
UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2005/2006

April/May 2006

EKC 361E – Dynamic & Process Control
[Dinamik & Kawalan Proses]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SEVENTEEN printed pages and FIVE printed pages of Appendix before you begin the examination.

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

Instruction: Answer **FOUR** (4) questions. Answer any **TWO** (2) questions from Section A. Answer any **TWO** (2) questions from Section B.

[Arahan: Jawab **EMPAT** (4) soalan. Jawab mana-mana **DUA** (2) soalan dari Bahagian A. Jawab mana-mana **DUA** (2) soalan dari Bahagian B.]

[Pelajar dibenarkan menjawab semua soalan dalam Bahasa Inggeris ATAU Bahasa Malaysia ATAU kombinasi kedua-duanya.]

...2/-

Section A : Answer any TWO questions.

Bahagian A : Jawab mana-mana DUA soalan.

1. [a] Which solutions of the following equations will exhibit convergent behaviour? Which are oscillatory?

[i] $\frac{d^3x}{dt^3} + 2\frac{d^2x}{dt^2} + 2\frac{dx}{dt} + x = 3$

[ii] $\frac{d^2x}{dt^2} - x = 2e^t$

[iii] $\frac{d^3x}{dt^3} + x = \sin t$

[iv] $\frac{d^2x}{dt^2} + \frac{dx}{dt} = 4$

[12 marks]

- [b] Determine which “short statement(s)” are correct:

[i] A transfer function can be used to provide information about how a process will respond to a single input. For a particular input change, it provides:

- (A) Only steady-state information about the resulting output change.
- (B) Only dynamic information about the output change.
- (C) Both, steady-state and dynamic information about the output change.

[ii] Laplace transform methods that form the basis for the development of transfer functions are only applicable when the process model is linear. If a process model is nonlinear:

- (A) A transfer function cannot be obtained.
- (B) A transfer function that describes the process operation exactly can be obtained.
- (C) A transfer function that describes the process operation approximately can be obtained.

...3/-

[iii] Three functions of the Laplace operator s are denoted by $M(s)$, $U(s)$, and $Y(s)$. These represent:

- (A) Transfer functions.
- (B) Process inputs that have been transformed.
- (C) Process outputs that have been transformed.
- (D) None of (A)-(C).
- (E) Any of (A)-(C).

[3 marks]

[c] For the process modelled by

$$2 \frac{dy_1}{dt} = -2y_1 - 3y_2 + 2u_1$$

$$\frac{dy_2}{dt} = 4y_1 - 6y_2 + 2u_1 + 4u_2$$

Find the four transfer functions relating the outputs (y_1, y_2) to the inputs (u_1, u_2) . The u and y are deviation variables.

[10 marks]

1. [a] *Penyelesaian-penyelesaian yang manakah bagi persamaan-persamaan berikut yang menunjukkan kelakuan tertumpu? Yang mana berayun?*

[i] $\frac{d^3x}{dt^3} + 2\frac{d^2x}{dt^2} + 2\frac{dx}{dt} + x = 3$

[ii] $\frac{d^2x}{dt^2} - x = 2e^t$

[iii] $\frac{d^3x}{dt^3} + x = \sin t$

[iv] $\frac{d^2x}{dt^2} + \frac{dx}{dt} = 4$

[12 markah]

...4/-

[b] Tentukan kenyataan-kenyataan manakah yang betul:

[i] Satu rangkap pindah boleh digunakan untuk memberikan maklumat bagaimana satu proses akan memberi sambutan bagi satu masukan. Bagi satu perubahan masukan tertentu, ia memberikan:

- (A) Hanya maklumat tentang perubahan hasil keluaran pada keadaan mantap.
- (B) Hanya maklumat tentang perubahan keluaran pada keadaan dinamik.
- (C) Kedua-dua maklumat tentang perubahan keluaran pada keadaan mantap dan keadaan dinamik.

[ii] Kaedah Jelmaan Laplace yang membentuk asas bagi pembangunan rangkap pindah hanya boleh digunakan bila model adalah linear. Jika model tidak linear:

- (A) Rangkap pindah tidak boleh diperolehi.
- (B) Rangkap pindah yang menjelaskan operasi proses secara tepat boleh diperolehi.
- (C) Rangkap pindah yang menjelaskan operasi proses secara anggaran boleh diperolehi.

[iii] Tiga rangkap bagi operator Laplace s ditandakan dengan $M(s)$, $U(s)$, dan $Y(s)$. Rangkap-rangkap ini mewakili:

- (A) Rangkap-rangkap pindah.
- (B) Masukan proses yang telah dijelmakan.
- (C) Keluaran proses yang telah dijelmakan.
- (D) Bukan (A)-(C).
- (E) Mana-mana (A)-(C).

[3 markah]

[c] Bagi proses yang diwakili oleh model

$$2 \frac{dy_1}{dt} = -2y_1 - 3y_2 + 2u_1$$

$$\frac{dy_2}{dt} = 4y_1 - 6y_2 + 2u_1 + 4u_2$$

Cari empat rangkap pindah yang menghubungkan di antara keluaran-keluaran (y_1, y_2) dengan masukan-masukan (u_1, u_2) . u dan y merupakan pembolehubah sisihan.

[10 markah]

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2. It is desired to control the exit concentration of c_3 of the liquid blending system shown in Figure Q.2.

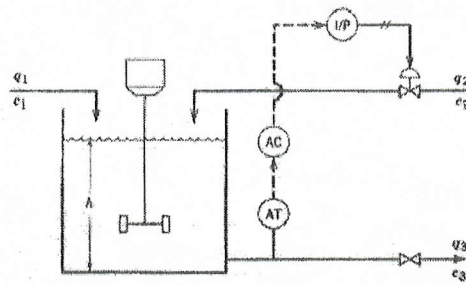


Figure Q.2: Liquid blending system

Using the information given at the end of the question

- [a] Draw a block diagram for the composition control scheme. (Use the symbols in the figure as much as possible.)
- [b] Derive an expression for each transfer function and substitute numerical values.
- [c] Suppose that the PI controller has been tuned for the nominal set of operating conditions. Indicate whether the controller should be retuned for each of the following situations (Briefly justify your answers).
- [i] The nominal value of c_2 changes to $\bar{c}_2 = 8.5$ lb solute/ft³.
 - [ii] The span of the composition transmitter is adjusted so that the transmitter output varies from 4 to 20 mA as c_3 varies from 3 to 14 lb solute/ft³.
 - [iii] The zero of the composition transmitter is adjusted so that the transmitter output varies from 4 to 20 mA as c_3 varies from 4 to 10 lb solute/ft³.

