UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2012/2013 Academic Session

June 2013

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH 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] 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.

Sebuah syarikat pegangan yang awam mempunyai loji menghadapi masalah ammonium yang tinggi dalam air sisa dengan piawai B JAS pada 20 mg/l. Isu ini telah ditangani dengan menyediakan kepekatan magnesium klorida dan natrium dihidrogen fosfat sebagai bahan tindak balas untuk bertindak balas dengan amonium. Magnesium amonium bagi membentuk fosfat (MAP) walaubagaimana pun, 10% amonium masih tidak bertindak balas. Tindak balas ini telah dijalankan dalam reaktor tangki teraduk dengan tiga aliran masuk ke tangki tindak balas. Tiga aliran tersebut adalah air sisa, natrium hidrogen fosfat dan magnesium klorida. Aliran natrium dihidrogen fosfat dikekalkan pada kadar mantap berdasarkan aspek ekonomi dan kekurangan kesannya pada tindak balas itu. Dua aliran yang lain itu boleh dimanipulasi dengan dua injap kawalan. Objektif operasi adalah (1) mengekalkan tahap amonium bawah had piawai JAS dan (2) mengawal kadar aliran keluar dari tangki tindak balas. Oleh kerana tindak balas ini menghasilkan pemendakan pepejal MAP, sebuah emparan diletakkan di hiliran bagi memisahkan pepejal itu dan cecair pada kemampuan maksimum 2 m^3/j. Proses ini dilengkapi dengan pengawal-pengawal, 'penderia perisian' amonium dan tolok aliran di hilirnya.

[i] Construct a schematic diagram of the process.
Binakan gambarajah skematik proses ini.
[4 marks/markah]

[ii] Construct a block diagram of multivariable process.
Binakan gambarajah blok proses pelbagai pembolehubah.
[4marks/markah]

[iii] What is source of disturbance?
Apakah punca gangguan?
[1 mark/markah]

[b] Due to improper control tuning parameters, when there is a disturbance, the results of controlled variables can be shown in the Figure Q.1.[b].[i]. and Figure Q.1.[b].[ii].

Disebabkan parameter penalaan kawalan yang tidak sesuai, apabila terdapat gangguan, keputusan pembolehubah kawalan boleh ditunjukkan dalam Rajah S.1.[b].[i]. dan Rajah S.1.[b].[ii].

[i] What is implication of result in Figure Q.1.[b].[i].?
Apakah impikasi keputusan Rajah S.1.[b].[i].?

[3 marks/markah]

[ii] What is implication of result in Figure Q.1.[b].[ii].?
Apakah implikasi keputusan Rajah S.1.[b].[ii].?

[3 marks/markah]

