UNIVERSITI SAINS MALAYSIA

First Semester Examination
2015/2016 Academic Session

December 2015 / January 2016

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

Duration : 3 hours
[Masa : 3 jam]

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

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

Instruction: Answer **ALL** (5) questions.

*[**Arahan:** Jawab **SEMUA** (5) 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.]

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Answer ALL questions.

1. [a] As a process engineer, you are assigned a unit with an exothermic chemical reactor. In order to learn more about the dynamics of the process, you decide to make a step change in the input variable, the coolant temperature, from 10°C to 15°C. Assume that the reactor was initially at a steady state. You obtain the plot for the output variable as shown in Figure Q.1.[a], which is reactor temperature.

[i] Calculate the values of process gain, τ, ζ, decay ratio and period of oscillation? (show units)

[ii] Write the second-order transfer function.

[6 marks]

Given:

Time to first peak: $t_p = \dfrac{\pi\tau}{\sqrt{1-\zeta^2}}$

Overshoot: $\mathrm{OS} = \exp\left(-\dfrac{\pi\zeta}{\sqrt{1-\zeta^2}}\right)$

Decay ratio: $\mathrm{DR} = \exp\left(-\dfrac{2\pi\zeta}{\sqrt{1-\zeta^2}}\right) = (\mathrm{OS})^2$

Period: $\mathrm{P} = \dfrac{2\pi\tau}{\sqrt{1-\zeta^2}}$

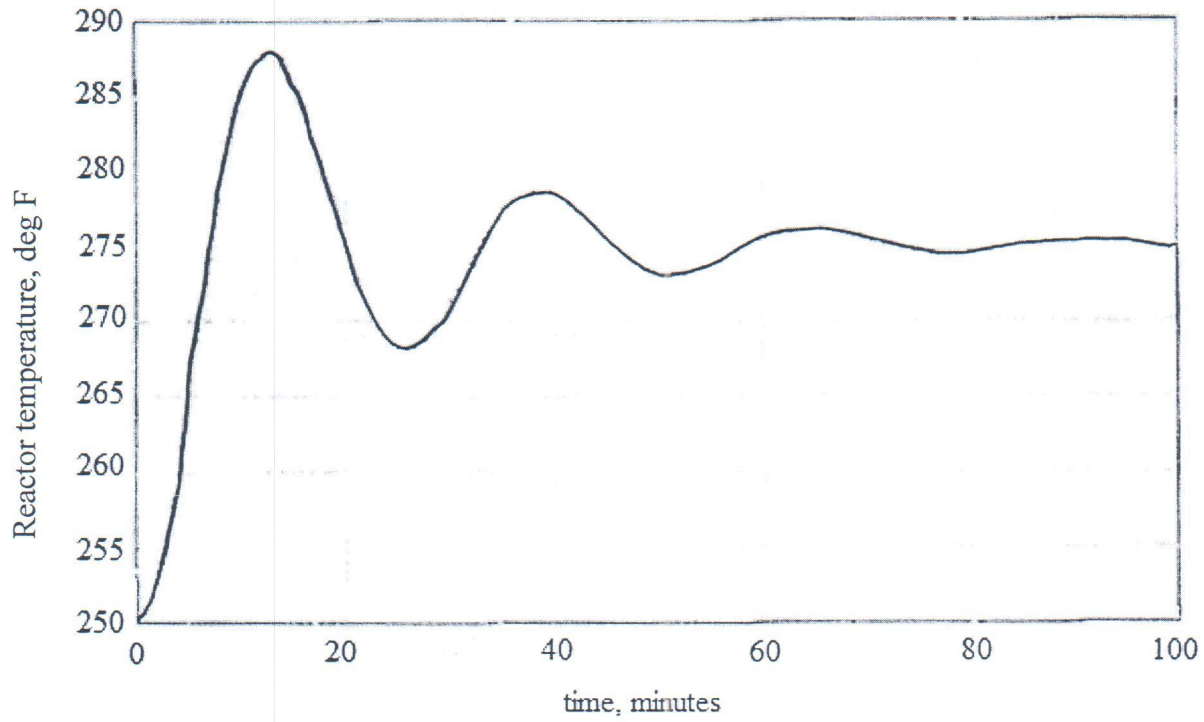

Figure Q.1.[a]

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Jawab SEMUA soalan.

