

**COLLEGE OF ENGINEERING
CHEMICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**

BINDER REPORT COVER PAGE

**CHEG 4303 – Y01
Process Control**

FALL 2021 SEMESTER

NAME OF INSTRUCTOR: Dr. Jorge Gabitto

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF CHEMICAL ENGINEERING
CHEG 4303 Y01 – Process Control
FALL 2021**

I. COURSE DESCRIPTION IN ABET FORMAT

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Below Average (Graded original work)

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Above Average (Graded original work)
Average (Graded original work)
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Course Description in ABET Format

CHEG 4303 Y01 Process Control

1.	Course number and name:	CHEG 4303 Process Control
2.	Credits and contact hours:	3 credit hours; 3 contact hours *Engineering topic
3.	Instructor's or course coordinator's name:	Dr. Jorge Gabitto
4.	Text book: Title:	"Process Control"
	Author:	Bequette, W. B.
	Publisher, Year & Edition:	Fifth Edition to First edition, Prentice Hall (2002).
	a. Other Supplemental material	"Process Dynamic and Control", Seborg, D. E., Edgard, T. F., and Mellicamp, D. A., First edition or later, John Wiley and Sons (1989).
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	Process Control. (3-0) Credit 3 semester hours. Dynamic response and control of chemical process equipment such as reactors, heat exchangers, distillation columns. Use is made of fundamental techniques of servomechanism theory such as block diagrams, transfer functions, and frequency response, stability analysis and control loop design. Unsteady state modeling and computer simulation of simple control systems.
	b. Prerequisites or Co-requisites	Senior standing in the Chemical Engineering major. CHEG 3063 and MATH 4173
	c. Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	**Required
6.	a. Specific goals for the course specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.) <i>Students will be able to :</i>	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course. <i>The specific goals for the course specific outcomes listed on the left column will address the following student learning outcomes:</i>

	1. To develop competence and confidence in using and designing analog controllers and sensors for safe operation of industrial and laboratory processes.	Outcome 1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics Outcome 7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
	2. To develop conceptual understanding of the mechanisms which control fluid flow, level, heat transfer, and mass transfer processes.	
	3. To develop understanding of modeling and simulation of industrial processes.	
	4. To develop competence in solving practical control problems used in industrial processes.	
7	Brief list of topics to be covered	
	Topic 1.	Introduction (2 classes)
	Topic 2.	Modeling and simulation (4 classes)
	Topic 3.	Solution of differential equations by Laplace transform (5 classes)
	Topic 4.	Block diagrams and transfer functions (5 classes)
	Topic 5.	Proportional, integral and derivative control (4 classes)
	Topic 6.	Stability and tuning (4 classes)
	Topic 7.	Three partial exams and final exam (4 classes)

* For all Engineering programs, indicate subject area from the following: **Math, Basic science, Engineering topic or Other**

** **Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group

End of Semester Course Assessment Reports Fall 2021 and Last Two Assessment Periods.

Each summary contains the following information.

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your Department.
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's **critical evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructors summary of overall performance trend for each outcome measured over the last three periods.

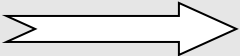
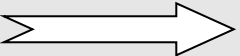
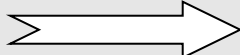
5. Were Expectations Met?

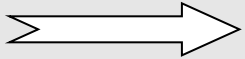
- Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer NO.

END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
CHEG4303-Y01 Process Control
Fall 2021 SEMESTER

Report Prepared by: Dr. Jorge Gabitto

Report Date: December 20, 2021

Semester	Analysis Type	Number of Students	Outcome 1 An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.			Outcome 7 Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice		
			Expected Average	Class Average	% Students Meeting Expected Average	Expected Average	Class Average	% Students Meeting Expected Average
Fall 2021	Direct	25	75	78.8	68.0	75	75.0	68.0
Fall 2020	Direct	32	75	87.0	81.3	75	81.7	78.2
Fall 2019	Direct	41	75	91.6	96.9	75	85.8	84.4
Implementation Summary			Class discussion about problem solving techniques. Strong emphasis on procedures discussed in class. Informal problems given that concentrated on solving techniques.			Class discussion about computer techniques and use of spread-sheets. Strong emphasis on procedures discussed in class.		
Perceived Problems			Students could not conceptualize, identify the physical laws, and analyze problems that are different from an example problem they have seen before. The availability of a tutor will help. Tutoring on advance math could also help. Computer learning assignments helped to produce some improvement.			Students were not familiar with use of MatLab and appropriate computer software. Influence of the Covid-19 pandemic noticed. Problems with remote classes also noticed.		
Plans for Addressing Problems			The instructor should: 1. The instructor reduce the time spent on giving notes on the board by making copies of notes for students, it is recommended that this be continued in subsequent semesters. 2. Need to continue providing tutoring assistance to interested students. 3. More problem sections to be offered.			The instructor should: 1. The instructor introduced new examples in class. 2. Need to provide tutoring assistance to interested students.		

Overall Trend over Periods		Students' performance was above average. There was a decrease compared to previous semesters. Improvement is needed.	Students' performance was average. However, there was a decrease in performance with respect to previous semesters. Need more work on improvement plan.
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Grades Sheet Showing Student and Class Performance in Outcomes

Grade Sheet Showing Student and Class Performance in Course Outcomes

CHEG 4303-Y01 FALL 2021 SEMESTER

	2nd test	4th HW	5th HW	Fina l	Outcome 1	Outcome 7
Student 1	9	5.5	9	10	8.6	9.5
Student 2	8	6	7.5	8.25	7.4	7.5
Student 3	7.5	5.5	1	8.25	5	5
Student 4	10	8.7	1	8.5	9.25	4.75
Student 5	8	4.5	8	7	7	7
Student 6	9.5	6	5	9	7.25	7.25
Student 7	9	5.5	9	8	8.35	8.35
Student 8	9	4	9	8	7.35	7.45
Student 9	9	7.8	7	7.75	7	7
Student 10	8	6	9.5	9	9.25	9.25
Student 11	8	3	9.5	7.55	8.1	8.1
Student 12	8.5	7.5	7	7.25	8.35	8.35
Student 13	6.5	4.5	8	7.9	8	8
Student 14	7	4	7.5	7	7.6	7.6
Student 15	9	7	9	8.4	8.75	8.75
Student 16	9	8.2	8	8.5	7.5	7.5
Student 17	9	10	10	9	10	10
Student 18	5	5	1	5.5	2.95	2.95
Student 19	10	10	1	8.5	3.8	3.8
Student 20	5	4	6	6.5	4.15	4.15
Student 21	9	6	9	8.25	7.85	7.85
Student 22	8.2	6	10	8.75	9.85	9.85
Student 23	6.7	5	10	10	8	10
Student 24	6	4	10	7.1	9.6	9.6
Student 25	6	5	7	9.2	5.65	8.1
					197.0	187.5
					7.88	7.5