[25 marks]

Available Information

- The tank is perfectly mixed.
- The volumetric flow rate and solute concentration of stream 2, q_2 and c_2 , vary with time, while those of stream 1 are constant.
- The flow-head relation for the valve on the exit line is given by $q_3 = C_v \sqrt{h}$
- The densities of all three streams are identical and do not vary with time.
- A 2-min time delay is associated with the composition measurement. The transmission output signal varies linearly from 4 to 20 mA as c_3 varies from 3 to 9 lb solute/ft³.
- The pneumatic control valve has negligible dynamics. Its steady-state behavior is summarized below where p_t is the air pressure signal to the control valve from the I/P transducer.

| p_t (psi) | q_2 (gal/min) |
|-------------|-----------------|
| 6 | 20 |
| 9 | 15 |
| 12 | 10 |

...6/-

- An electronic, direct-acting, PI controller is used.
- The current-to-pressure transducer has negligible dynamics and a gain of 0.3 psi/mA.
- The nominal operating conditions are:

$$\rho = 75 \text{ lb/ft}^3$$

$$\bar{q}_1 = 10 \text{ gal/min}$$

$$\bar{q}_2 = 15 \text{ gal/min}$$

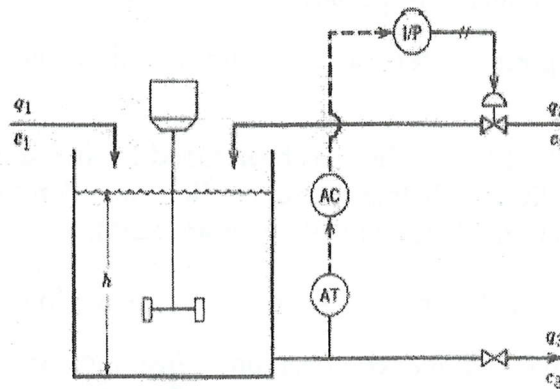
$$\bar{c}_3 = 5 \text{ lb of solute/ft}^3$$

$$\bar{c}_2 = 7 \text{ lb of solute/ft}^3$$

$$C_v = 12.5 \text{ gal/min} \cdot (\text{ft})^{1/2}$$

$$D = \text{tank diameter} = 4 \text{ ft.}$$

2. *Rajah S.2 menunjukkan sistem kawalan untuk mengawal kepekatan keluar c_3 bagi satu sistem adunan cecair*



Rajah S.2: Sistem adunan cecair

Dengan menggunakan maklumat yang diberikan di bahagian akhir soalan ini:

- [a] *Lukiskan gambarajah blok bagi skim kawalan komposisi tersebut. (Gunakan simbol-simbol dalam rajah sebanyak yang mungkin).*
- [b] *Terbitkan ungkapan bagi setiap rangkap pindah dan gantikan nilai-nilai berangka.*
- [c] *Katakan pengawal PI telah ditala bagi keadaan operasi nominal. Nyatakan samada pengawal perlu ditala semula bagi keadaan-keadaan berikut (Berikan justifikasi jawapan anda secara ringkas).*
 - [i] *Nilai nominal c_2 berubah kepada $\bar{c}_2 = 8.5$ paun bahan larut/kaki³.*
 - [ii] *Rentang pengantar komposisi dilaraskan agar keluaran pengantar berubah dari 4 ke 20 mA apabila c_3 berubah dari 3 ke 14 paun bahan larut/kaki³.*
 - [iii] *Sifar bagi pengantar komposisi dilaraskan agar keluaran pengantar berubah dari 4 ke 20 mA apabila c_3 berubah dari 4 ke 10 paun bahan larut/kaki³.*

[25 markah]

...7/-

Maklumat:

- *Tangki teraduk secara sempurna.*
- *Kadar aliran isipadu dan kepekatan bahan larut bagi aliran 2, q_2 dan c_2 , berubah dengan masa manakala bagi aliran 1 adalah tetap.*
- *Hubungan aliran-ketinggian bagi injap pada aliran keluar diberi sebagai $q_3 = C_v \sqrt{h}$*
- *Ketumpatan bagi ketiga-tiga aliran adalah sama dan tidak berubah dengan masa.*
- *Masa lengah 2 minit dikaitkan dengan pengukuran komposisi. Isyarat keluaran bagi pengantar berubah secara linear dari 4 ke 20 mA apabila c_3 berubah dari 3 ke 9 paun bahan larut/kaki³.*
- *Dinamik bagi injap kawalan pneumatik boleh diabaikan. Sifat pada keadaan mantapnya diringkaskan di bawah di mana p_1 adalah isyarat tekanan udara ke injap kawalan dari transduser I/P.*

| p_1 (psi) | q_2 (gelen/min) |
|-------------|-------------------|
| 6 | 20 |
| 9 | 15 |
| 12 | 10 |

- *Pengawal PI elektronik dan bertindak-terus digunakan.*
- *Dinamik bagi transduser elektrik-ke-tekanan boleh diabaikan dan gandaannya ialah 0.3 psi/mA.*
- *Keadaan operasi nominal ialah:*

$$\begin{aligned} \bar{\rho} &= 75 \text{ paun/kaki}^3 \\ \bar{q}_1 &= 10 \text{ gelen/min} \\ \bar{q}_2 &= 15 \text{ gelen/min} \\ \bar{c}_3 &= 5 \text{ paun bahan larut/kaki}^3 \\ \bar{c}_2 &= 7 \text{ paun bahan larut/kaki}^3 \\ C_v &= 12.5 \text{ gelen/min. (kaki)}^{1/2} \\ D &= \text{Garispusat tangki} = 4 \text{ kaki.} \end{aligned}$$

3. [a] Define the following terms:

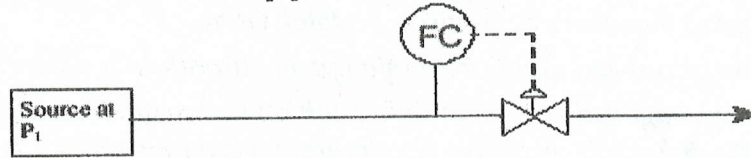
- [i] Rise Time
- [ii] Time to First Peak
- [iii] Settling Time
- [iv] Overshoot
- [v] Decay Ratio
- [vi] Period of Oscillation

[6 marks]

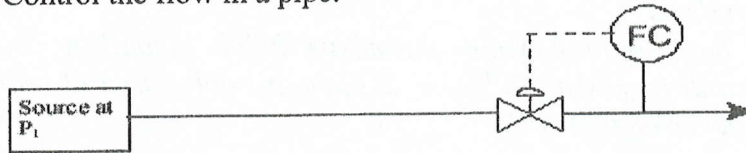
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[b] Discuss whether each of the following control designs satisfies the specified control objective.

