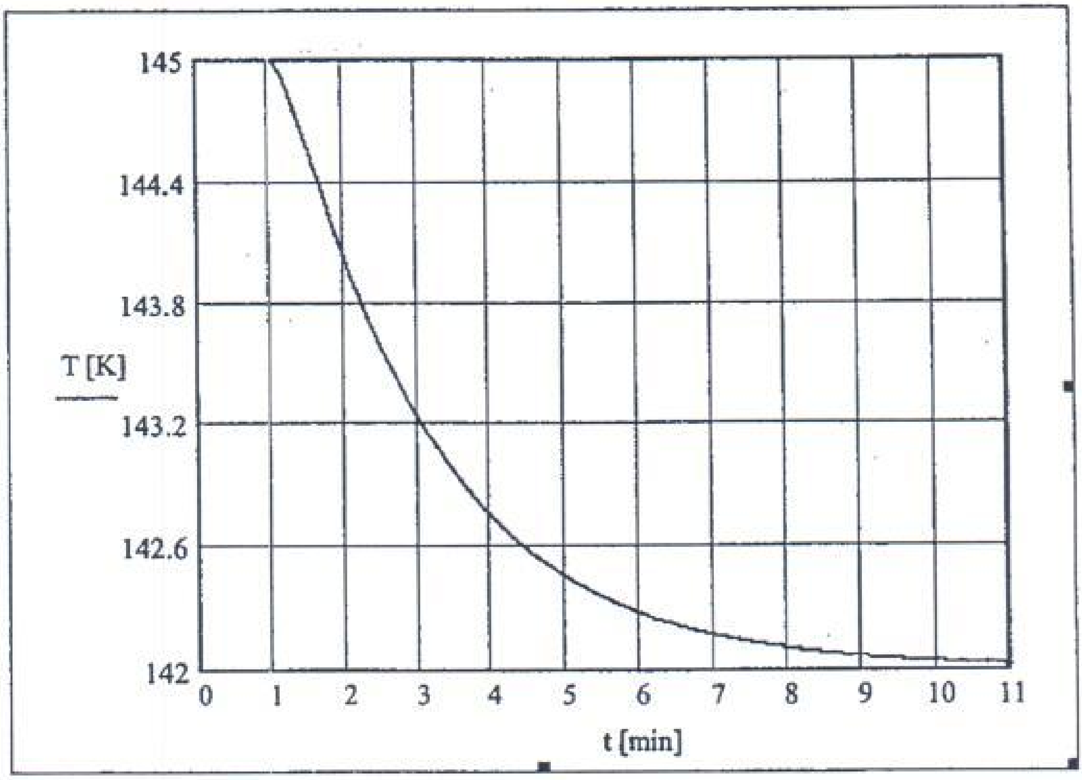
[c] Variation of the feed temperature occurs and acts as a disturbance to the system shown in the Figure Q.4.

[i] Draw the new closed loop block diagram of an improved control scheme including a feed forward element into the temperature control loop.

[7 marks]

[ii] Draw the new control configuration proposed in part [i] in the Figure A.4 provided in Appendix and attached with your answer booklet.

[6 marks]



Rajah S.3. : Tindak balas gelung terbuka bagi penukar haba

4. *Suhu di dalam sebuah reaktor eksotermik dikawal dengan mengubah kadar aliran air penyejuk ke dalam jaket reaktor seperti yang ditunjukkan dalam Rajah S.4.*

   [a] *Kenapa skima kawalan seperti berikut digunakan untuk sistem ini?*

   [5 markah]

   [b] *Lukiskan gambarajah blok bagi sistem kawalan suhu reaktor yang dilaksanakan dalam bahagian [a].*

   [7 markah]

   [c] *Perubahan suhu masukan telah berlaku dan bertindak sebagai gangguan seperti yang ditunjukkan dalam Rajah S.4.*

   [i] *Lukiskan gambarajah blok gelung tertutup bagi skema kawalan baharu yang lebih baik termasuk elemen suap depan dalam kawalan suhu gelung tertutup.*

   [7 markah]