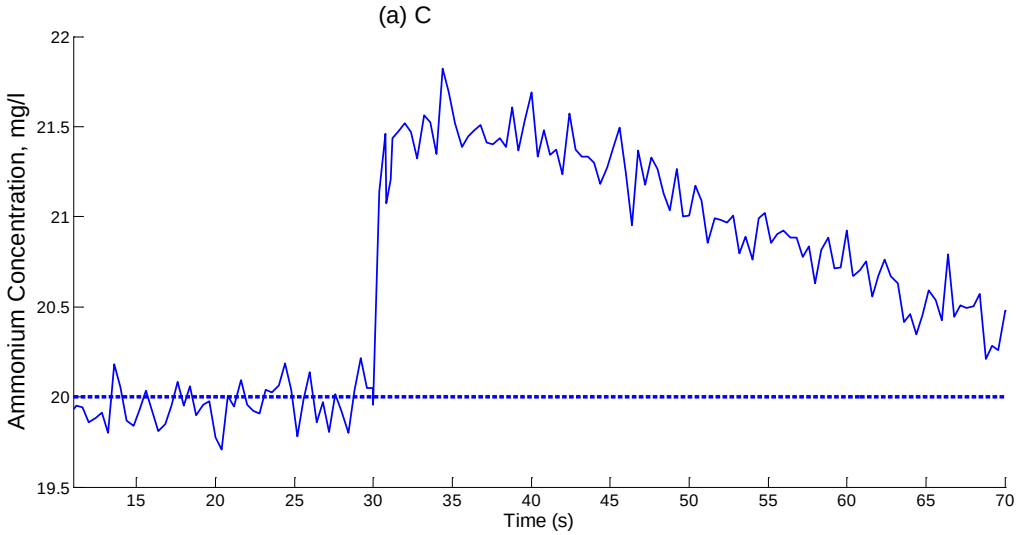

Figure Q.1.[b].[i]. Concentration at the outlet
Rajah S.1.[b].[i]. Kepekatan di alur keluar

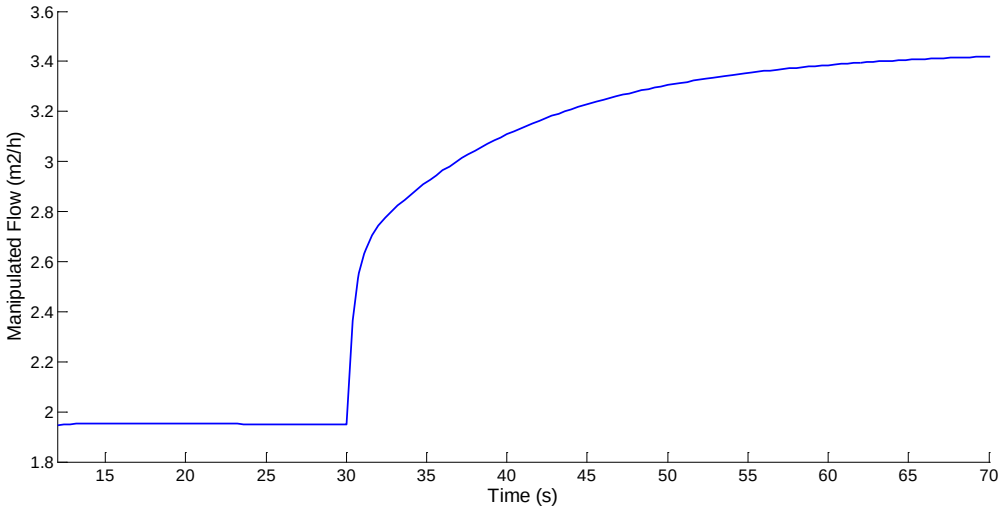

Figure Q.1.[b].[ii]. Manipulated response due to disturbance
Rajah S.1.[b].[ii]. Respon manipulasi disebabkan gangguan

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2. A system has the following open loop input-output relationships:
Sistem ini mempunyai hubungan keluar-masuk gelung terbuka:

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

The process transfer function are shown in the Table Q.2.:
Fungsi rangkap proses ditunjukkan dalam Jadual S.2.:

Table Q.2.
Jadual S.2.

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

[a] Find the gain for G_{11} based on the Figure Q.2.[a].
Cari gandaan G_{11} berdasarkan Rajah S.2.[a]. *[2 marks/markah]*

