Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2019/2020

COURSE NAME	:	PROCESS CONTROL
COURSE CODE	:	BNQ 30703
PROGRAMME	:	BNN
EXAMINATION DATE	:	DECEMBER 2019/ JANUARY 2020
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **NINE (9)** PAGES

Q1 (a) A chemical plant is an arrangement of processing units integrated with one another in a systematic and rational manner. During plant operation, several requirements imposed by its designers and the general, economic and social condition in the presence of ever-changing external influences must be satisfied.

(i) Discuss **THREE (3)** requirements needed for a process control as incentive of the chemical plant operation.

(6 marks)

(ii) Interpret the following statements with either true/false answer.

(a) *Feedback* control will always take action regardless of the accuracy of any process model that was used to design it and the source of disturbance.

(b) *Feedforward* control can be perfect in the theoretical sense that the controller can take action via the manipulated variable even while the controlled variable remains equal to its desired value.

(c) *Feedforward* control can provide perfect control; that is, the output can be kept at its desired value, even with an imperfect process model.

(d) The process variable to be controlled is measured in *feedback control.*

(4 marks)

(b) Consider the air-heating system used to regulate the temperature in a house in **Figure Q1 (b)**. The heat is supplied from the combustion of fuel oil.

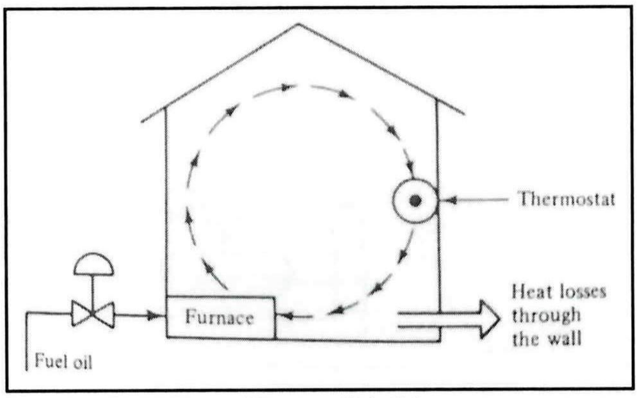

Figure Q1 (b)

(i) Identify the control objective, the available measurements, potential disturbances for the system shown in **Figure Q1 (b)** and state if the system is either MIMO/SISO with reasons.

(8 marks)

(ii) Draw a feedback control configuration complete with necessary label to achieve your objective stated in **Q1 (b) (i)**

(3 marks)

(iii) Predict the possibility of using feedforward control configuration to achieve the similar objective in **Q1 (b) (i).** Explain your prediction.

(4 marks)

Q2 (a) Two surge tanks are connected together in an unusual way as shown in **Figure Q2 (a).**

Notes:

The density of the incoming liquid, ρ, is constant.

The cross-sectional area of the two tanks are A_1 and A_2

W_2 is positive for flow from Tank 1 and Tank 2

The two valves are linear with resistances R_2 and R_3.

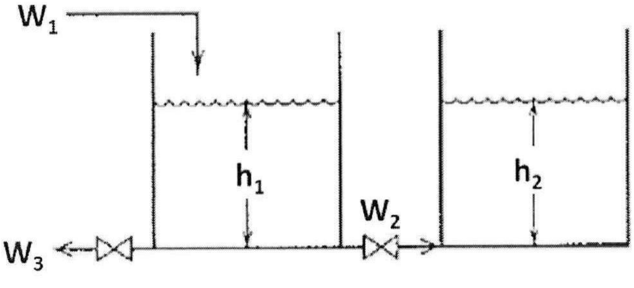

Figure Q2 (a): Two surge tanks

(i) Develop a model for this system that can be used to find h_1, h_2, W_2 and W_3 as functions of time for any given variations of inputs.

(8 marks)

(ii) Perform a complete degree of freedom analysis by identifying all parameters, variables and equations involves, number of degree of freedom, specified input and output variables from the models developed in **Q2 (a) (i)**.