1. [a] *Sebagai seorang jurutera, anda telah ditugaskan untuk satu unit reaktor kimia eksotermik. Untuk lebih mengetahui tentang dinamik proses tersebut, anda telah melakukan perubahan langkah terhadap pembolehubah masukan iaitu suhu penyejuk, dari 10°C ke 15°C. Anggapkan reaktor pada awalnya pada keadaan mantap. Anda mendapat plot bagi pembolehubah keluaran iaitu suhu reaktor seperti yang ditunjukkan dalam Rajah S.1.[a].*

[i] Kirakan nilai bagi gandaan proses, τ, ζ, nisbah reputan dan tempoh ayunan (tunjukkan unit-unitnya).

[ii] Tuliskan rangkap pindah tertib kedua.

[6 markah]

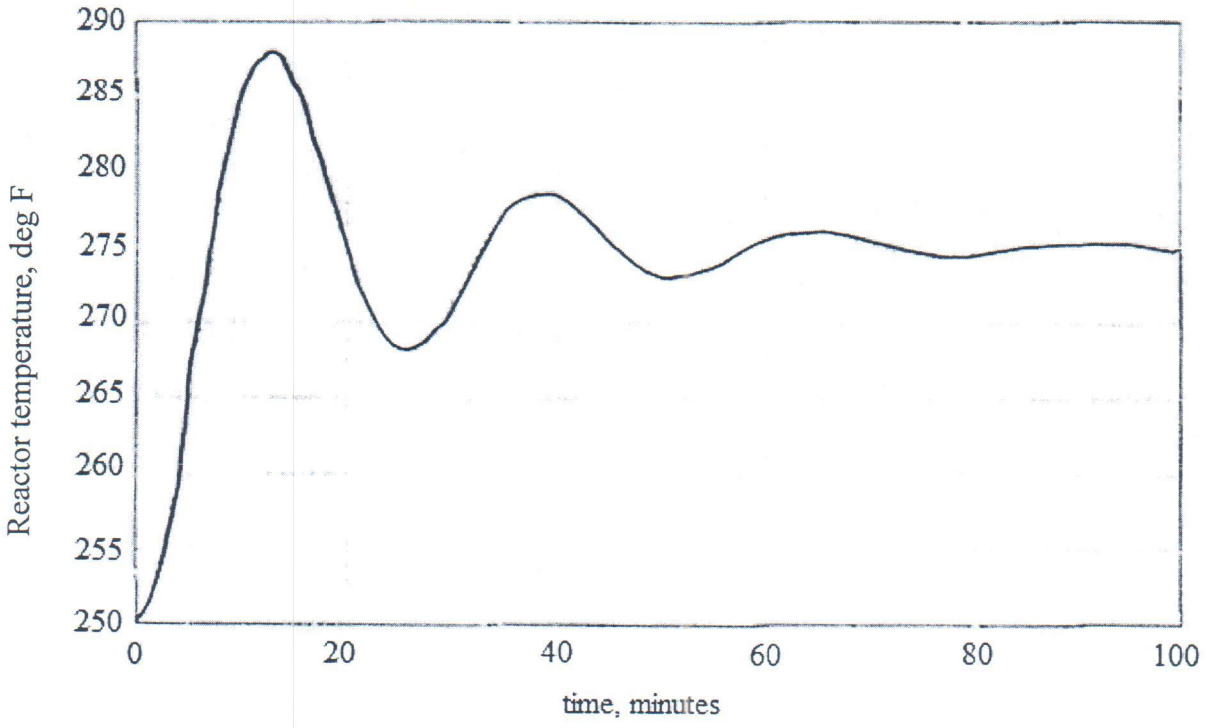
Diberi:

Masa untuk puncak pertama: $t_p = \dfrac{\pi\tau}{\sqrt{1-\zeta^2}}$

Terlajak: $\mathrm{OS} = \exp\left(-\dfrac{\pi\zeta}{\sqrt{1-\zeta^2}}\right)$

Nisbah susut: $DR = \exp\left(-\dfrac{2\pi\zeta}{\sqrt{1-\zeta^2}}\right) = (\mathrm{OS})^2$

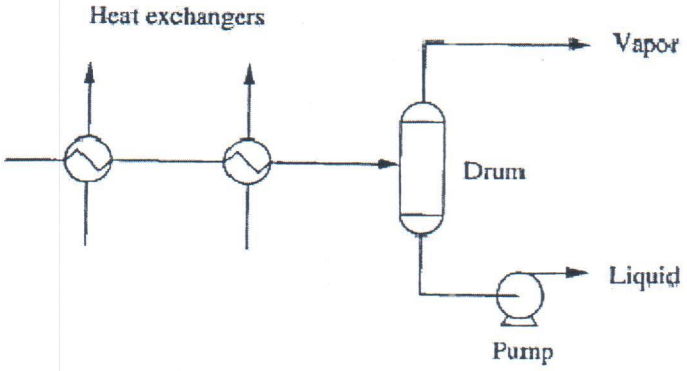
Tempoh: $\mathrm{P} = \dfrac{2\pi\tau}{\sqrt{1-\zeta^2}}$



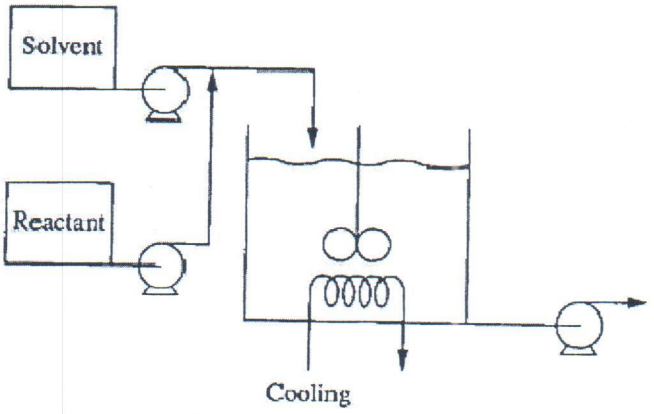
Rajah S.1[a]

[b] The preliminary process designs have been prepared for the systems in Figure Q.1.[b]. The key variables to be controlled for the systems are (i) flowrate, temperature, composition, and pressure for the flash system and (ii) composition, temperature, and liquid level for the continuous-flow stirred tank chemical reactor. For both processes, disturbances occur in the feed temperature and composition. Select controller pairings; that is, select which measured variable should be controlled by adjusting which manipulated variable. Re-draw the figure and sketch the controller pairings with a necessary control loops in it.

[8 marks]



(i)



(ii)

Figure Q.1.[b]

[c] A two-input/two-output process involving simultaneous heating and liquid-level changes is illustrated in Figure Q.1.[c]. Develop the transfer function models and expressions for the gains and the time constant, τ for this process. Calculate the output response for:

[i] a unit step change in Q.

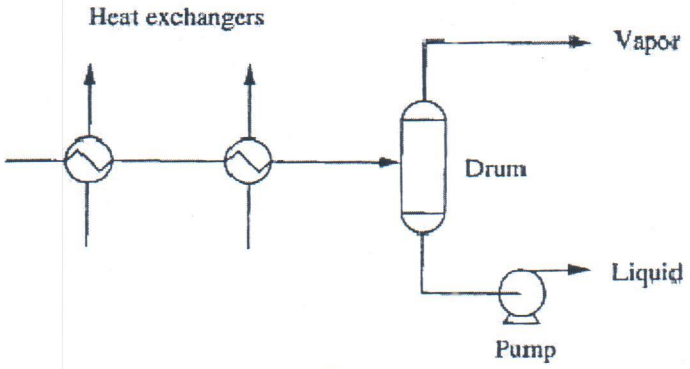
[ii] a unit step change in w.