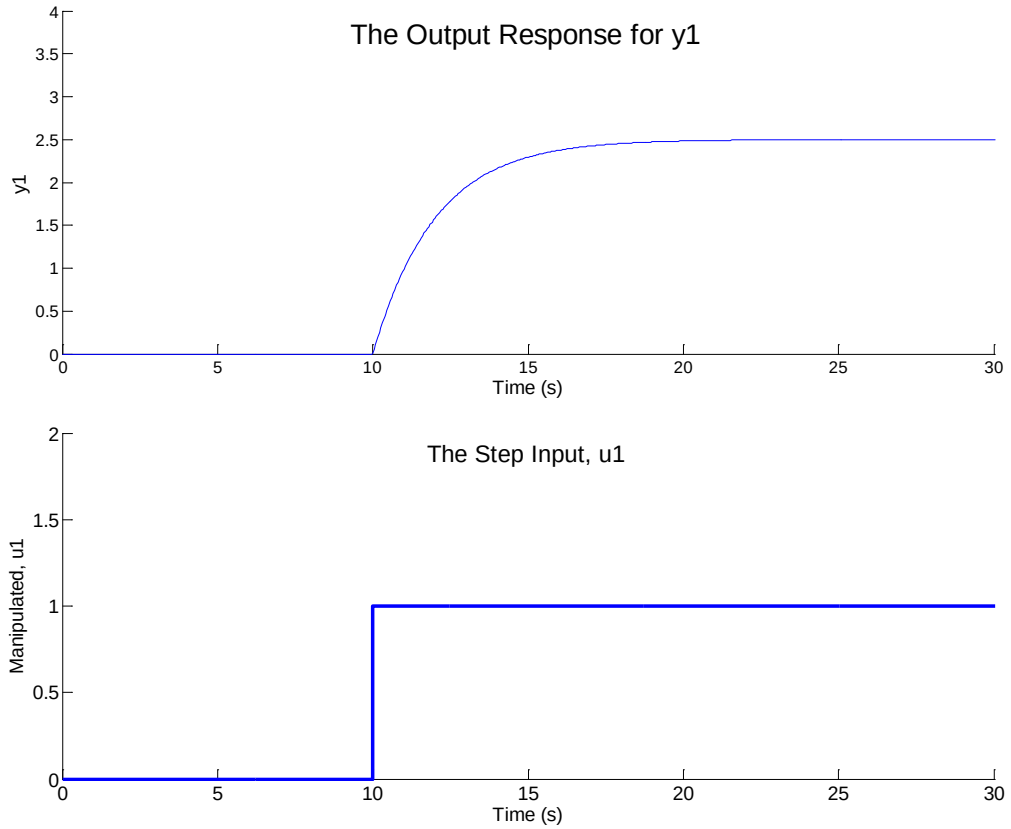

Figure Q.2.[a]
Rajah S.2.[a].

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[b] The transfer function G_{12} is in second order behaviour and this can be reduced to simple model. Two diagrams in Figure Q.2.[b]. show the result of reduction. Pick the correct model suitable for reduction of model G_{12} with reference to Figure Q.2.[b]. Explain your choice.

Fungsi rangkap G_{12} adalah kelakuan tertib kedua dan ianya boleh diubah kepada model mudah. Dua Rajah S.2.[b]. menunjukkan keputusan pengubahan tersebut. Pilih model yang sesuai dengan penurunan model G_{12} dengan merujuk pada Rajah S.2.[b]. Terangkan pilihan anda.

[4 marks/markah]