(9 marks)

(b) The liquid storage tank shown in **Figure Q2 (b)** has two inlet streams with mass flow rate w_1 and w_2 and an exit stream with flow rate w_3. The cylindrical tank is 2.5 m tall and 2 m in diameter. The liquid has a density of 800 kg/m^3. Normal operating procedure is to fill the tank until the liquid level reaches a nominal value of 1.75 m using constant flow rate of $w_1 = 120$ kg/min, $w_2 = 100$ kg/min and $w_3 = 200$ kg/min. At that point, inlet flow rate w_1 is adjusted so that the level remains constant. However, on this particular day, corrosion of the tank has opened up a hole in the wall at a height of 1 m, producing a leak whose volumetric flow rate q_4 (m^3/min) can be approximated by:

$$q_4 = 0.025\sqrt{h - 1}$$

Where h is height in meters.

(i) If the tank was initially empty, determine the time it takes for the liquid level to reach the corrosion point.

(4 marks)

(ii) If mass flow rates w_1, w_2 and w_3 are kept constant indefinitely, predict the chances of the tank to eventually overflow. Justify your answer.

(4 marks)

Q3 (a) For the process modelled by:

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

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

Determine **FOUR (4)** transfer functions relating the output (y_1, y_2) to the input (u_1, u_2). The u_i and y_i are deviation variables.

(8 marks)

(b) (i) Consider two tanks with different cross-sectional area of A_1 and A_2, where $A_1 > A_2$ with the same resistance subjected to the same step unit changes in inlet flow rate which results shown in **Figure Q3 (b) (i)**. Discuss your understanding regarding **Figure Q3 (b)(i)**.

(3 marks)

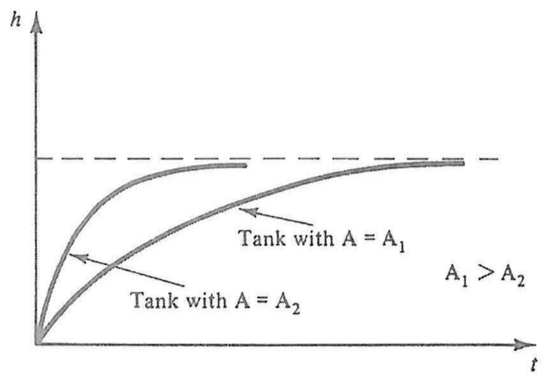

Figure Q3 (b) (i): Effect of time constant in the response of first order lag systems

(ii) Consider two tanks with different cross-sectional area of A_1 and A_2, where $A_1 > A_2$ with different flow resistance R_1 and R_2 such that:

$$\frac{A_1}{A_2} = \frac{R_1}{R_2}$$

Both tanks were subjected to the same step unit changes in inlet flow rate which results shown in **Figure Q3 (b) (ii)**. Discuss your understanding regarding **Figure Q3 (b) (ii)**.

(4 marks)

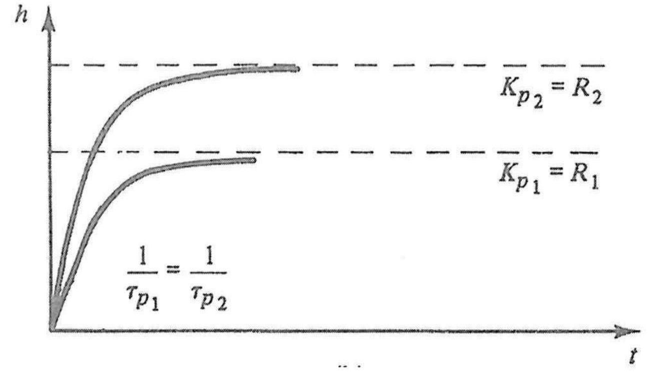

Figure Q3 (b) (ii): Effect of static gain in the response of first order lag systems.

(c) A vented cylindrical tank is used for storage between a tank car unloading facility and a continuous reactor that uses the tank car contents as feedstock (refer **Figure Q3 (c)**). The reactor feed exits the storage tank at a constant flow rate of 0.02 m^3/s. During some periods of operation, feedstock is simultaneously transferred from the tank to the feed tank and from the tank to the reactor. The operators have to be particularly careful not to let the feed tank overflow or empty. The feed tank is 5 m high (distance to the vent) and has an internal cross-sectional area of 4 m^2.