[11 marks]

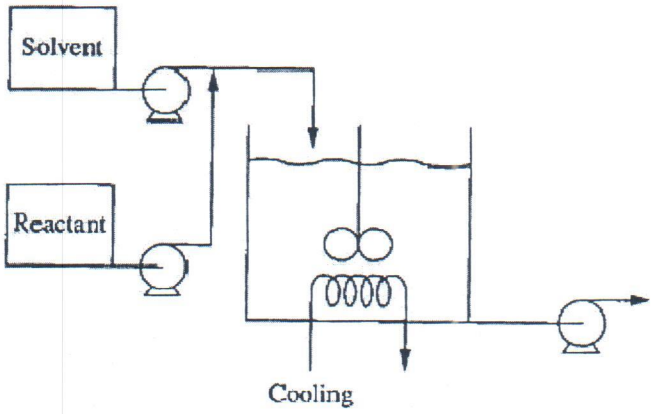
...5/-

[b] *Rekabentuk awal proses telah dibuat bagi sistem-sistem dalam Rajah S.1.[b]. Pembolehubah utama yang akan dikawal bagi sistem-sistem ialah (i) kadar aliran, suhu, komposisi dan tekanan bagi sistem kilat (ii) komposisi, suhu dan aras cecair bagi reaktor kimia tangki teraduk aliran berterusan. Bagi kedua-dua proses, gangguan berlaku pada suhu dan komposisi masukan. Pilih pasangan pengawal; iaitu pilih pembolehubah terukur manakah yang akan dikawal dengan mengubah pembolehubah olahan. Lukis semula rajah dan lakarkan pasangan pengawal tersebut dengan gelung kawalan yang perlu.*

[8 markah]



(i)



(ii)

Rajah S.1.[b].

[c] *Satu proses dua-masukan/dua-keluaran yang melibatkan perubahan serentak pemanasan dan aras cecair ditunjukkan dalam Rajah S.1.[c]. Binakan model rangkap pindah dan ungkapan bagi gandaan-gandaan dan masa malar, τ bagi proses ini. Kirakan sambutan keluaran bagi:*

[i] satu unit perubahan langkah dalam Q

[ii] satu unit perubahan langkah dalam w.

[11 markah]

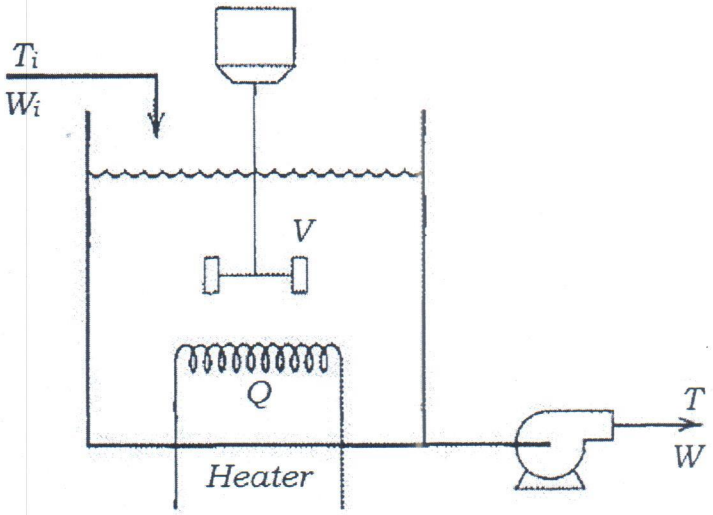


Figure Q.1.[c]

2. [a] Briefly describe the following terms: -

[i] First order process

[ii] Second order process

[iii] Open – loop system

[iv] Closed – loop system

[v] Interacting and noninteracting process

[vi] Control variable, manipulated variable and disturbance

[6 marks]

[b] A tank used to dampen liquid flow rate surges is known to exhibit second-order dynamics. The input flow rate changes suddenly from 120 to 140 gal/min. An operator notes that the tank level changes as follows:

Before input change: level = 6 ft and steady
Four minutes later: level = 11 ft
Forty minutes later: level = 10 ft and steady

Identify a transfer function model that describes this process. Evaluate all the parameters in your model, including units.