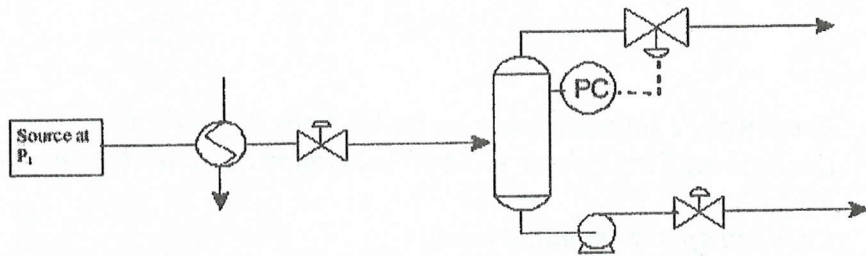
[i] Control the flow in a pipe.



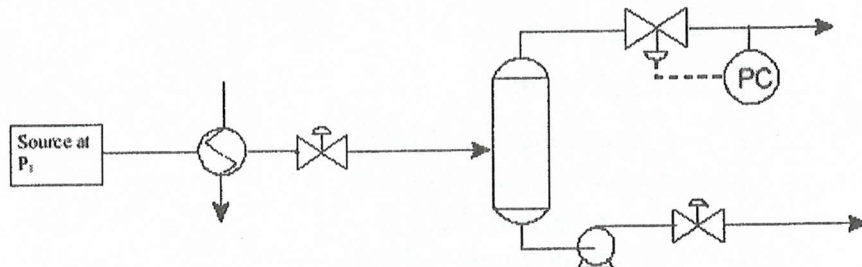
[ii] Control the flow in a pipe.



[iii] Control the pressure in an enclosed vessel.



[iv] Control the pressure in an enclosed vessel.



[4 marks]

[c] A process has been modeled and has been Laplace transformed to obtain the following two equations:

$$(\tau_a s + 1)Y_1(s) = K_1 U_1(s) + K_b Y_2(s)$$

$$(\tau_b s + 1)Y_2(s) = K_2 U_2(s) + Y_1(s)$$

where the outputs are Y_1 and Y_2 , and the inputs are U_1 and U_2 .

[i] Find the transfer functions

$$\frac{Y_1(s)}{U_1(s)} \text{ and } \frac{Y_2(s)}{U_1(s)}$$

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- [ii] What is the gain of each transfer function? (You may develop these analytically or use the Final Value Theorem.)
- [iii] What can you conclude about the form of $Y_2(s)/U_1(s)$? In other words, is it first or second order? If second order, can you determine if it is over- or underdamped? Is there some choice of parameters (τ_a , τ_b , K_1 , K_2 , and K_b) that would make this process operate as an integrator, that is, produce an s term in the denominator?

[15 marks]

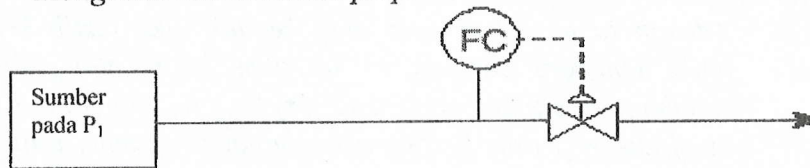
3. [a] Takrifkan sebutan-sebutan berikut:

- [i] Masa naik
- [ii] Masa untuk puncak pertama
- [iii] Masa penganapan
- [iv] Terlajak
- [v] Nisbah susut
- [vi] Tempoh ayunan

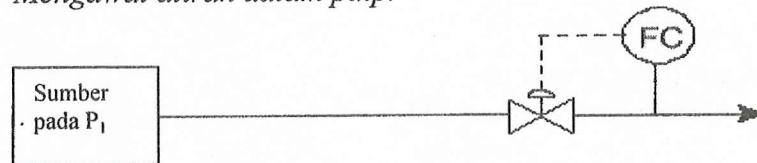
[6 markah]

[b] Bincangkan samada setiap rekabentuk-rekabentuk berikut memenuhi objektif kawalan yang dinyatakan.

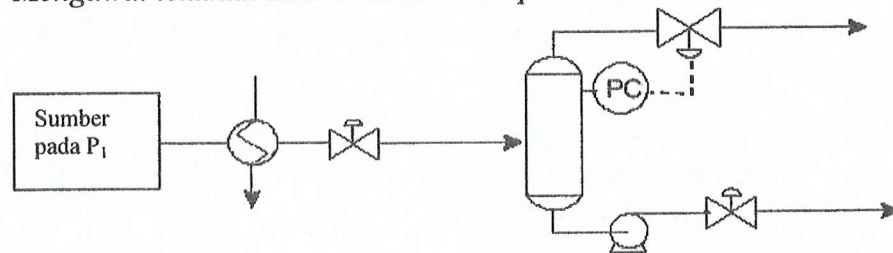
[i] Mengawal aliran dalam paip.



[ii] Mengawal aliran dalam paip.

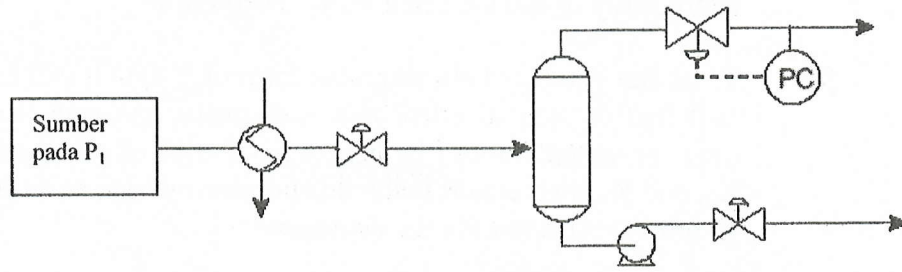


[iii] Mengawal tekanan dalam bekas tertutup.