**CHEMICAL ENGINEERING LAB. III
SPRING 2021**

Title of Assignment: Homework 1

TOPICS COVERED IN Homework 1

1. Derivation of Transient Equations

**PROCESS CONTROL
FALL 2021**

Homework Questions for Homework 1

CHEG 4033
Process Control
Homework 1

1). Derive the model mass equation, for a CSTR reactor with a first order reaction,

A = Product

Assume: constant temperature and density. Use: mass balance for species A

2). Derive the model equations, energy, for a CSTR reactor with a first order reaction,

A = Product

Assume: constant density. Use: energy balance for species A, energy generated by reaction, a heater, and heat transfer to the outside.

3). Derive the model equations, mass, for a Batch reactor with a first order reaction,

A = Product

Assume: constant density. Use: mass balance for species A

ABOVE AVERAGE

Mohamed Nabil PRINOTCHO

CHEG 4033

Process Control

9.7

Homework 2

1) the model mass equation for a CSTR reactor with a first order equation, is

$T = \text{constant}$, $A = \text{product}$, $P = \text{constant}$



$$I_N - \text{out} + \text{gen} = \text{Acc}$$

$$\dot{n}_A^{\text{in}} - \dot{n}_A^{\text{out}} + R_A V_R = \frac{dn_A}{dt} \quad (2)$$

We know that $\dot{n}_A = V C_A$

$$R_A V_R = -k C_A \times V_R$$

now ② becomes

$$\dot{V} C_A^{\text{in}} - \dot{V} C_A^{\text{out}} - k C_A V_R = \frac{d(C_A V_R)}{dt} = V_R \frac{dC_A}{dt}$$

$$\dot{V} C_A^{\text{in}} - \dot{V} C_A - k C_A V_R = V_R \frac{dC_A}{dt}$$


2) the model equations, energy, for a CSTR reactor with a first order reaction, A=product

In - out + generation = Accumulation

$$\dot{H}_{\text{in}} - \dot{H}_{\text{out}} + \text{generation} = \text{Accumulation} = \frac{du}{dt} = m \frac{du}{dt}$$

$$\Rightarrow \dot{m}_{\text{in}} h_{\text{in}} - \dot{m}_{\text{out}} h_{\text{out}} + \text{generation} = m \frac{du}{dt}$$

$$\Rightarrow \dot{m}_{\text{in}} C_p T_{\text{in}} + \dot{m}_{\text{out}} C_p T_{\text{out}} + \text{generation} = m C_p \frac{dT}{dt}$$

Generation = Enthalpy generation by chemical Reaction +
enthalpy generation by heat input + Enthalpy generation by heat
exchange.

$$\text{chemical reaction generation} = V_R R_A \Delta H_{\text{reaction}}$$

$$\text{Generation by heat input} = \dot{Q}$$

$$\text{Generation by heat transfer with the environment} = K_{HT} \cdot A_{HT} (T_{out} - T)$$

* the final equation is

$$\dot{m}_{in} C_{pin} T_{in} - \dot{m}_{out} C_{pout} T_{out} + V_R R_A \Delta H_{\text{reaction}} + \dot{Q} + K_{HT} A_{HT} (T_{out} - T)$$

$$= m C_p \frac{dT}{dt}$$

3) The model equations, mass, for a Batch Reactor with First order
reaction are

A = Product

In - out + generation = Accumulation

For a batch Reaction there is no input or output so
generation = accumulation

then

$$R_A V_R = \frac{dn_A}{dt} \quad (1)$$

We know that $n_A = V C_A$

$$R_A V_R = -k C_A \cdot V_R$$

now (1) becomes

$$-k C_A V_R = V_R \frac{dC_A}{dt}$$


AVERAGE

09/19 Homework #1

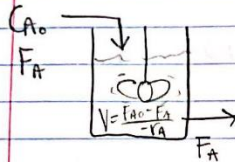
7.5

1) Derive the mass equation, for a CSTR reactor with a first order reaction.

A = product

Assume: constant temperature & density.

Use: mass balance for species A



Step 1 General Mole Balance Equation

$$\text{IN} - \text{OUT} + \text{GEN} = \text{ACC.}$$

$$F_{A0} - F_A + \int r_A dV = \frac{dN_A}{dt}$$

steady state $\frac{dN_A}{dt} = 0$

* CSTRs operate in steady state conditions

And we'd assume that A would be well mixed

$$\therefore \int r_A dV = r_A V$$

Now the Energy Balance is...

$$F_{A0} - F_A + r_A V = 0$$

$$V = \frac{F_{A0} - F_A}{-r_A}$$

Step 2 Find concentration

since CSTR is continuous this will be used...

$$C_A = \frac{F_A}{V} \frac{\text{mol. Flow rate}}{\text{Vol. Flow rate}} \rightarrow F_A = C_A V (\text{continuous})$$

Step 3 Reaction Rate

Since it's a first order rxn...

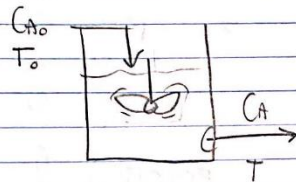
$$-r_A = k C_A$$

k = reaction rate const.

2) Derive the model equations, energy, for a CSTR reactor w/ a 1st order rxn.

A = Product

Assume: const. p . Use: energy balance for species A, energy generated by rxn, a heater, & heat transfer to the outside



Prop. = Energy $\rightarrow$ Enthalpy $\rightarrow T$

$$IN - OUT + GEN = ACC.$$

$$\dot{H}_{in} - \dot{H}_{out} + GEN. = \frac{dU}{dt}$$

$$\dot{H} = \dot{m}h = \dot{m}C_pT, \quad U = m_rU = m_rC_vT$$

$$ACC - IN - OUT \quad p = \text{const.}$$

$$p \frac{dV_r}{dt} = pV_r^{in} - V_r^{out}p \quad m = pV$$

$$V_r = \text{const.} = \frac{dV_r}{dt} = 0$$

$$\therefore \dot{V}^{in} = \dot{V}^{out}$$

$$GEN. = r_A V_r \Delta H_r + \dot{Q} + KA(T - T_{out})$$

3) Derive the model equations, mass, for a Batch reactor w/ First order rxn.