   [ii] *Lukiskan konfigurasi kawalan baharu yang dicadangkan di bahagian [c].[i] dalam Lampiran A.4 dan kepilkan jawapan anda bersama buku jawapan.*

   [6 marks]

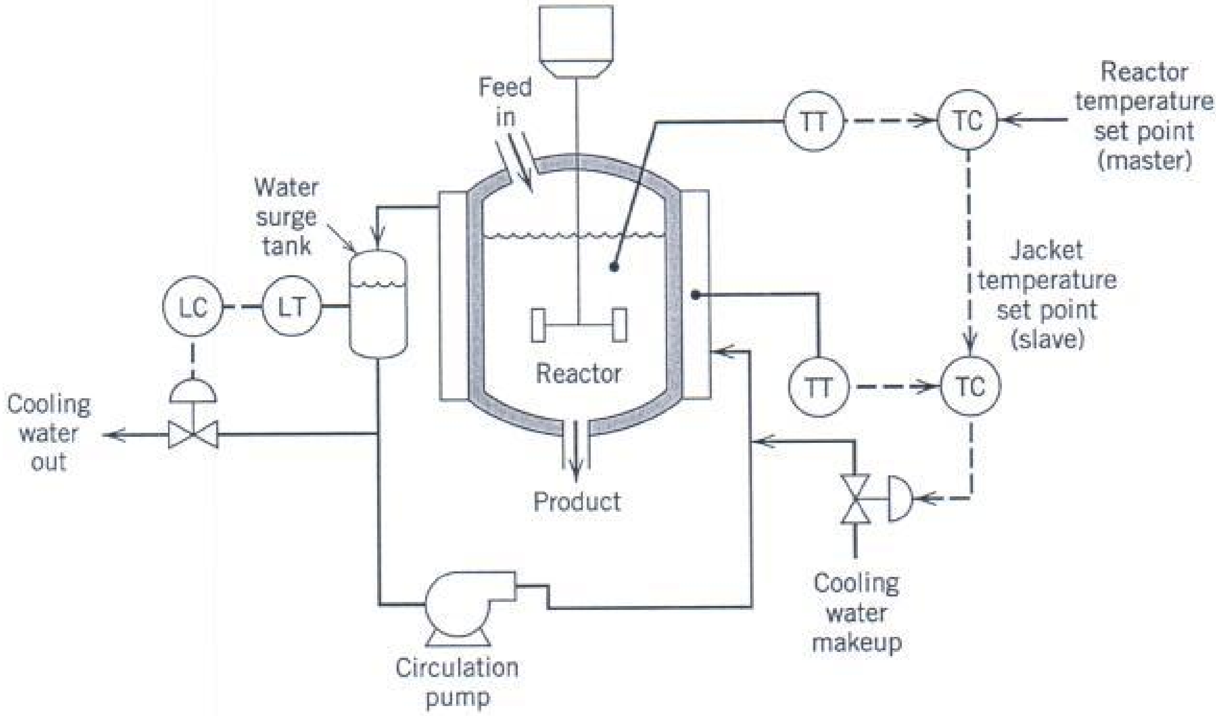
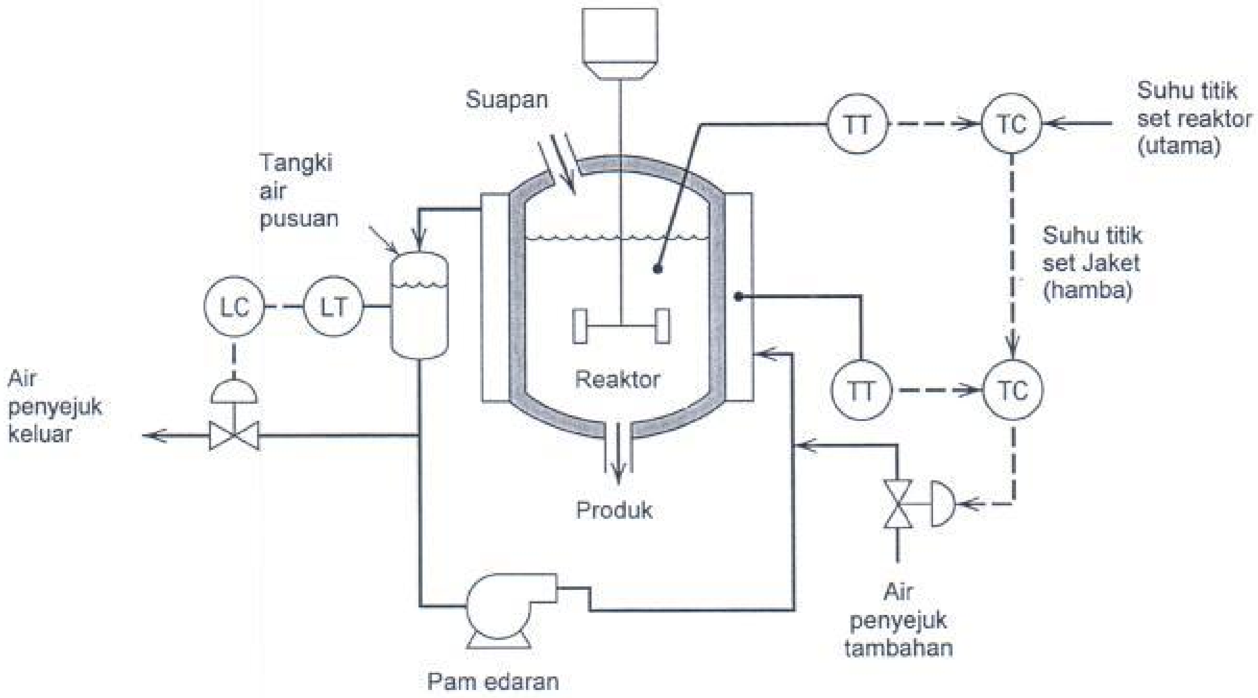