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[iv] Mengawal tekanan dalam bekas tertutup.



[4 markah]

[c] Satu proses telah dimodel dan dijelma dengan menggunakan Jelmaan Laplace dan menghasilkan dua persamaan berikut:

$$(\tau_a s + 1)Y_1(s) = K_1 U_1(s) + K_b Y_2(s)$$

$$(\tau_b s + 1)Y_2(s) = K_2 U_2(s) + Y_1(s)$$

Di mana Y_1 dan Y_2 adalah keluaran dan U_1 and U_2 adalah masukan.

[i] Carikan rangkap-rangkap pindah

$$\frac{Y_1(s)}{U_1(s)} \text{ dan } \frac{Y_2(s)}{U_1(s)}$$

[ii] Apakah gandaan bagi setiap rangkap pindah tersebut? (Anda boleh membinanya secara analitis atau menggunakan teorem nilai akhir)

[iii] Apakah kesimpulan yang anda boleh buat tentang bentuk $Y_2(s)/U_1(s)$? Adakah ia tertib pertama atau kedua? Jika tertib kedua, bolehkah anda tentukan samada ia teredam lebih atau kurang? Adakah sebahagian pilihan parameter (τ_a , τ_b , K_1 , K_2 , and K_b) yang boleh menjadikan proses beroperasi sebagai pengamir, iaitu menghasilkan sebutan s di pembawah pecahan?

[15 markah]

Section B : Answer any TWO questions.

Bahagian B : Jawab mana-mana DUA soalan.

4. The objective is to control the liquid level, L , using flow out, F_{OUT} (kg/hr) as shown in Figure Q. 4. The major disturbance to the process is the flow in to the system, F_{IN} (kg/hr)

[a] Derive the differential equation describing the change in the level of the system with respect to time, F_{OUT} and F_{IN} . State all the assumptions and give the units of all variables used.

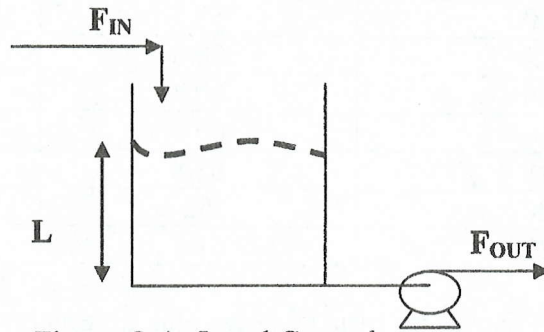
[12 marks]

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- [b] Using a proportional feedback control law **P**, derive the transfer function describing the dynamics between the flow in (F_{IN}) and the level of liquid in the tank (L)

[8 marks]

- [c] The maximum expected step changed in F_{IN} , based on the plant operating record, is 2 kg/s. The maximum permitted change in level is 0.5 m. Estimate the gain of the proportional controller that will ensure the maximum permitted change in level is not exceeded. The gain should be expressed in units of m^2/min .



[5 marks]

Figure Q.4 : Level Control

4. Rajah S.4 menunjukkan kawalan aras cecair, L dengan mengawal aliran keluaran F_{KELUAR} (kg/jam). Gangguan utama dalam proses ini adalah aliran masuk ke dalam sistem, F_{MASUK} (kg/jam).

- [a] Terbitkan persamaan pembezaan menerangkan perubahan dalam aras cecair sistem tersebut dengan perubahan masa, F_{KELUAR} dan F_{MASUK} . Nyatakan semua andaian dan berikan unit untuk semua pembolehubah yang digunakan.

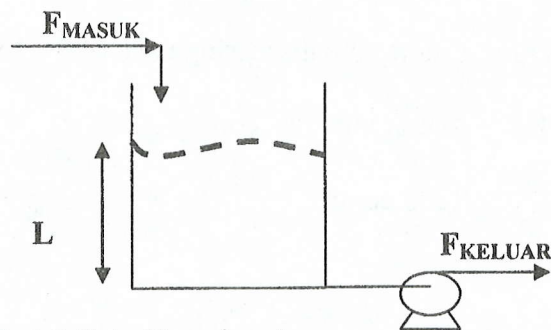
[12 markah]

- [b] Dengan menggunakan pengawal kadaran (**P**) suap balik, terbitkan rangkap pindah yang menerangkan dinamik di antara aliran masuk (F_{MASUK}) dan aras cecair di dalam tangki (L)

[8 markah]

- [c] Perubahan langkah maksimum yang dijangka dalam F_{MASUK} , berdasarkan catatan operasi dari kilang adalah 2 kg/s. Perubahan maksimum yang dibenarkan dalam aras cecair adalah 0.5 m. Anggarkan gandaan pengawal kadaran yang akan memastikan supaya perubahan maksimum yang dibenarkan di dalam aras cecair tidak akan dilepasi. Unit untuk gandaan adalah m^2/min .

[5 markah]



Rajah S.4 : Kawalan Aras

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5. The following data has been obtained from an open loop step test on a shell and tube heat exchanger

| Time(min) | Temperature (°C) | Stem valve (%) |
|------------|------------------|----------------|
| 0 | 52 | 50-55 |
| 2 | 52 | 55 |
| 4 | 53 | 55 |
| 6 | 54.5 | 55 |
| 8 | 56 | 55 |
| 10 | 57.5 | 55 |
| 12 | 58.8 | 55 |
| 14 | 60.2 | 55 |
| 16 | 60.4 | 55 |
| 18 | 61.8 | 55 |
| 20 | 62 | 55 |
| 22 | 61.8 | 55 |

- [a] Fit the parameter of a 1st order plus time delay model to this data (**the units must be in second**)

[10 marks]

- [b] Calculate the parameter for PI and PID setting using Cohen-Coon tuning rules

| | k_c | T_i | T_D |
|------------|---|--|--|
| P | $\frac{1}{k_p} \frac{\tau}{\theta} \left(1 + \frac{\theta}{3\tau}\right)$ | | |
| PI | $\frac{1}{k_p} \frac{\tau}{\theta} \left(\frac{9}{10} + \frac{\theta}{12\tau}\right)$ | $\theta \frac{30 + 3(\theta/\tau)}{9 + 20(\theta/\tau)}$ | |
| PID | $\frac{1}{k_p} \frac{\tau}{\theta} \left(\frac{4}{3} + \frac{\theta}{4\tau}\right)$ | $\theta \frac{32 + 6(\theta/\tau)}{13 + 8(\theta/\tau)}$ | $\theta \frac{4}{11 + 2(\theta/\tau)}$ |

In the table k_p is the process gain, τ is the process time constant and θ is the process time delay.