A = product

Assume: const. ρ

Use: mass balance for species A


$$\frac{dN_A}{dt} = r_A V$$

Step 1 Mole Balance

$$IN - OUT + GEN. = ACC.$$

$$F_{A0} - F_A + \int r_A dV = \frac{dN_A}{dt}$$

★ NO IN or OUT flow since it's batch

$$\rightarrow F_{A0} - F_A = 0$$

$$\therefore ACC. = GEN$$

$$\frac{dN_A}{dt} = r_A V$$

Now when we isolate t & integrate

$$dt = \frac{dN_A}{r_A V}$$

→ Boundary conditions

$$\text{When } t=0 \quad N_A = N_{A0}$$

$$t=t \quad N_A = N_A$$

$$t = \int_{N_{A0}}^{N_A} \frac{dN_A}{r_A V}$$

Time is necessary to reduce the # moles
of A from N_{A0} to N_A

? step 2 concentration & rxn rate

$$C_A = \frac{N_A}{V}$$

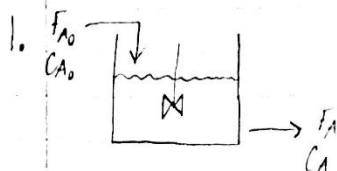
$\therefore$ 1st order. $r_A = k C_A$

BELOW AVERAGE

5.5

Shampert
Kubay

HW #1



$$In - Out + Gen = \frac{dC}{dt}$$



Steady state $\frac{dC}{dt} = 0$

Control Input	Control Output	Control Parameters
C_{A0}	F_{A0}	k
	C_A	V
	F_A	

$$\dot{m}_A^{in} - \dot{m}_A^{out} + F_A V = 0$$

$$\downarrow \quad \quad \downarrow$$

$$\text{mass A/s} + \text{mass A/s} = 0$$

1-2

$$V/F_A = t$$

$$F_{A0} C_{A0} - F_A C_A = k C_A V$$

$$F_A (C_{A0} - C_A) = k C_A V$$

$$\text{1st order: } \frac{C_{A0} - C_A}{k C_A} = \frac{V}{F_A} \Rightarrow \boxed{\frac{C_{A0} - C_A}{C_A} = k t}$$

2. $In - Out + Gen = Acc$

$$\dot{m} \rho C_p T_0 - \dot{m} \rho C_p T + 0 = k_0 e^{-(E_a/R T)} C_A V \Delta H$$

$$\dot{m} \rho C_p (T_0 - T) = k_0 e^{-(E_a/R T)} C_A V \Delta H$$

Control In	Control Out	Control Parameters
T_0	$\dot{m}$	C_A
	T	k_0
		V
		ρ
		C_p

$$\frac{\rho C_p (T_0 - T)}{e^{-(E_a/R T)} C_A \Delta H} = \frac{k_0 V}{\dot{m}}$$

?

$$\text{1st order: } \boxed{k_0 T = \frac{\rho C_p (T_0 - T)}{e^{-(E_a/R T)} C_A \Delta H}}$$

-2

3



$$\dot{I}_A^0 - \dot{Q}_A^0 + \text{Gen} = \text{Acc}$$

$$0 - 0 - k C_A V = \frac{dC_A}{dt} V$$

$$\therefore -dC_A/C_A = k dt$$

$$k C_A V = -V \frac{dC_A}{dt} \Rightarrow -\frac{dC_A}{dt} = k C_A \quad \checkmark$$

$$-\ln C_A = kt + C$$

$$-\ln C_{A0} = C$$

$$\ln C_A = kt - \ln C_{A0}$$

$$-kt = \ln C_A/C_{A0}$$

-5

$$\therefore C_A/C_{A0} = e^{-kt}$$

$$\text{1st order: } C_A = C_{A0} e^{-kt}$$

Control In	Control Out	Control Parameters
C_{A0}	C_A	k
		t
		V

61

**PROCESS CONTROL
FALL 2021**

Title of Assignment: Homework 3

TOPICS COVERED IN Homework 3

3. Laplace Transform

**PROCESS CONTROL
FALL 2021**

Homework Questions for Homework 3

CHEG 4033
3rd HomeWork

1). Calculate the Laplace equivalent of the following equations:

- A step of size Du
- A pulse of integral P
- $\sin(\omega t)$
- $\frac{dT}{dt} = K_P u$

2). Calculate the Laplace equivalent of the following equations:

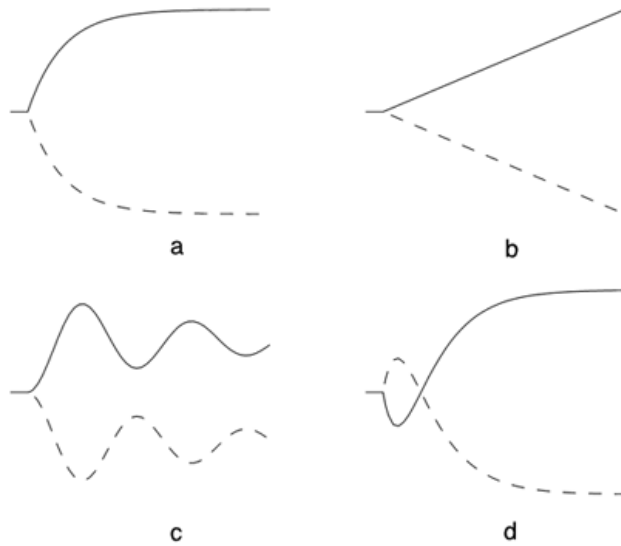
$$\tau_p \frac{dT}{dt} = (u_1 - T) + u_2 A + u_3 B,$$

where T is the output variable, A and B are constants and u_1 , u_2 , and u_3 are the deviations variables for the input temperature (T_i), input flow (F) and input heat flow (Q_r), respectively.

$$\tau_p \frac{d^2T}{dt^2} + \frac{dT}{dt} A = (u_1 - T) + u_2 B + \frac{du_3}{dt},$$

where T is the output variable, A, B, and C are constants and u_1 , u_2 and u_3 are the deviations variables for the input temperature (T_i), input flow (F) and input heat flow (Q_r), respectively.

3). Describe qualitatively the following dynamic responses to a step in the input variable:



Hint: Analyze response at short times, functional description, and convergence of the eight systems shown above, 4 given by solid lines and 4 given by broken lines.