Figure Q.4.: Control configuration for exothermic chemical reactor



Rajah S.4.: Konfigurasi kawalan bagi reaktor eksotermik kimia

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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. $\frac{1}{b_1-b_2}(e^{-b_2 t}-e^{-b_1 t})$	$\frac{1}{(s+b_1)(s+b_2)}$
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. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1 t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2 t}$	$\frac{s+b_3}{(s+b_1)(s+b_2)}$
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. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1\neq\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
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. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1\neq\tau_2)$	$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$	$sF(s)-f(0)$
25. $\frac{d^n f}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
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.

Cohen-Coon Settings

1. For a proportional controller, use :

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(1 + \frac{t_d}{3\tau}\right)$$

2. For a PI controller, use :

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(0.9 + \frac{t_d}{12\tau}\right) \qquad \tau_I = t_d\,\frac{30 + 3t_d/\tau}{9 + 20t_d/\tau}$$

3. For a PID controller, use :

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(\frac{4}{3} + \frac{t_d}{4\tau}\right) \qquad \tau_I = t_d\,\frac{32 + 6t_d/\tau}{13 + 8t_d/\tau} \qquad \tau_D = t_d\,\frac{4}{11 + 2t_d/\tau}$$

Pade Approximation

1st Order

$$e^{-\theta s} \approx \frac{1 - k_1 s}{1 + k_1 s}\text{, where } k_1 = \frac{\theta}{2}$$

2nd order

$$e^{-\theta s} \approx \frac{1 - k_1 s + k_2 s^2}{1 + k_1 s + k_2 s^2}\text{, where } k_1 = \frac{\theta}{2},\ k_2 = \frac{\theta^2}{12}$$

Note: Please attached with your answer book.
Nota: Sila kepilkan bersama buku jawapan.