[10 marks]

- [c] Write a short note discussing **each** of the following topics:

- [i] Averaging level control
- [ii] Ratio control

[5 marks]

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5. Data berikut diperolehi dari ujian langkah titik gelung terbuka ke atas penukar haba kelompong dan tiub.

| Masa (min) | Suhu (°C) | Kedudukan bukaan injap (%) |
|------------|-----------|----------------------------|
| 0 | 52 | 50-55 |
| 2 | 52 | 55 |
| 4 | 53 | 55 |
| 6 | 54.5 | 55 |
| 8 | 56 | 55 |
| 10 | 57.5 | 55 |
| 12 | 58.8 | 55 |
| 14 | 60.2 | 55 |
| 16 | 60.4 | 55 |
| 18 | 61.8 | 55 |
| 20 | 62 | 55 |
| 22 | 61.8 | 55 |

- [a] Padankan data tersebut untuk mendapatkan parameter sistem tertib pertama dengan masa lenghan (semua unit hendaklah dalam saat)

[10 markah]

- [b] Kirakan parameter pengawal bagi pengawal PI dan PID bagi sistem ini dengan menggunakan kaedah talaan Cohen dan Coon

| | k_c | T_i | T_D |
|------------|---|--|--|
| P | $\frac{1}{k_p} \frac{\tau}{\theta} \left(1 + \frac{\theta}{3\tau} \right)$ | | |
| PI | $\frac{1}{k_p} \frac{\tau}{\theta} \left(\frac{9}{10} + \frac{\theta}{12\tau} \right)$ | $\theta \frac{30 + 3(\theta/\tau)}{9 + 20(\theta/\tau)}$ | |
| PID | $\frac{1}{k_p} \frac{\tau}{\theta} \left(\frac{4}{3} + \frac{\theta}{4\tau} \right)$ | $\theta \frac{32 + 6(\theta/\tau)}{13 + 8(\theta/\tau)}$ | $\theta \frac{4}{11 + 2(\theta/\tau)}$ |

k_p adalah gandaan proses, τ adalah pemalar masa proses dan θ adalah masa lenghan bagi proses.

[10 markah]

- [c] Bincangkan secara ringkas setiap perkara yang tertera di bawah:

[i] Kawalan aras purata

[ii] Kawalan nisbah

[5 markah]

...14/-

6. Considered the distillation column shown in Figure Q.6 [a].

[a] Sketch the develop control strategy of the process based on the control parameters stated below.

- [i] Pressure control loop
- [ii] Level control loop
- [iii] Composition control loop

and considering each control loop in above, briefly discuss the anticipated dynamics characteristics of the loop paying particular attention to possible system interaction (closed loop performance). Sketch the develop control strategies in the figures given in Appendix A, B and C.

[12 marks]

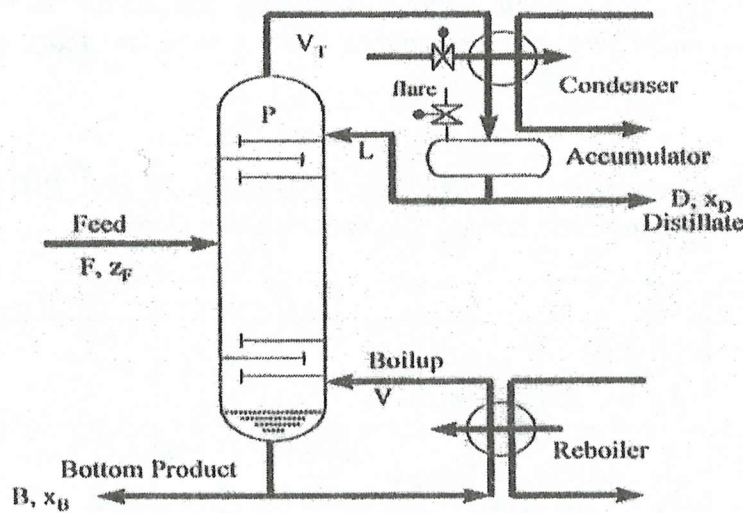


Figure Q. 6 [a] : Distillation process diagram

[b] A reactor system under consideration is shown in Figure Q.6 [b].

The reactor is fed by a stream rich in reactant A, of concentration C_{in} and flowrate F_{IN} . Within the system the following exothermic reaction take place, $A \rightarrow B \rightarrow C$. Reactant A is converted to product B, but at high temperatures B undergoes further reaction and is transformed to undesired by-product C. The reactor is cooled by means of a heat exchanger. The objectives is to maintain the temperature of the reaction mass at the desired value when subjected to changes in inlet concentration (C_{in}) and temperature (T_{in}).

- [i] Define what is the manipulated variable (MV), control variable (CV) and disturbances in this process and also sketch the control loop if feed forward (FF) control strategy is implemented in this process. Sketch the control loop in figure given in Appendix D.

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- [ii] Draw the block diagram representing the FF control strategy.

[8 marks]

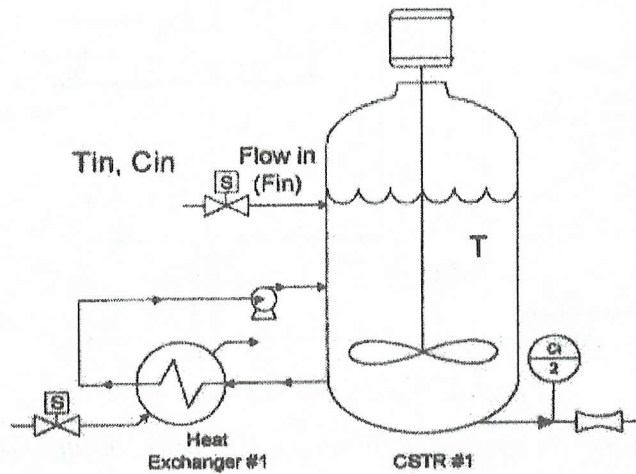


Figure 6 [b]: CSTR exothermic reaction

- [c] In cascade control schemes, supposed that the secondary loop process are represented by the symbol $G_{PS}(s)$ and the secondary loop controller by $G_{CS}(s)$. The primary loop dynamics for the process and the controller are given by $G_{PP}(s)$ and $G_{CP}(s)$ respectively. Draw the block diagram representing the cascade control strategy, and derive the closed loop transfer function describing the response of the primary controlled output to a change in the primary set point.