ABOVE AVERAGE

CHEG 4033
3rd HomeWork



1). Calculate the Laplace equivalent of the following equations:

- A step of size Du
- A pulse of integral P
- $\sin(\omega t)$
- $dT/dt = K_p u$

2). Calculate the Laplace equivalent of the following equations:

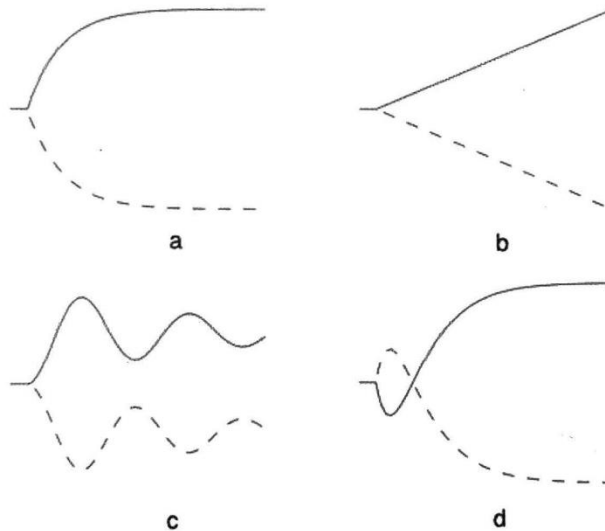
$$\tau_p dT/dt = (u_1 - T) + u_2 A + u_3 B,$$

where T is the output variable, A and B are constants and u_1 , u_2 , and u_3 are the deviations variables for the input temperature (T_i), input flow (F_i) and input heat flow (Q_F), respectively.

$$\tau_p d^2T/dt^2 + dT/dt A = (u_1 - T) + u_2 B + du_3/dt,$$

where T is the output variable, A , B , and C are constants and u_1 , u_2 , and u_3 are the deviations variables for the input temperature (T_i), input flow (F_i) and input heat flow (Q_F), respectively.

3). Describe qualitatively the following dynamic responses to a step in the input variable:



Hint: Analyze response at short times, functional description, and convergence of the eight systems shown above, 4 given by solid lines and 4 given by broken lines.

Chad Gonchar

Process Control HW #3

Real	Laplace
Step of size D	D/s
Pulse of $\int P$	P
$\sin(\omega t)$	$\omega/s^2 + \omega^2$
dT/dt	$T = k_P/s^2$

#2

$\mathcal{L}_p \frac{dT}{dt} = (u_1 \cdot T) + u_2 A + u_3 B$, then take Laplace of both sides

$$\mathcal{L}_p \mathcal{L} \left[\frac{dT}{dt} \right] = \mathcal{L} [u_1 \cdot T] + A \mathcal{L} [u_2] + B \mathcal{L} [u_3]$$

known:

$T = \text{output}$

$A, B = \text{constants}$

$u_1 = T_i$ $u_3 = R_F$

$u_2 = F_i$ linear (1st-order)

(i) $\mathcal{L}_p s T = T_i - T + A F_i + B R_F$

(ii) $\mathcal{L} \left[\mathcal{L}_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A \right] = \mathcal{L} [(u_1 - T) + u_2 B + \frac{du_3}{dt}]$

$$\mathcal{L}_p \mathcal{L} \left[\frac{d^2 T}{dt^2} \right] + A \mathcal{L} \frac{dT}{dt} = \mathcal{L} [u_1 - T] + B \mathcal{L} u_2 + \mathcal{L} \frac{du_3}{dt}$$

known:

$T = \text{output}$

$A, B, C = \text{constants}$

$u_1 = T_i$ $u_3 = R_F$

$u_2 = F_i$ second order

$\mathcal{L}_p s^2 T + A s T = T_i - T + B F_i + S R_F$

#3 (a) direct monotonic convergent

(b) Direct monotonic divergent

(c) Direct oscillatory convergent

(d) Reverse monotonic convergent

AVERAGE

CHEG 4033
3rd HomeWork

7.8

1). Calculate the Laplace equivalent of the following equations:

- A step of size Du
- A pulse of integral P
- $\sin(\omega t)$
- $\frac{dT}{dt} = K_p u$

2). Calculate the Laplace equivalent of the following equations:

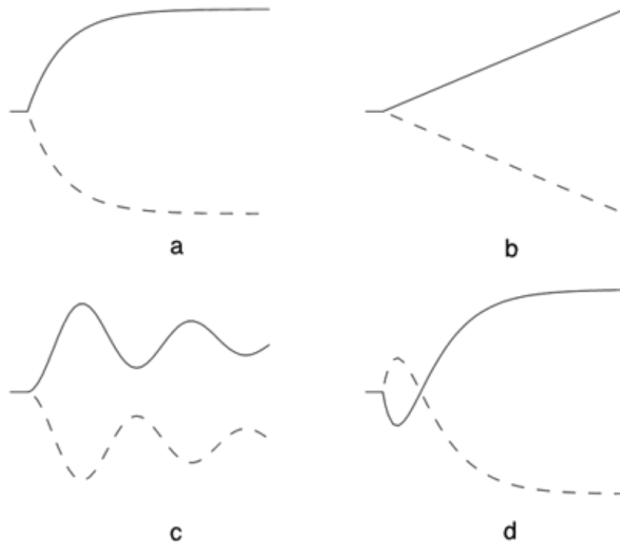
$$\tau_p \frac{dT}{dt} = (u_1 - T) + u_2 A + u_3 B,$$

where T is the output variable, A and B are constants and u_1 , u_2 , and u_3 are the deviations variables for the input temperature (T_i), input flow (F_i) and input heat flow (Q_i), respectively.

$$\tau_p \frac{d^2T}{dt^2} + \frac{dT}{dt} A = (u_1 - T) + u_2 B + \frac{du_3}{dt},$$

where T is the output variable, A, B, and C are constants and u_1 , u_2 , and u_3 are the deviations variables for the input temperature (T_i), input flow (F_i) and input heat flow (Q_i), respectively.

3). Describe qualitatively the following dynamic responses to a step in the input variable:



Hint: Analyze response at short times, functional description, and convergence of the eight systems shown above, 4 given by solid lines and 4 given by broken lines.

1.