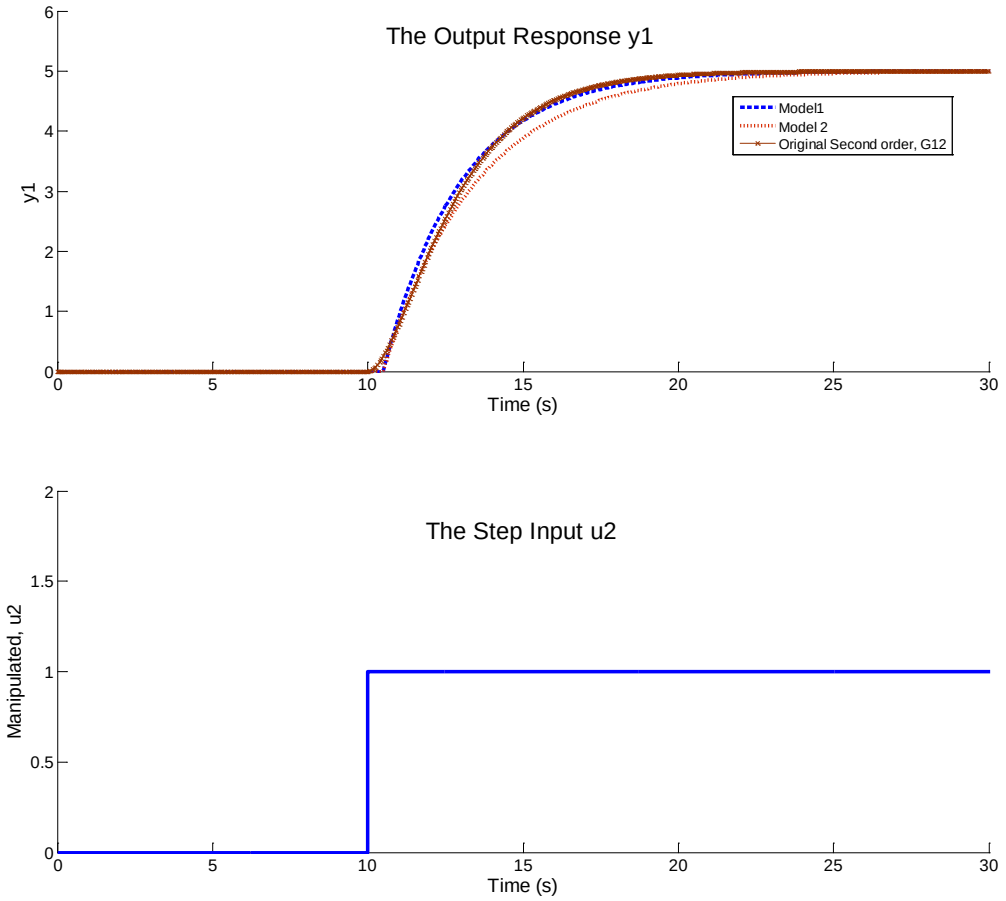

Figure Q.2.[b].
Rajah S.2.[b].

[c] Based on your answer in [b], let say the transfer function of G_{12} is $\frac{5}{2.5s+1}$. As for now you have completed all the transfer functions for the multi-loop process;

Berdasarkan jawapan anda dalam [b], katakan fungsi rangkap G_{12} adalah $\frac{5}{2.5s+1}$. Pada masa ini, anda telah melengkapkan fungsi-fungsi rangkap untuk proses pelbagai gelung;

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[i] Determine how would you pair variables for your control loops?
Tentukan bagaimana anda ingin pasangkan pembolehubah-pembolehubah untuk gelung-gelung kawalan anda?
[7 marks/markah]

[ii] Explain your choice in [c].[i].
Terangkan pilihan anda dalam [c].[i]. *[2 marks/markah]*

3. A company proposes Model Predictive Control (MPC) system for an evaporator unit in its plant as part of its modernization and migration strategy as a consultant. 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.

Sebuah syarikat mencadangkan sistem Kawalan Ramalan Model (MPC) untuk unit penyejat dalam lojinya. Cadangan ini adalah sebahagian daripada pemodenan dan strategi migrasi lojinya. Anda telah dipilih sebagai Pengurus Projek (PM) untuk projek pemodenan ini oleh syarikat anda. Anda diberikan perihal awalan untuk unit tersebut di mana pelaksanaannya akan dilakukan. Oleh demikian, syarikat anda perlu menyediakan aspek dan spesifikasi teknikal projek ini. Perihalannya dinyatakan di bawah:

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.3.

Penyejat edaran paksa telah diguna untuk memekatkan larutan urea yang cair dengan pelarut pengeluwapan dari aliran masuk. Suapan dicampurkan dengan urea yang dikitar semula dan kemudian dipam ke bahagian tiub dalam penukar haba tegak. Stim memasuki bahagian kelompang dalam penukar haba tegak dan memeluwap pada bahagian luar tiub-tiub. Larutan urea itu dipeluwapkan secara separa semasa ia melalui bahagian tiub penukar haba itu. Kemudian, ianya melalui pemisah. Wap dari penyejat dipeluwapkan dengan penukar air sejuk di mana sebahagian aliran cecair dari pemisah dikutip sebagai produk dan sebahagian lainnya diedarkan semula ke penukar haba. Gambarajah instrumentasi dan proses skematik ditunjukkan dalan Rajah S.3.