[5 marks]

6. Pertimbangkan turus penyulingan yang ditunjukkan dalam Rajah S.6 [a].

- [a] Lakarkan strategi kawalan proses yang dibina berdasarkan parameter kawalan yang dinyatakan di bawah.

[i] Gelung kawalan tekanan

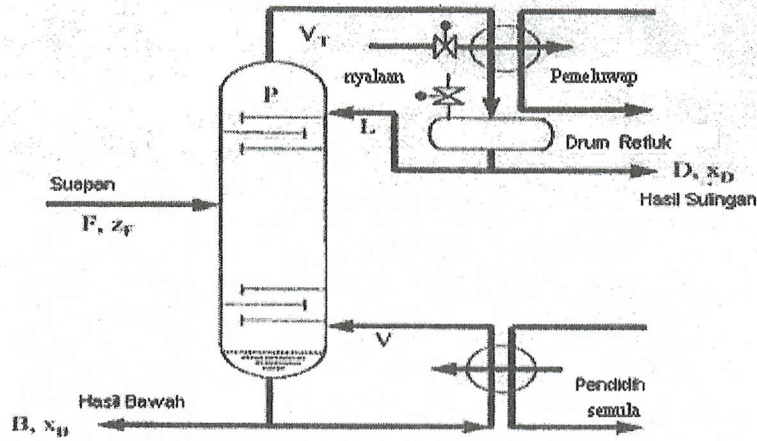
[ii] Gelung kawalan aras

[iii] . Gelung kawalan komposisi

Dengan mengambil kira setiap gelung kawalan di atas, terangkan dengan ringkas ciri-ciri dinamik jangkaan gelung kawalan tersebut dengan setiap interaksi antara sistem (prestasi gelung tertutup). Lakarkan strategi kawalan proses yang dibina menggunakan Rajah yang diberikan di Lampiran A, B dan C.

[12 markah]

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Rajah S. 6 [a] : Turus penyulingan

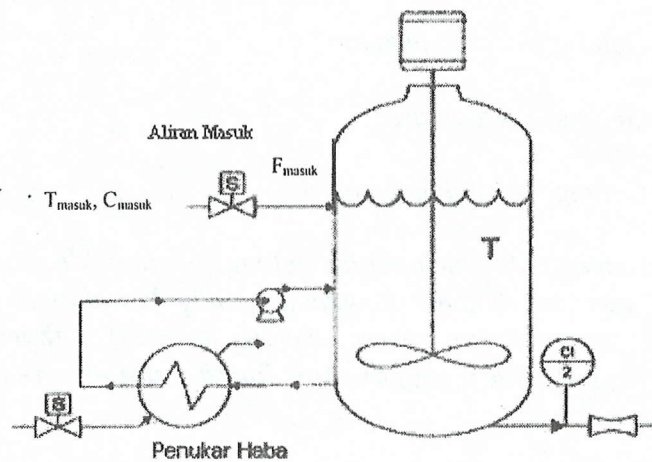
[b] Pertimbangkan sistem rektor yang ditunjukkan dalam Rajah S.6 [b].

Reaktor disuap dengan aliran yang kaya dengan bahan tindak balas A, pada kepekatan, $C_{(masuk)}$ dengan kadar aliran $F_{(masuk)}$. Dalam sistem tersebut, tindak balas eksotermik yang berikut berlaku, $A \rightarrow B \rightarrow C$. Bahan tindak balas A di tukarkan ke produk B, tetapi pada suhu tinggi B akan mengalami tindak balas seterusnya menghasilkan produk sampingan C yang tidak diinginkan. Reaktor disejukkan dengan menggunakan penukar haba. Matlamat operasi ini ialah untuk mengekalkan suhu tindak balas pada nilai yang dikehendaki apabila dikenakan perubahan pada kepekatan aliran masuk (C_{masuk}) dan suhu (T_{masuk})

[i] Berikan pembolehubah pengolah (MV), pembolehubah kawalan (CV) dan gangguan di dalam proses ini. Lakarkan gelung kawalan jika strategi kawalan suap-depan (FF) dilaksanakan menggunakan Rajah yang diberikan dalam Lampiran D.

[ii] Lukiskan gambarajah blok mewakili strategi kawalan FF.

[8 markah]