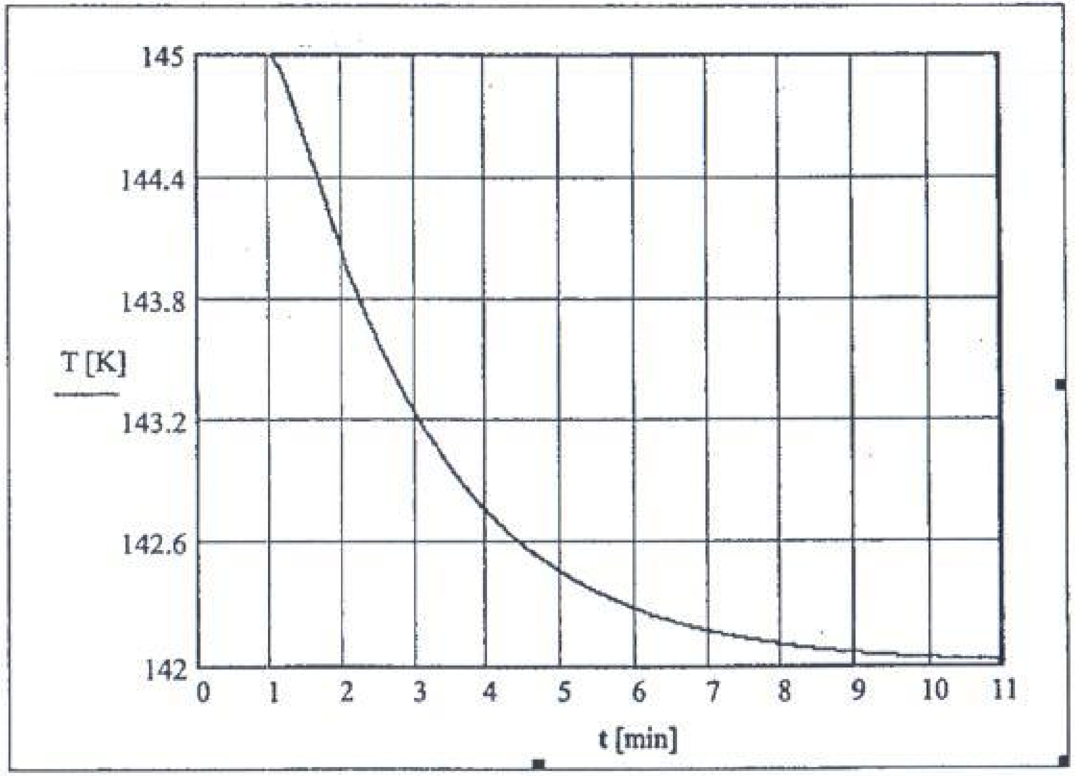

Figure A.3. : Open loop response for heat exchanger.

Note: Please attached with your answer book.
Nota: Sila kepilkan bersama buku jawapan.

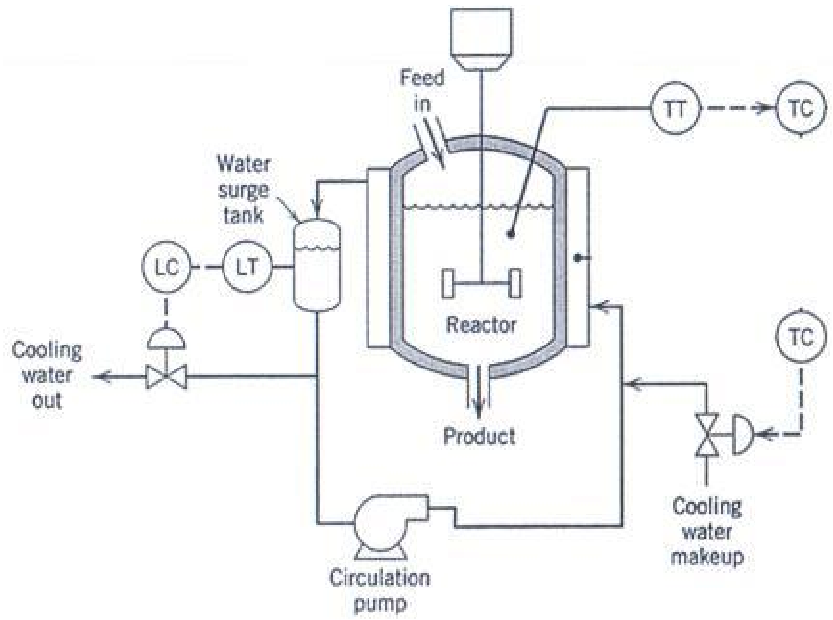

Figure A.4.: Control configuration for exothermic chemical reactor