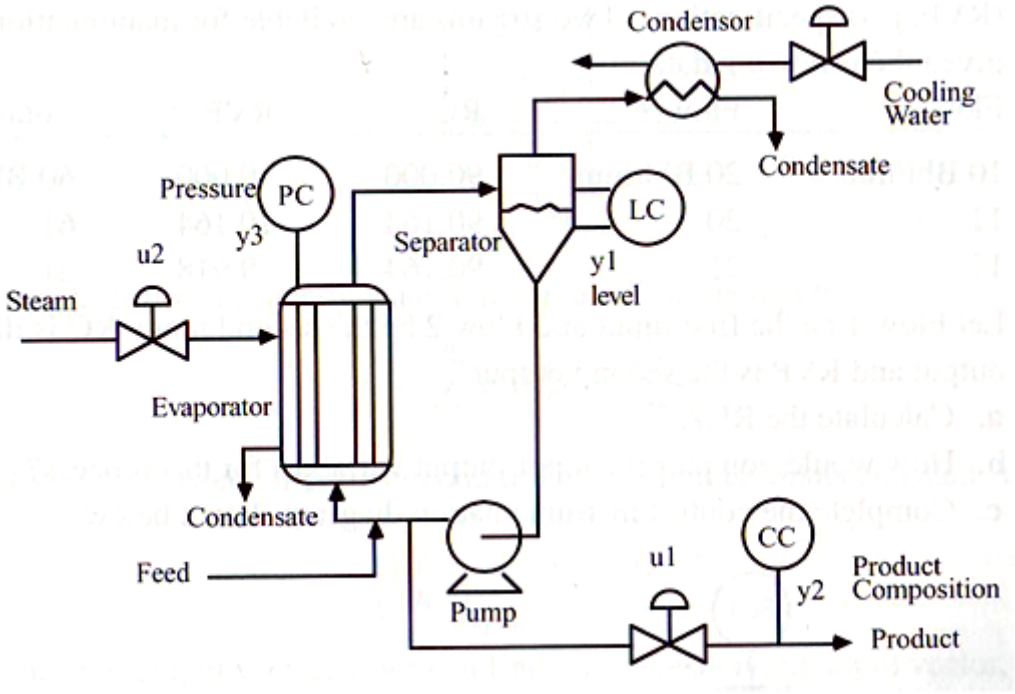

Figure Q.3.
Rajah S.3.

Please report your initial project proposal for your client based on these items:
Sila laporkan cadangan projek awalan untuk pelanggan anda berdasarkan perkara-perkara ini.

[a] Define type of resources needed.
Takrifkan jenis sumber-sumber yang diperlukan.
[3 marks/markah]

[b] Describe the important variables involved.
Perihalkan pembolehubah-pembolehubah penting yang terlibat.
[3 marks/markah]

[c] Explain how to investigate the functional relationship for variables.
Terangkan bagaimana diselidiki hubungan fungsi antara pembolehubah-pembolehubah.
[3 marks/markah]

[d] Describe how to formulate the model for MPC.
Perihalkan bagaimana mengformulasi model untuk MPC.
[8 marks/markah]

[e] Describe how to validate the model.
Perihalkan bagaimana untuk mengesahkan model itu.
[3 marks/markah]

4. [a] You have just started a week in the company as a process cum control engineer. Your superior has given you the task to troubleshoot the persistent tuning problem for the neutralization unit in the plant. Currently, PID controller is used to maintain the pH of the output stream of the neutralization tank. The waste stream (dilute hydrochloric acid) is neutralized in the neutralization tank by adding a base stream (sodium hydroxide) of known concentration. It is a known fact that the concentration and the flow rate of the waste acid stream vary unpredictably. Past experience has indicated that it is a horrendous task to tune a standard PID controller so that satisfactory control occurs over full range of operating conditions. Your task is to evaluate the problem and recommend advanced control strategy that has the potential of greatly improved control performance. Justify your proposed method, being as specific as possible. Include any additional information (i.e. schematic diagrams, block diagrams, graphical visualization, etc.) if necessary.