Rajah S 6 [b]: CSTR Tindakbalas Eksotermik

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Lampiran

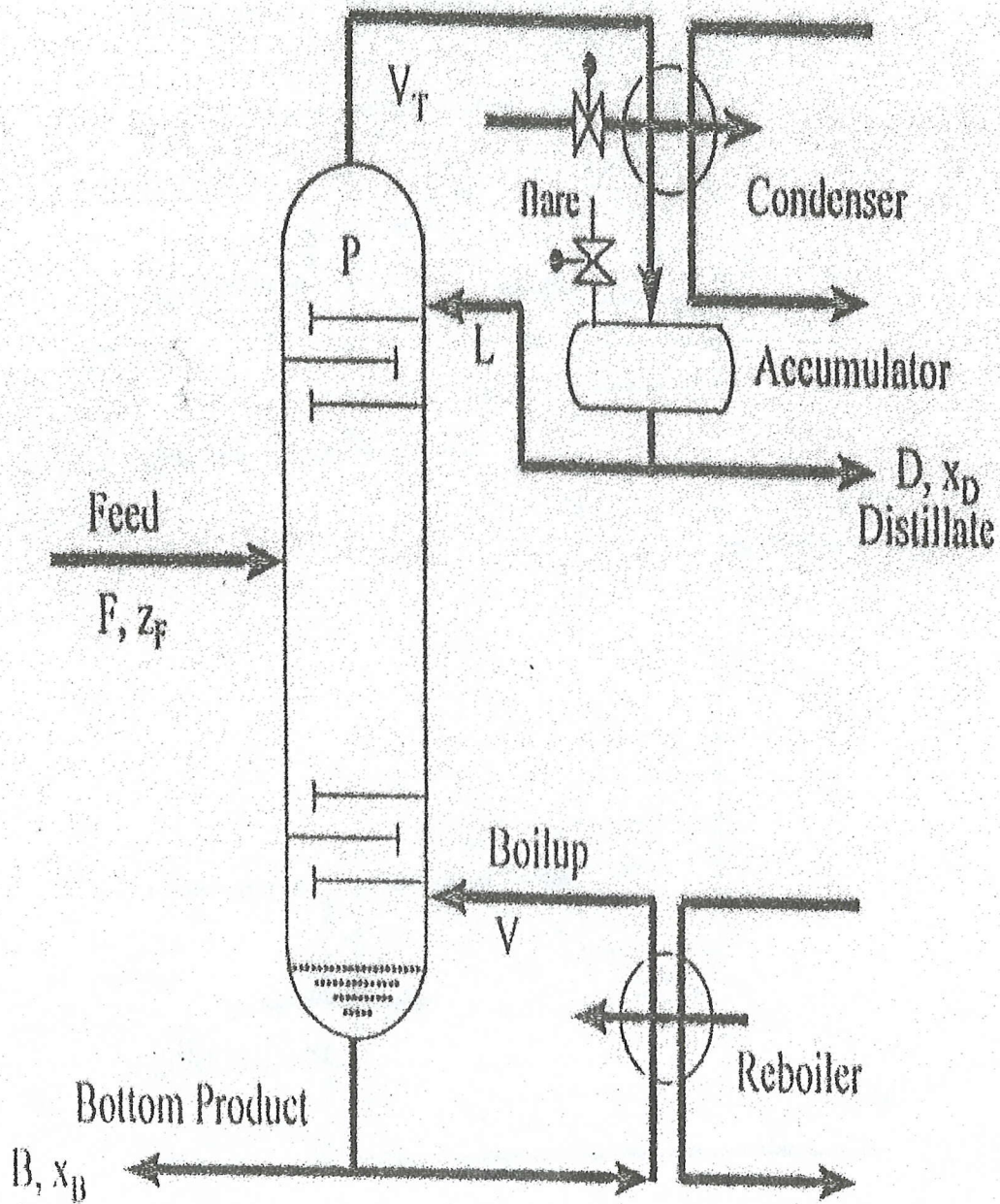
Table Laplace Transforms for Various Time-Domain Functions^a

| $f(t)$ | $F(s)$ |
|---|--|
| 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. $1 - e^{-t}$ | $\frac{1}{s(\tau s + 1)}$ |
| 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. $e^{-bt} \sin \omega t$ | $\left\{ \begin{array}{l} \frac{\omega}{(s+b)^2 + \omega^2} \\ \frac{s+b}{(s+b)^2 + \omega^2} \end{array} \right.$ |
| 18. $e^{-bt} \cos \omega t$ | |
| b, ω real | |
| 19. $\frac{1}{\tau \sqrt{1-\zeta^2}} e^{-\zeta t/\tau} \sin(\sqrt{1-\zeta^2} t/\tau)$ ($0 \leq \zeta < 1$) | $\frac{1}{\tau^2 s^2 + 2\zeta \tau s + 1}$ |
| 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. $1 - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta t/\tau} \sin[\sqrt{1-\zeta^2} t/\tau + \psi]$ $\psi = \tan^{-1} \frac{\sqrt{1-\zeta^2}}{\zeta}$, ($0 \leq \zeta < 1$) | $\frac{1}{s(\tau^2 s^2 + 2\zeta \tau s + 1)}$ |
| 22. $1 - e^{-\zeta t/\tau} [\cos(\sqrt{1-\zeta^2} t/\tau) + \frac{\zeta}{\sqrt{1-\zeta^2}} \sin(\sqrt{1-\zeta^2} t/\tau)]$ ($0 \leq \zeta < 1$) | $\frac{1}{s(\tau^2 s^2 + 2\zeta \tau s + 1)}$ |
| 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. $\frac{d^n f}{dt^n}$ | $s^n F(s) - s^{n-1} f(0) - s^{n-2} f^{(1)}(0) - \dots - s f^{(n-2)}(0) - f^{(n-1)}(0)$ |
| 26. $f(t - t_0) S(t - t_0)$ | $e^{-t_0 s} F(s)$ |

^aNote that $f(t)$ and $F(s)$ are defined for $t \geq 0$ only.

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Appendix A (Attach this sheet with the Answer script)