[6 marks]

Given:

Time to first peak: $t_p = \dfrac{\pi\tau}{\sqrt{1-\zeta^2}}$

Overshoot: $\text{OS} = \exp\left(-\dfrac{\pi\zeta}{\sqrt{1-\zeta^2}}\right)$

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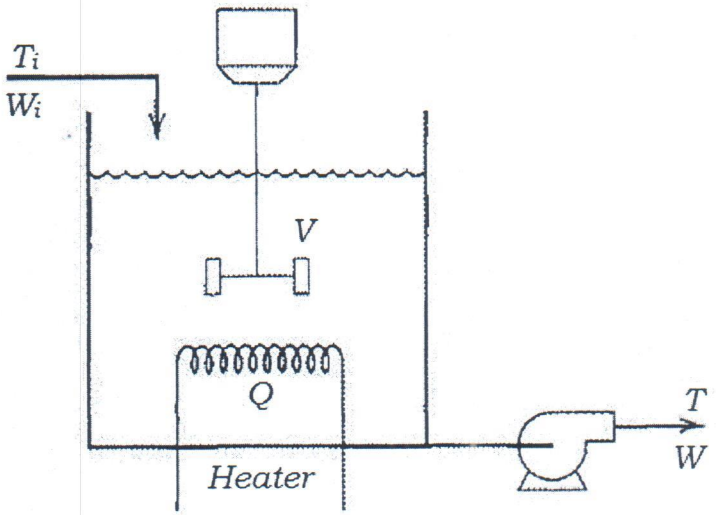

Rajah S.1.[c].

2. [a] *Terangkan secara ringkas terma-terma berikut: -*

[i] Proses tertib pertama

[ii] Proses tertib kedua

[iii] Sistem gelung terbuka

[iv] Sistem gelung tertutup

[v] Proses saling tindak dan proses tidak saling tindak

[vi] Pembolehubah kawalan, pembolehubah pengolah dan gangguan

[6 markah]

[b] *Satu tangki digunakan untuk meredam kadar pusuan aliran cecair yang menunjukkan dinamik tertib kedua. Kadar aliran masukan berubah secara mendadak dari 120 ke 140 gal/min. Seorang operator mendapati bahawa aras tangki berubah seperti berikut:*

Sebelum perubahan masukan: aras = 6 kaki dan mantap
Empat minit kemudian: aras = 11 kaki
Empat puluh minit kemudian: aras = 10 kaki dan mantap

Kenalpasti satu model rangkap pindah yang menerangkan proses ini. Nilaikan semua parameter dalam model anda termasuk unit-unitnya.

[6 markah]

Diberi:

Masa untuk puncak pertama: $t_p = \dfrac{\pi\tau}{\sqrt{1-\zeta^2}}$

Terlajak: $\mathrm{OS} = \exp\left(-\dfrac{\pi\zeta}{\sqrt{1-\zeta^2}}\right)$

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[c] A thermocouple has the following characteristics when it is immersed in a stirred bath:

Mass of thermocouple = 1 g
Heat capacity of thermocouple = 0.25 cal/g°C
Heat transfer coefficient = 20 cal/cm^2 h °C (for thermocouple and bath)
Surface area of thermocouple = 3 cm^2

[i] Develop a transfer function model for the thermocouple relating the change in its indicated output T to the change in the temperature of its surroundings T_s, assuming uniform temperature (no gradients in the thermocouple bead), no conduction in the leads, constant physical properties, and conversion of the millivolt-level output directly to a °C reading by a very fast meter.

[ii] If the thermocouple is initially out of the bath and at 23°C, identify the maximum temperature that it will register if it is suddenly plunged into the bath (80°C) and held there for 20 s?