Step of size ΔU

$$\mathcal{L}[D_u] = \frac{D}{s}$$

$S(s)$ (unit step) $\rightarrow 1/s$

Pulse of integral P

$$\mathcal{L}[P] = P$$

Unit impulse $\rightarrow 1$

$\sin(\omega t)$

$$\mathcal{L}[\sin(\omega t)] = \frac{\omega}{s^2 + \omega^2}$$

$$\frac{dT}{dt} = K_p U$$

$$ST(s) = K_p U(s)$$

$$T(s) = K_p U$$

2.

$$\tau_p \frac{dT}{dt} = (U_i - T) + U_i A + U_i B$$

$$\mathcal{L}\left[\tau_p \frac{dT}{dt}\right] = \mathcal{L}[(U_i - T)] + \mathcal{L}[U_i A + U_i B]$$

$$\tau_p ST(s) = [U_i(s) - T(s)] + AU_i(s) + BU_i(s)$$

$$T(s) = \frac{U_i(s) - T(s)}{\tau_p s} + \frac{A}{\tau_p s} U_i(s) + \frac{B}{\tau_p s} U_i(s)$$

$$\tau_p \frac{dT}{dt} + \frac{dT}{dt} A = (U_i - T) + U_i B + \frac{dU_i}{dt}$$

$$\tau_p s^2 T(s) + ST(s) A = U_i(s) - T(s) + BU_i(s) + sU_i(s)$$

$$T(s)(\tau_p s^2 + sA) = U_i(s) - T(s) + BU_i(s) + sU_i(s)$$

$$T(s) = \frac{U_i(s) - T(s)}{\tau_p s^2 + sA} + \frac{BU_i(s)}{\tau_p s^2 + sA} + \frac{sU_i(s)}{\tau_p s^2 + sA}$$

3.

a.

- Monotonic change in input (overdamped)
- First order
- Trans. func. relationship: $Y(s) = \frac{K_p e^{-\theta s}}{\tau_p s + 1} U(s)$
- Response to step input change:
 - $t < 0, y(t) = 0$
 - $t \geq 0, y(t) = K_p \Delta u \{1 - \exp(-(t-0)/\tau_p)\}$

- Solid line Pos. gain
- dashed line Neg. gain

- .35

b.

- Integrating Processes
- Trans. func. relationship: $Y(s) = \frac{K e^{-\theta s}}{s}$
- Response to step input change:
 - $t < 0, y(t) = 0$
 - $t \geq 0, y(t) = K \Delta u (t - 0)$

- Solid line Pos. gain
- dashed line Neg. gain



c.

- underdamped, or oscillatory
- Trans. func. relationship:

$$\frac{K_p}{\{c_p^2 s^2 + 2\zeta\} p s + 1}$$

- Solid line Pos. gain
- dashed line Neg. gain

✓
- .7

d. . inverse response

- Solid line Pos. gain
- dashed line Neg. gain

✓
- .5

BELOW AVERAGE

$$2. T_p \cdot dT/dt = (U_1 - T) + U_2 A + U_3 B$$

$$T_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A = (U_1 - T) + U_2 B + \frac{dU_3}{dt}$$

$$T_p \frac{dT}{dt} = (U_1 - T) + U_2 A + U_3 B$$

$$T_p s T(s) = T_i(s) - T(s) + A F_i(s) + B Q F(s)$$

$$\frac{T(s)}{1 + T_p(s)} = \frac{T_i(s) + A F_i(s) + B Q F(s)}{1 + T_p(s)}$$

$$T_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A = (U_1 - T) + U_2 B + \frac{dU_3}{dt}$$

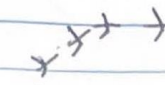
$$T_p s^2 T(s) + A s T(s) = T_i(s) - T(s) + A F_i(s) + S Q F(s)$$

$$T_p s^2 T(s) - T_i(s) - A F_i(s) - S Q F(s) = -T(s) - A s T(s)$$

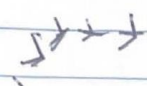
$$-T(s) [1 + A s] = T_p s^2 T(s) - T_i(s) - A F_i(s) - S Q F(s)$$

$$-T(s) = \frac{T_p s^2 T(s) - T_i(s) - A F_i(s) - S Q F(s)}{1 + A s}$$

$$T(s) = - \frac{(T_p s^2 T(s) - T_i(s) - A F_i(s) - S Q F(s))}{1 + A s}$$

3. A 

$$\frac{Y(s)}{X(s)} = \frac{K_1 C^{-T} s}{T s + 1}$$

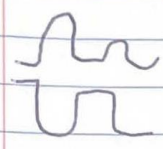
B. 

$$\frac{Y(s)}{X(s)} = \frac{A}{s}$$

$$X(s) = 1/s; \quad Y(s) = A/s^2$$

$$Y(t) = A + U(t)$$

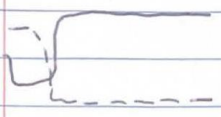
* increasing over time

C. 

* system indicates, 2nd order

$$Y(s) = \frac{A}{T^2 s^2 + 2\zeta T s + 1}$$

$$\zeta_j < 1$$

D. 

* inverse response

$$\frac{Y(s)}{X(s)} = \frac{k_1}{T_1 s + 1} - \frac{k_2}{T_2 s + 1}$$

-2

**PROCESS CONTROL
FALL 2021**

Title of Assignment: Homework 4

TOPICS COVERED IN Homework 4

4. Dynamic Behavior

PROCESS CONTROL
FALL 2021

Homework Questions for Homework 4

ABOVE AVERAGE

homework 3

9.3

- ① Lag phase: NO increase in number of living bacterial cells
- ② Log phase: Exponential increase in number of living bacterial cells.
- ③ Stationary phase: Plateau in number of living bacterial cells; rate of cell division and death roughly equal
- ④ Death decline phase: Exponential decrease in number of living bacterial cells.

$$(2) \quad \frac{dC_x}{dt} = \mu C_x$$

$$\int_{C_{x0}}^{C_x} \frac{dC_x}{C_x} = \int_{t_0}^t \mu dt = C_x = C_{x0} \exp[\mu(t-t_0)]$$

(3)

$$\text{In} - \text{Out} + \text{Gen} = \text{Acc}$$

$$V_R V_R = \frac{dC_x}{dt} = \mu C_x V_R = \frac{\mu_{\max} C_s C_x}{K_s + C_x} V_R - \frac{1}{\theta} C_x$$

$$Y_{x/s} = - \frac{dC_x}{dC_s}$$

$$dC_x = -Y_{x/s} dC_s$$

$$\boxed{\frac{dC_s}{dt} = - \frac{\mu_{\max} C_s C_x}{Y_{x/s} (K_s + C_x)}}$$

(4) $In - Out + Gen = 0$

$C_{x0} \dot{V}^0 - C_x \dot{V} + R_x \dot{V}_R = 0$

$\frac{\dot{V}}{\dot{V}_R} (C_{x0} - C_x) + R_x = 0$

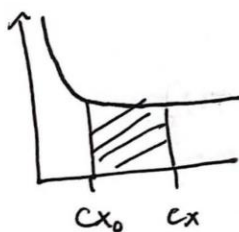
$Y_{x/s} = -\frac{\Delta C_x}{\Delta C_s}$