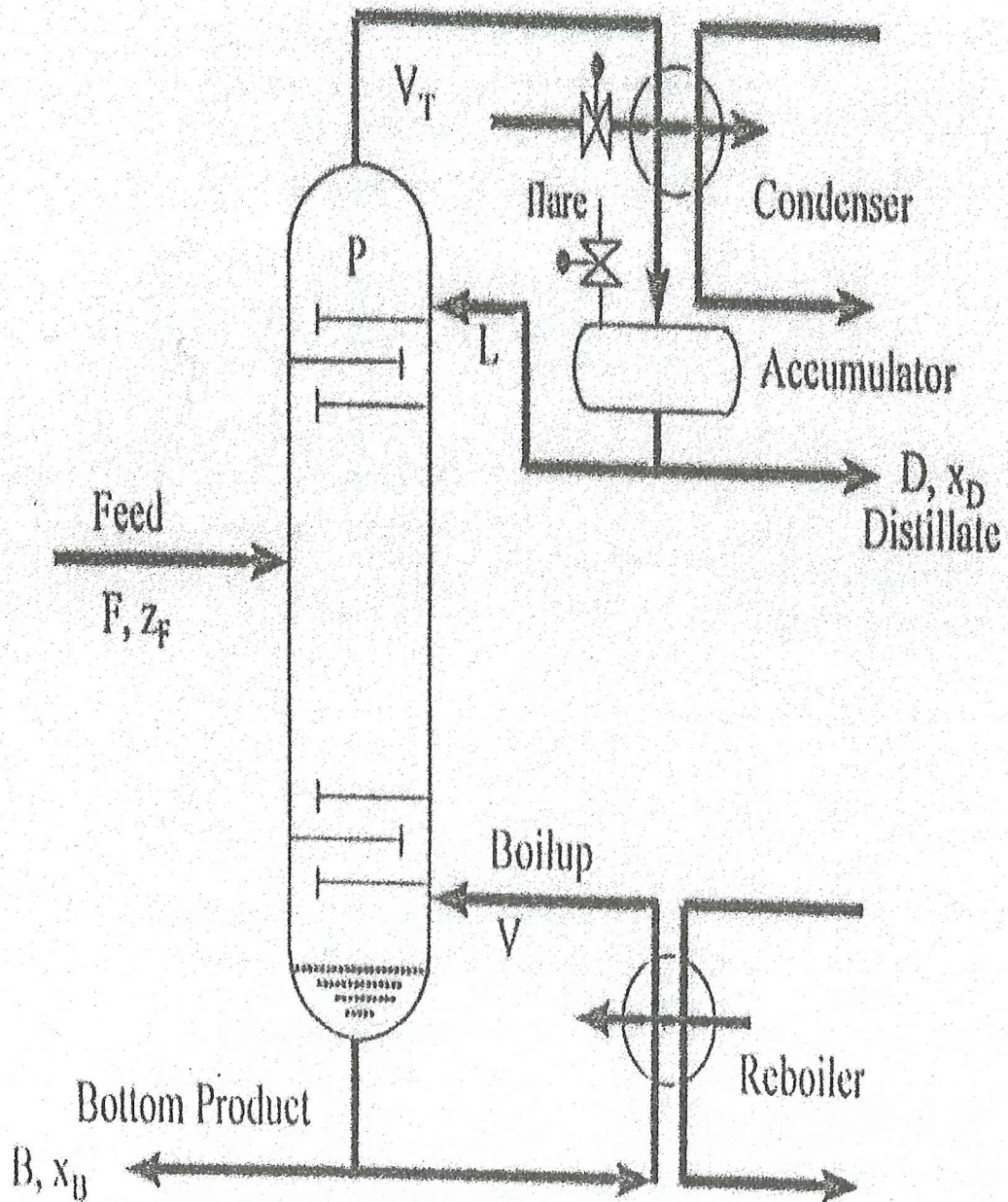


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Appendix B (Attach this sheet with the Answer script)

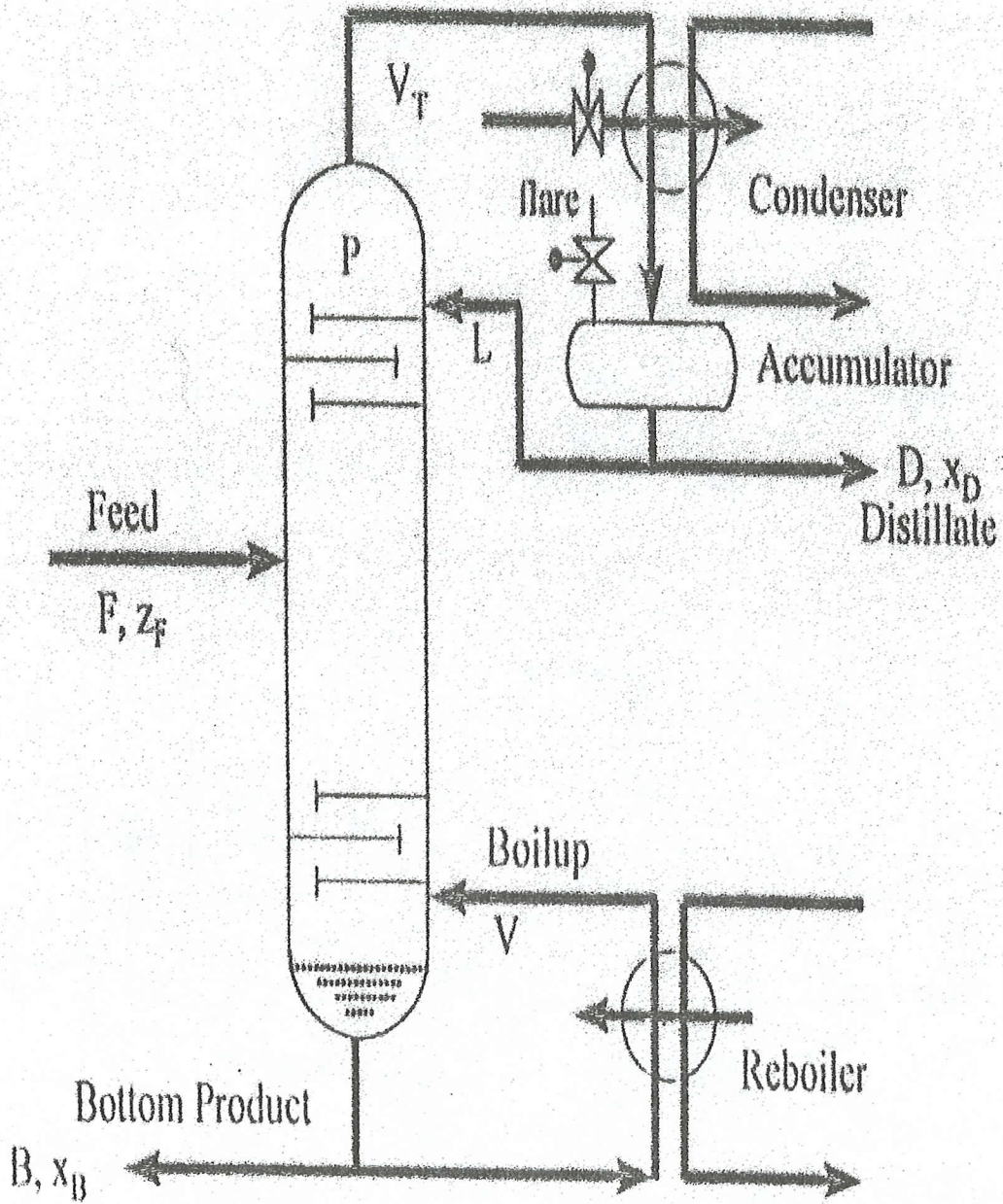


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Appendix C (Attach this sheet with the Answer script)



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Appendix D (Attach this sheet with the Answer script)