[13 marks]

3. A temperature transmitter is installed and calibrated as follows:
80°C ➔ 20 mA and 20 °C ➔ 4 mA. For the transmitter, with the aid of a diagram determine:

[a] the gain

[b] the zero

[c] the span

[10 marks]

4. Take a case of level control when two streams enter a tank. One stream is used to manipulate in order to control the level. Figure Q.4. shows the control diagram of the system.

[a] Complete the Table Q.4 (provided in Appendix) with your preferable scenario.
[9 marks]

[b] Write an analysis at least in 100 words.
[9 marks]

[c] Write a concluding sentence from your analysis.
[2 marks]

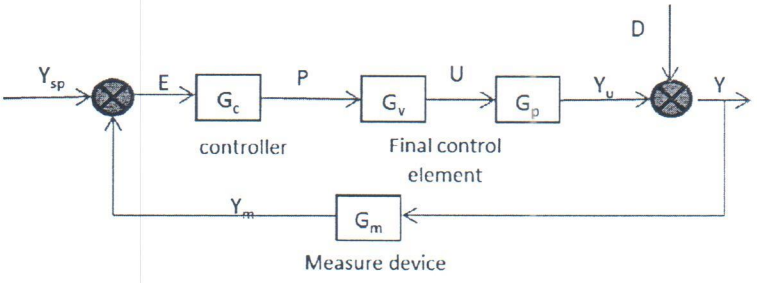


Figure Q.4.: Control Diagram

[c] *Satu pengganding suhu mempunyai ciri-ciri berikut bila dicelupkan dalam satu bekas mandi teraduk:*

Jisim pengganding suhu = 1 g
Muatan haba bagi pengganding suhu = 0.25 cal/g ℃
Pekali pemindahan haba = 20 cal/sm^{2}j ℃ (bagi pengganding suhu dan bekas mandi)
Luas permukaan bagi pengganding suhu = 3 sm^2

[i] *Binakan satu model rangkap pindah bagi pengganding suhu yang mengaitkan perubahan dalam* T *keluarannya terhadap perubahan perubahan suhu persekitarannya,* T_s, *anggap suhu adalah seragam. (tiada kecerunan dalam manik pengganding suhu), tiada konduksi dalam manik, sifat-sifat fizik adalah malar dan penukaran bagi aras keluaran milivolt ke bacaan ℃ dibuat oleh meter dengan pantas.*

[ii] *Sekiranya pengganding suhu pada awalnya berada di luar bekas mandi pada 23 ℃, kenalpasti suhu maksimum yang akan dicatatkan sekiranya ia dicelupkan secara mendadak ke dalam bekas mandi (80 ℃) dan dibiarkan di situ selama 20 saat?*

[13 markah]

3. *Satu penghantar suhu telah dipasang dan ditentukur seperti berikut:* 80^oC ➔ *20 mA and* $20\ ^oC$ ➔ *4 mA. Untuk tentukur ini, tentukan dengan bantuan gambarajah:*

[a] *gandaan*

[b] *sifar*

[c] *rentang*

[10 markah]

4. *Untuk kes kawalan aras apabila dua aliran memasuki sebuah tangki satu aliran digunakan untuk mengolah bagi tujuan mengawal aras. Rajah S.4 menunjukkan gambarajah kawalan untuk sistem itu.*

[a] *Lengkapkan Jadual S.4 (dibekalkan dalam Apendik) dengan keadaan yang anda inginkan.*

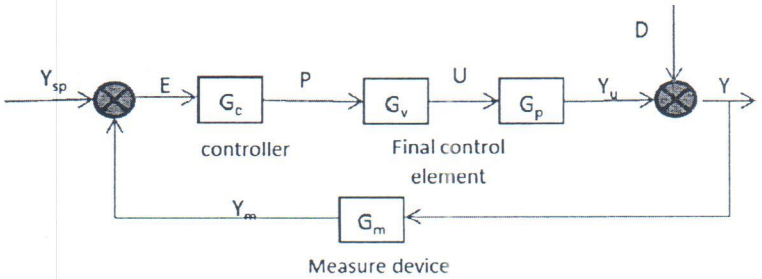
[9 markah]