Anda baru sahaja bermula bekerja selama seminggu di dalam syarikat sebagai jurutera proses dan kawalan. Ketua anda telah memberi satu tugas untuk menyelesaikan masalah talaan yang selalu berlaku bagi unit peneutralan di dalam loji. Buat masa ini, penala PID diguna untuk mengekalkan pH bagi aliran keluaran tangki peneutralan tersebut. Aliran sisa (asid hidroklorik cair) dineutralkan di dalam tangki peneutralan dengan menambahkan aliran alkali (sodium hidroksida) berkepekatan yang diketahui. Adalah satu fakta yang diketahui umum, kepekatan dan kadar aliran sisa asid adalah berubah dan susah diramal. Pengalaman lampau telah menunjukkan penalaan pengawal PID piawai adalah satu tugas yang merumitkan bagi mencapai kawalan yang bersesuaian untuk keseluruhan julat keadaan kendalian. Tugas anda adalah untuk menilai permasalahan tersebut dan memberi perakuan strategi kawalan lanjutan yang mempunyai potensi untuk menambahbaik prestasi kawalan. Wajarkan kaedah yang anda cadangkan, secara terperinci yang mungkin. Sertakan informasi tambahan (contoh: rajah skematik, rajah blok, gambaran grafik dan lain-lain) sekiranya perlu.

[9 marks/markah]

[b] You have had the experience of providing solutions to the problem mentioned in [a]. Based on your expertise, indicate the best approach to improve control performance via advanced process control strategies with given examples for easy explanation.

Anda telah mempunyai pengalaman dalam memberikan penyelesaian bagi permasalahan yang disebutkan di [a]. Berdasarkan kepakaran anda, pilih pendekatan yang terbaik untuk menambahbaik prestasi kawalan melalui strategi-strategi kawalan proses termaju dengan memberikan contoh-contoh bagi penjelasan yang mudah.

[9 marks/markah]

[c] Cascade control is an example of advanced process control strategy via enhancing the single-loop control strategies. Discuss how does cascade control improve the furnace temperature control as shown in Figure Q.4.

Kawalan lata adalah satu contoh strategi kawalan proses termaju melalui strategi-strategi kawalan gelung-tunggal tertingkat. Bincangkan bagaimana kawalan lata menambaik kawalan suhu relau yang ditunjukkan dalam Rajah S.4. *[7 marks/markah]*

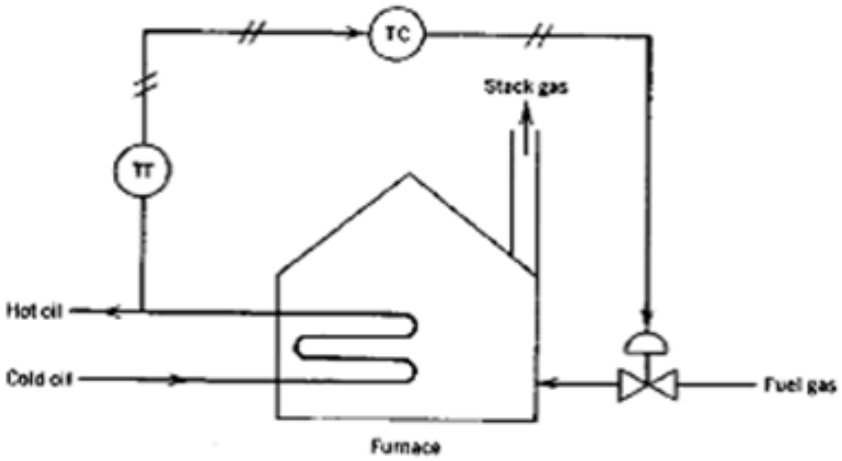

Figure Q.4. A furnace temperature control that uses conventional feedback control.
Rajah S.4. Satu kawalan suhu relau yang menggunakan kawalan suap-balik.

5. [a] Packed bed reactors often exhibit "wrong way" (inverse response) behaviour. You are responsible for the control-system design for a packed bed reactor that has the following step response behavior as shown in Figure Q.5., where a step decrease in steam valve position was made at t = 5 minutes.