$\frac{\dot{V}}{\dot{V}_R} (C_s - C_{s^0}) + R_x = 0$

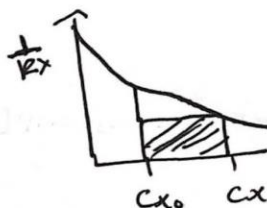
(5)

$\frac{dC_x}{dt} = R_x \int_{C_{x0}}^x \frac{dC_x}{R_x} = +$

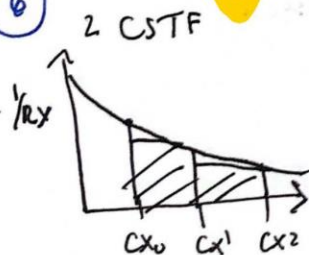
Batch



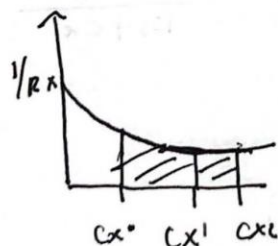
CSTF



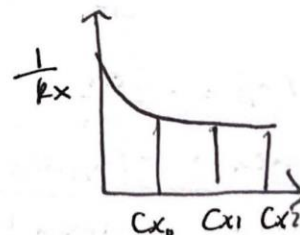
(6)



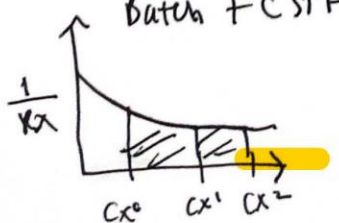
CSTF + Batch



2 Batch



Batch + CSTF



AVERAGE

HW-3

- 1) a) LAG Period - cells growth
- b) Exponential growth
- c) Stationary Period
- d) Death Period - cell die exponentially

$$2) \frac{dC_x}{dt} = \mu C_x = \int_{C_0}^{C_x} \frac{dC_x}{C_x} = \int_{t_0}^t \mu dt \rightarrow C_x = C_0 e^{\mu(t-t_0)}$$

$$3) \text{In- Out} + \text{GEN} = \text{ACC}$$

$$R_x V_R = \frac{dC_x}{dt} = \mu C_x V_R = \frac{\mu C_s C_x}{K_s (V_R + C_x)}$$

$$4. \text{In- Out} + \text{Gen} = 0 \quad F_0 S^0 = \dot{V} \frac{V}{V_R} (C_s^0 C_x) + R_x = 0$$

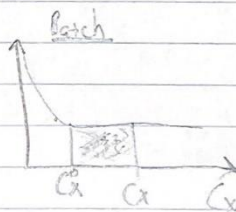
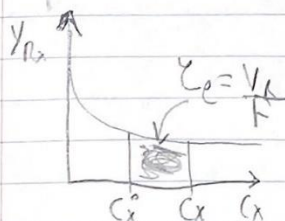
$$C_x^0 V^0 - C_x \dot{V} + R_x V_R = 0$$

$$Y_{XS} = - \frac{\Delta C_x}{\Delta C_s} \rightarrow \frac{\dot{V}}{V_R} (C_s - C_s^0) + R_x = 0$$

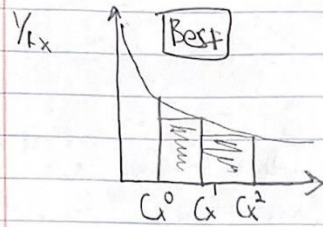
$$R_x = \frac{\mu_{max} C_s}{K_s + C_s}$$

$$5. \frac{dC_x}{dt} = R_x \int_{C_0}^{C_x} \frac{dC_x}{R_x} = t \quad \frac{1}{R_s}$$

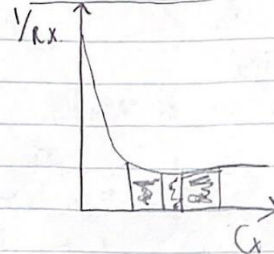
CSTR



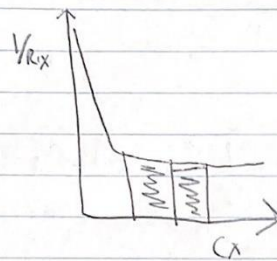
6) 2 CSTE



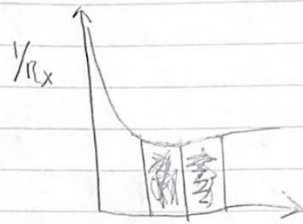
CSTE + Batch



Batch + CSTE



2 Batch (worst)



BELOW AVERAGE

Mohamed NABIL AKINOTCHU

CHEG 4153 Y01



Homework 3:

1) The Four steps in cell growth in a batch reactor are:

Lag phase: Bacteria adapt themselves to growth conditions. During the lag phase cell changes very little, the period can last for 1 hour to several days.

* The log phase: The number of new bacteria appearing per unit time is proportional to the present population.

* The stationary phase is often due to a growth-limiting factor.

* Death phase: bacteria die.



2) We know that

$$R_N = \frac{C_N}{dt} = \mu C_N \quad \text{then} \quad \frac{C_N}{C_{N0}} = \mu \cdot dt$$

Let's integrate both sides

$$\int_{C_{N0}}^{C_N} \frac{dC_N}{C_N} = \int_{t_0}^t \mu dt \quad \Rightarrow \quad \ln(C_N) [C_N - C_{N0}] = \mu [t - t_0]$$

$$\Rightarrow \ln \left| \frac{C_N}{C_{N0}} \right| = \mu [t - t_0] \quad \Rightarrow \quad \frac{C_N}{C_{N0}} = \exp \mu [t - t_0]$$

$$\Rightarrow C_N = (C_{N0}) \exp \mu [t - t_0]$$

3) For a Batch Reactor we have

Accumulation = generation

$$\Rightarrow \cancel{V_R} \frac{dC_X}{dt} = R_X \cancel{V_R} \quad \Leftrightarrow \quad \frac{dC_X}{dt} = R_X$$

$$\Leftrightarrow \int_{t_0}^t dt = \int_{C_{x0}}^{C_x} \frac{dC_x}{R_x} \Leftrightarrow \left[t - t_0 = \int_{C_{x0}}^{C_x} \frac{dC_x}{R_x} \right] \quad \checkmark$$