[b] *Tuliskan satu analisis sekurang-kurangnya dalam 100 perkataan.*

[9 markah]

[c] *Tuliskan satu ayat kesimpulan daripada analisis anda.*

[2 markah]



Rajah S.4. Gambarajah Kawalan

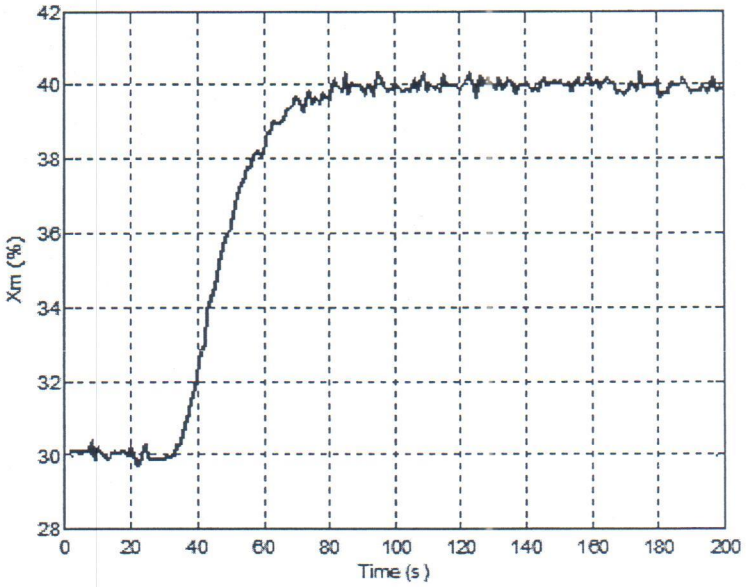
Table Q.4: Analysis Table

Y_m	E	G_c	P	G_v	U	G_p	Y	G_m	Σ
Y_{sp}	0	+	0	+	0	+	0	+	+
↑	↓	+	↓	+	↓	+	↓	+	+

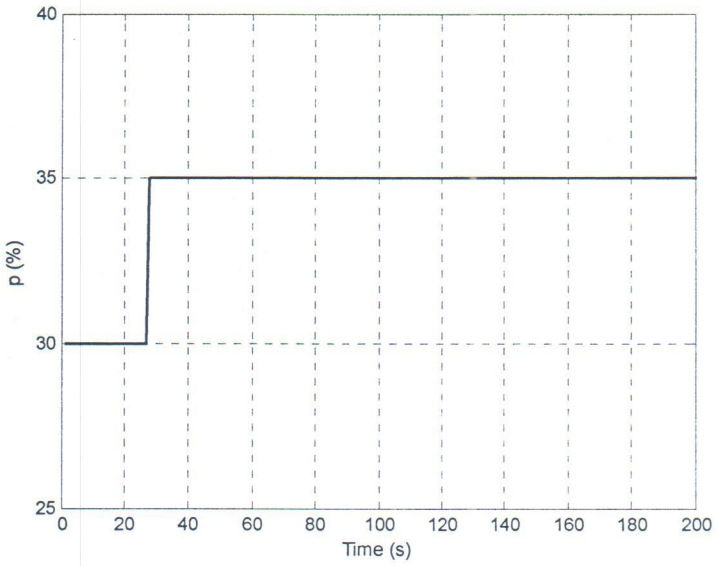
Note: 0: Does not change; ↑: Increase ↓: Decrease
(Gv = +): Air to Open (Gv = -): Air to Close

5. Figure Q.5 below shows a system subjected to a simple step change at time, t = 30. Determine the model of this system and the controller parameters. Describe how you arrive at this solution.