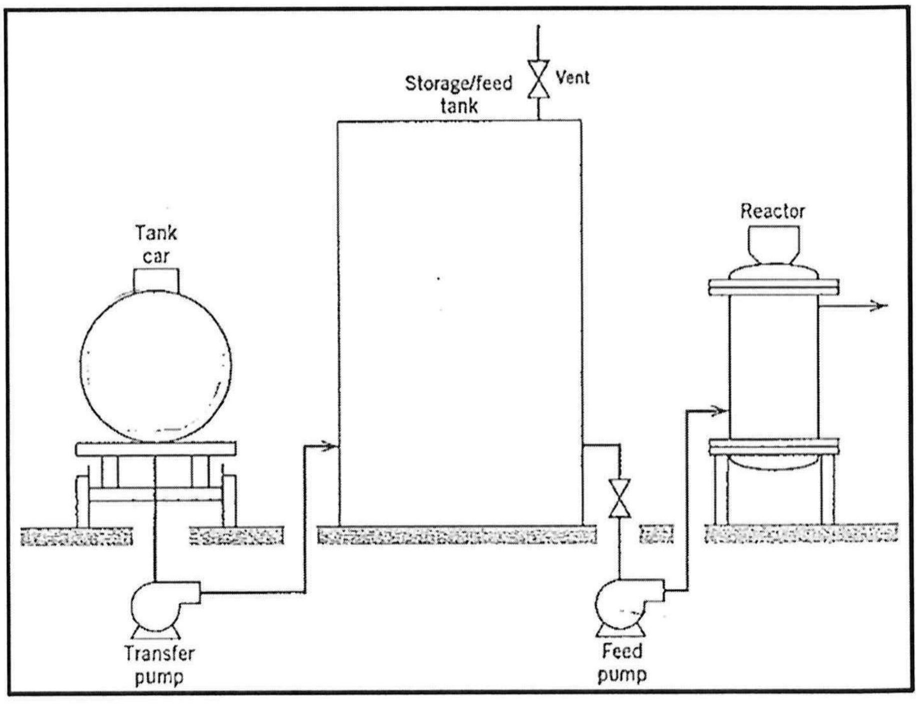

Figure Q3 (c): Unloading and Storage Facility for a continuous reactor

(i) Suppose after a long period of operation, the tank level is 2 m at the time the tank car empties. Calculate the reactor operation time before the feed tank is depleted.
(6 marks)

(ii) Another tank car is moved into place and connected to the tank, while flow continuous into the reactor at 0.02 m^3/s. If flow is introduce into the feed tank just as the tank level reaches 1 m. Calculate the time needed for the transfer pump to be operated before the feed tank is overflow. Assume that, the transfer pump is operated at a constant rate of 0.1 m^3/s when switch on.

(4 marks)

Q4 (a) (i) Define a first order system process by its characteristics

(4 marks)

(ii) Suggest and describe **TWO (2)** categories of which a second-order system can occur.

(4 marks)

(b) Ratio control is a special type of feed forward control system

(i) Define the function of a ratio control system

(1 marks)

(ii) Demonstrate **THREE (3)** examples of typical applications of ratio control

(6 marks)

(c) (i) The selection of appropriate controller is very critical for a control system to effectively function and achieve desired control objective. Differentiate between Proportional Controller and PID Controller in term of function, suitability and usage.

(6 marks)

(ii) Compare the basic concepts of feedforward and feedback control system.

(4 marks)

-END OF QUESTIONS-

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RELATED EQUATIONS

Table 1: Laplace Transformations for various time-domain functions.