Let's use the non-graphical method

We know that $\frac{dC_x}{dt} = R_x = \mu C_x$

The monod kinetic equation is $\mu = \frac{\mu_{\max} \cdot C_s}{K_M + C_s}$ then

$$\boxed{\frac{dC_x}{dt} = \frac{\mu_{\max} C_s C_x}{K_M + C_s}} \quad (I) \quad \checkmark \quad \gamma_2 = - \frac{dC_x}{dC_s} \cdot \frac{dt}{dt} \quad (2)$$

$$(3) \Leftrightarrow - \frac{dC_x}{dt} \times \frac{1}{dC_s/dt} \Leftrightarrow \frac{dC_x}{dt} = - \gamma \frac{dC_s}{dt}$$

$$\text{then } \boxed{- \frac{dC_s}{dt} = \frac{\mu_{\max} C_s C_x}{\gamma (K_M + C_s)}} \quad (I) \quad \checkmark$$

4) CSTF

Input - out + generation = Accumulation $\rightarrow 0$

$$\Leftrightarrow F_i C_{xi} - F C_x + V_R R_x = 0 \quad \Leftrightarrow V_R = F \frac{C_x - C_{xi}}{R_x}$$

$$\therefore Y_{Lm} = \frac{V_R}{F} = \frac{C_x - C_{xi}}{R_x}$$

We know that $R_x = U C_x$ and $U = \frac{N_{max} \cdot C_s}{K_M + C_s}$

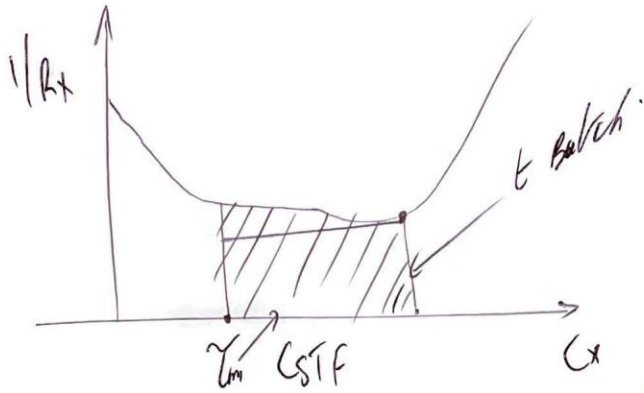
then
$$Y_{Lm} = \frac{(C_x - C_{xi})(K_M + C_s)}{N_{max} \cdot C_s \cdot C_x} \quad (I)$$

We know that
$$Y = \frac{\Delta C_x}{\Delta C_s} = - \frac{C_x - C_{xi}}{C_s - C_{s0}}$$

then now

$$Y_{Lm} = - \frac{(C_s - C_{s0}) Y (K_M + C_s)}{N_{max} \cdot C_s \cdot C_x} \quad (II)$$

5)

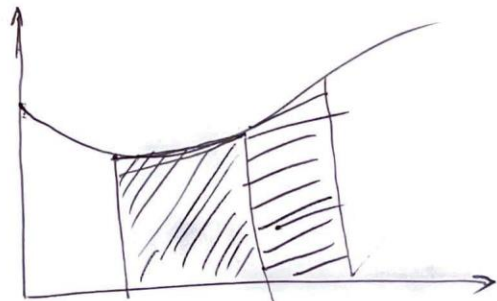
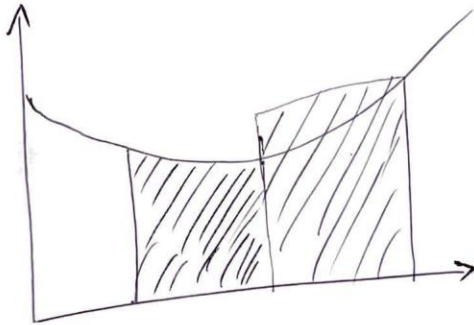


CSIF > Batch

The smaller area performs better.



6)



Right is better



**BIOENGINEERING
SPRING 2021**

Title of Assignment: Homework 4

TOPICS COVERED IN Homework 4

- 1. Transport Phenomena in Biological Systems**
- 2. Sterilization**

CHEG 4033
4th Homework

1). Calculate the Laplace equivalent of the following equation:

$$\tau_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A = (u_1 - T) + B \frac{du_1}{dt},$$

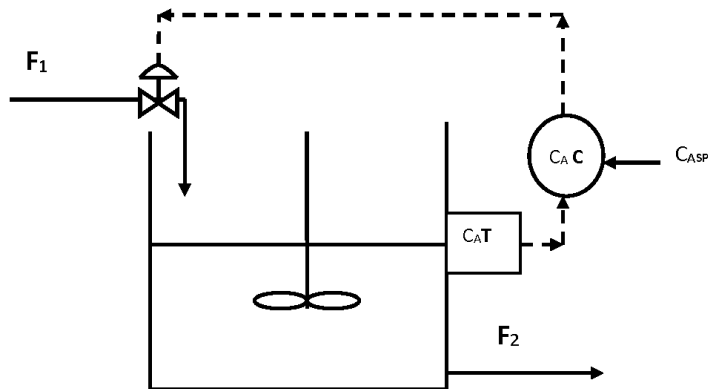
where T is the output variable, A, B, and τ_p are constants and u_1 is the deviation variable.

2). In a previous problem the following system transfer function has been obtained:

$$Y(s) = k / (\tau^2 s^2 + 2 \zeta \tau s + 1) U(s)$$

- Calculate the qualitative response to a positive impulse disturbance ($U(s) = P$).
- If k is positive comment on short time behavior.
- If ζ and τ are positive will the system oscillate? What kind of oscillations?
- Which is the value of the system long time respond? Same for short time.

3). Derive the appropriate control block flow diagram using the attached P&I D.



4). In a previous problem the following system transfer function has been obtained:

$$Y(s) = k / (\tau^2 s^2 + 2 \zeta \tau s + 1) U(s)$$

- Calculate the qualitative response to a positive step disturbance ($U(s) = \Delta U/s$).
- If τ is positive comment on stability.
- If ζ and τ are positive will the system oscillate? What kind of oscillations?
- Which is the system long time respond?