[20 marks]



(i)



(ii)

Figure Q.5: (i) Process Response and (ii) Manipulated Input

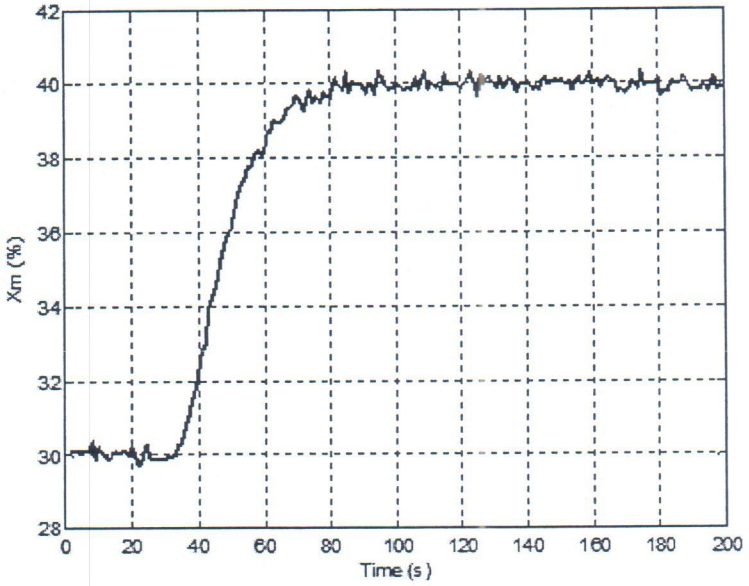
Rajah S.4. Jadual Analisis

Y_m	E	G_c	P	G_v	U	G_p	Y	G_m	Σ
Y_{sp}	0	+	0	+	0	+	0	+	+
↑	↓	+	↓	+	↓	+	↓	+	+

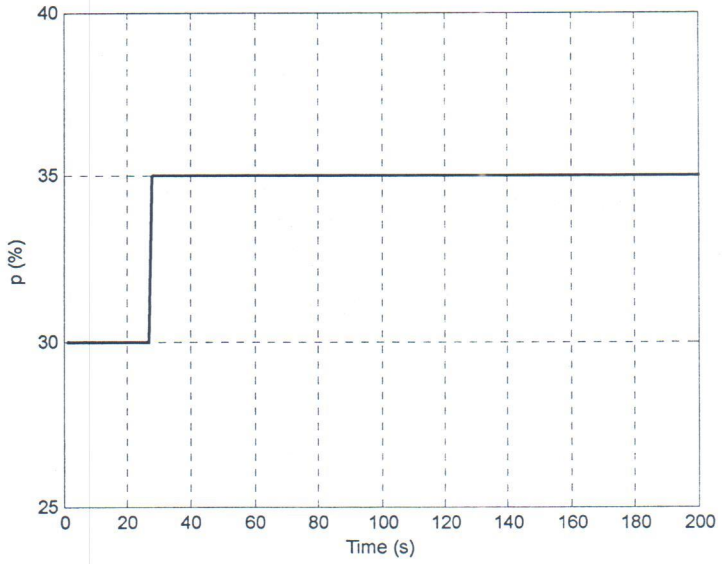
Note: 0: Tiada perubahan; ↑: Peningkatan ↓: Penurunan
(Gv = +): Pembukaan udara (Gv = -): Penutupan udara

5. *Rajah S.5. di bawah menunjukkan satu sistem yang tertakluk pada tukaran langkah mudah pada masa* t = *30. Tentukan model untuk sistem dan paramater kawalan. Terangkan bagaimana anda mendapat penyelesaiannya.*

[20 markah]



(i)



(ii)

Rajah S.5: (i) Sambutan Proses dan (ii) Masukan Olahan

- 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.	$e^{-bt}\sin \omega t$	$\frac{\omega}{(s+b)^2+\omega^2}$
18.	$e^{-bt}\cos \omega t$	$\frac{s+b}{(s+b)^2+\omega^2}$
	b, ω real	
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.	$1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\neq\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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 $t \geq 0$ only.

...2/-

Table Q.4: Analysis Table

Y_m	E	G_c	P	G_v	U	G_p	Y	G_m	Σ
Y_{sp}	0	+	0	+	0	+	0	+	+
↑	↓	+	↓	+	↓	+	↓	+	+

Note: 0: Does not change; ↑: Increase ↓: Decrease
(Gv = +): Air to Open (Gv = -): Air to Close

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