$f(t)$	
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. $\sin(\omega t+\phi)$	$\frac{\omega\cos\phi+s\sin\phi}{s^2+\omega^2}$

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Table 1: Laplace transformation for various time-domain functions (cont')

$f(t)$	$F(s)$
17. $e^{-bt}\sin\omega t$ (b, ω real)	$\dfrac{\omega}{(s+b)^2+\omega^2}$
18. $e^{-bt}\cos\omega t$ (b, ω real)	$\dfrac{s+b}{(s+b)^2+\omega^2}$
19. $\dfrac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0 \le \lvert\zeta\rvert<1)$	$\dfrac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\dfrac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1 \neq \tau_2)$	$\dfrac{1}{s(\tau_1s+1)(\tau_2s+1)}$
21. $1-\dfrac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\dfrac{\sqrt{1-\zeta^2}}{\zeta}$, $(0 \le \lvert\zeta\rvert<1)$	$\dfrac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\dfrac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0 \le \lvert\zeta\rvert<1)$	$\dfrac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
23. $1+\dfrac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\dfrac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1 \neq \tau_2)$	$\dfrac{\tau_3s+1}{s(\tau_1s+1)(\tau_2s+1)}$
24. $\dfrac{df}{dt}$	$sF(s)-f(0)$
25. $\dfrac{d^nf}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
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.

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Time Response

$$C(s)=\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$$

$$T_p=\frac{\pi}{\omega_n\sqrt{1-\zeta^2}}=\frac{\pi}{\omega_d}$$

$$\%OS=100e^{-\left(\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right)}$$

$$\zeta=\frac{-\ln(\%OS/100)}{\sqrt{\pi^2+\ln^2(\%OS/100)}}$$

$$T_s=\frac{4}{\zeta\omega_n}=\frac{4}{\sigma_d}$$

$$T_r=\frac{1.321}{\omega_n}$$

Table 2: Test waveforms used in control systems

Name	Time function	Laplace transform
Step	$u(t)$	$\frac{1}{s}$
Ramp	$tu(t)$	$\frac{1}{s^2}$
Parabola	$\frac{1}{s}t^2$	$\frac{1}{s^3}$
Impulse	$\delta(t)$	1
Sinusoid	$\sin\omega tu(t)$	$\frac{\omega}{s^2+\omega^2}$
Cosine	$\cos\omega tu(t)$	$\frac{s}{s^2+\omega^2}$

Root Locus

$$K=\frac{1}{|G(s)H(s)|}=\frac{\prod \text{pole lengths}}{\prod \text{zero lengths}}$$

$$\sigma_a=\frac{\sum \text{finite poles}-\sum \text{finite zeros}}{\#\text{finite poles}-\#\text{finite zeros}}$$

$$\theta_a=\frac{(2k+1)\pi}{\#\text{finite poles}-\#\text{finite zeros}}$$

$$KG(s)H(s)=-1=1\angle(2k+1)180^\circ$$

$$\theta=\sum \text{finite zero angles}-\sum \text{finite pole}$$

Differentiation (quotient rule)

If $u=f(x)$ and $v=g(x)$ then

$$\frac{d}{dx}\left(\frac{u}{v}\right)=\frac{v(du/dx)-u(dv/dx)}{v^2}=\frac{g(x)f'(x)-f(x)g'(x)}{[g(x)]^2}$$

Steady-state Error

$$e(\infty)=e_{step}(\infty)=\frac{1}{1+\lim_{s\to 0}G(s)};\quad K_p=\lim_{s\to 0}G(s)$$

$$e(\infty)=e_{ramp}(\infty)=\frac{1}{\lim_{s\to 0}sG(s)};\quad K_v=\lim_{s\to 0}sG(s)$$

$$e(\infty)=e_{parabola}(\infty)=\frac{1}{\lim_{s\to 0}s^2G(s)};\quad K_a=\lim_{s\to 0}s^2G(s)$$

Damping with Step Response

$$y(t)=KM\left(1-\frac{\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2}}{\tau_1-\tau_2}\right)$$

$$y(t)=KM\left[1-\left(1+\frac{t}{\tau}\right)e^{-t/\tau}\right]$$

$$y(t)=KM\left\{1-e^{-\xi t/\tau}\left[\cos\left(\frac{\sqrt{1-\xi^2}}{\tau}t\right)+\frac{\xi}{\sqrt{1-\xi^2}}\sin\left(\frac{\sqrt{1-\xi^2}}{\tau}t\right)\right]\right\}$$