Reaktor-reaktor lapisan terpadat selalu menunjukkan sifat "salah arah" (respon terbalik). Anda bertanggungjawab bagi mereka sistem-kawalan untuk reaktor lapisan terpadat yang mempunyai sifat sambutan langkah yang ditunjukkan dalam Rajah S.5., di mana langkah penurunan di dalam posisi injap wap telah dibuat pada t = 5 minit.

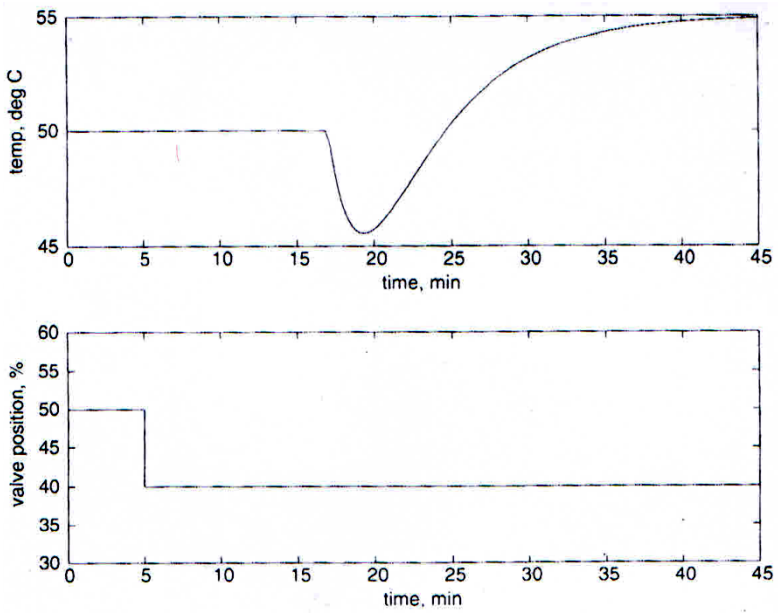

Figure Q.5.
Rajah S.5.

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You have developed the following process model (the time units is minutes).
Anda telah membina model proses berikut (unit bagi masa adalah minit).

$$\tilde{g}_p(s) = \frac{-0.1(-10s+1)e^{-12s}}{(5s+1)(3s+1)}$$

[i] Design an Internal Model Control (IMC) for this process. Use the all-pass factorization for the RHP zero, and assume the designed controller, *q*(*s*) is semiproper.

Reka satu Kawalan Model Dalaman (IMC) bagi proses ini. Gunakan pemfaktoran "all-pass" bagi RHP sifar, dan andaikan pengawal yang direka, q(s) *adalah separuh-wajar.* *[7 marks/markah]*

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

Andaikan model yang sempurna, plot secara kualitatif bagaimana suhu akan berubah bagi satu langkah titik set 1 °C.

[3 marks/markah]

[b] The following process transfer function represents the relationship between the boiler feedwater flow rate and steam drum level:

Fungsi pindahan proses tersebut mewakili hubungan di antara kadar aliran suapan air pendandang dan aras stim drum:

$$\tilde{g}_p(s) = \frac{k_p(-\beta s+1)}{s(\tau_p s+1)}$$

[i] Use the all-pass factorization method to show that the IMC-Based PID controller is PD with a first-order lag.

Gunakan kaedah pemfaktoran "all-pass" untuk menunjukkan bahawa pengawal PID berdasarkan IMC adalah PD dengan ekoran tertib-pertama. *[8 marks/markah]*

[ii] Use $f(s) = \frac{2\lambda s+1}{(\lambda s+1)^2}$ and non-"all-pass" factorization to develop a PID controller.

Gunakan $f(s) = \frac{2\lambda s+1}{(\lambda s+1)^2}$ *dan pemfaktoran bukan-"all-pass" untuk membina satu pengawal PID.* *[7 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.	$e^{-bt}\sin \omega t$	$\frac{\omega}{(s+b)^2+\omega^2}$
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.	$1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\ne\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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.