ABOVE AVERAGE

Anh Nguyen

HW4

GIEG 4303

Dr. Gabitto

Nov 3, 2021

$$1) \tau_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A = (u_1 - T) + B \frac{du_1}{dt}$$

$$\rightarrow \mathcal{L}\left[\tau_p \frac{d^2 T}{dt^2}\right] + \mathcal{L}\left[A \frac{dT}{dt}\right] = \mathcal{L}\left[(u_1 - T)\right] + \mathcal{L}\left[B \frac{du_1}{dt}\right]$$

$$\Rightarrow \tau_p s^2 T(s) + A s T(s) = u_1(s) - T(s) + B s u_1(s)$$

$$2) Y(s) = \frac{k}{\tau^2 s^2 + 2\zeta \tau s + 1} U(s)$$

$$U(s) = P \Rightarrow Y(s) = \frac{k \cdot P}{\tau^2 s^2 + 2\zeta \tau s + 1}$$

a, Qualitative response:

* $k < 0 \rightarrow$ reverse

$k > 0 \rightarrow$ direct

* Roots for denominator function

$$s_1 = \frac{-2\zeta\tau + \sqrt{4\zeta^2\tau^2 - 4\tau^2}}{2\tau^2} = \frac{-\zeta + \sqrt{\zeta^2 - 1}}{\tau}$$

$$s_2 = \frac{-\zeta - \sqrt{\zeta^2 - 1}}{\tau}$$

• If $-1 < \zeta < 1 \rightarrow$ oscillatory

• If $\zeta > 1$ or $\zeta < -1 \rightarrow$ monotonic

* If $\zeta \leq 0 \rightarrow$ divergent
If $\zeta > 0 \rightarrow$ convergent } for $\tau > 0$

b, $k > 0 \rightarrow$ direct

c, $\zeta > 0, \tau > 0$

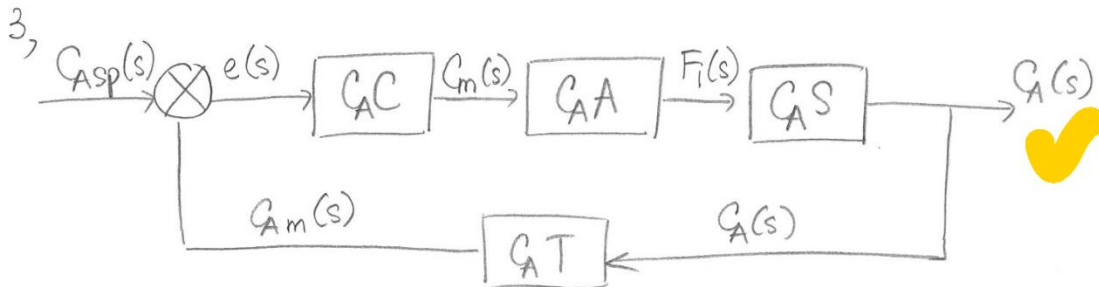
The system will oscillate if $0 < \zeta < 1$. It will be convergent oscillation

d, Long term response

$$\lim_{s \rightarrow 0} sY(s) = \lim_{s \rightarrow 0} \frac{skp}{\tau^2 s^2 + 2\zeta\tau s + 1} = \frac{0}{1} = 0$$

Short term response

$$\lim_{s \rightarrow \infty} sY(s) = \lim_{s \rightarrow \infty} \frac{skp}{\tau^2 s^2 + 2\zeta\tau s + 1} = \lim_{s \rightarrow \infty} \frac{kp}{\tau^2 s + 2\zeta\tau + \frac{1}{s}} = \frac{kp}{\infty} = 0$$



4, $Y(s) = \frac{k}{\tau^2 s^2 + 2\zeta\tau s + 1} U(s)$

$$U(s) = \frac{\Delta u}{s} \Rightarrow Y(s) = \frac{k}{\tau^2 s^2 + 2\zeta\tau s + 1} \frac{\Delta u}{s}$$

a, Qualitative response

* $k < 0 \rightarrow$ reverse

$k > 0 \rightarrow$ direct

* Roots for denominator function

$$s_1 = \frac{-\zeta + \sqrt{\zeta^2 - 1}}{\tau}$$

$$s_2 = \frac{-\zeta - \sqrt{\zeta^2 - 1}}{\tau}$$

If $-1 < \zeta < 1 \rightarrow$ oscillatory

If $\zeta > 1$ or $\zeta < -1 \rightarrow$ monotonic

* If $\zeta \leq 0 \rightarrow$ divergent
 $\zeta > 0 \rightarrow$ convergent } $\tau > 0$

b, $\tau > 0$, stability depends on $-\zeta \pm \sqrt{\zeta^2 - 1}$

$-1 < \zeta < 1 \rightarrow$ oscillatory

$\zeta < -1$ or $\zeta > 1 \rightarrow$ monotonic

c, The system will oscillate if $0 < \zeta < 1$. It will be convergent.

d, long term response

$$\lim_{s \rightarrow 0} sY(s) = \lim_{s \rightarrow 0} s \cdot \frac{k}{\tau^2 s^2 + 2\zeta\tau s + 1} \cdot \frac{\Delta u}{s} = k\Delta u$$

AVERAGE

Tyecia Franklin
Homework 4

7.8

$$1.) \tau_p \frac{d^2 T}{dt^2} + \frac{dT}{dt} A = u_1 - T + B \frac{du_1}{dt}$$

$$\mathcal{L} \left[\tau_p \frac{d^2 T}{dt^2} \right] + \mathcal{L} \left[A \frac{dT}{dt} \right] = \mathcal{L} [u_1 - T] + \mathcal{L} \left[B \frac{du_1}{dt} \right]$$

$$\tau_p s^2 T(s) + A s T(s) = u_1(s) - T(s) + B s u_1(s) \quad \checkmark$$

$$2.) Y(s) = \frac{K}{\tau^2 s^2 + 2C_1 \tau s + 1} \times U(s) ; U(s) = P$$

Therefore,

$$Y(s) = \frac{K \times P}{\tau^2 s^2 + 2C_1 \tau s + 1} \quad \checkmark$$

(A) $K > 0 \rightarrow \text{direct} ; K < 0 \rightarrow \text{reverse} \quad \checkmark$

$$\begin{aligned} \text{Roots } \rightarrow s_1/s_2 &= \frac{-2C_1 \tau \pm \sqrt{4C_1^2 \tau^2 - 4\tau^2}}{2\tau^2} \\ &= \frac{-C_1 \pm \sqrt{C_1^2 - 1}}{\tau} < 0 \end{aligned}$$

(B) $K > 0 = \text{direct}$

(C) $C_1 > 0$ and $\tau > 0$; yes the system will oscillate because it's a convergent oscillatory

$$C_1 < 1 \Rightarrow \zeta < 1 \Rightarrow \text{oscillatory}$$

B.) $\tau > 0$

As τ decreases, C_1 decreases which will cause the second loop to decrease.

C.) $C_1 > 0$ and $\tau > 0$ meaning system will oscillate

$C_1 > 1$: system is overdamped meaning no oscillation ✓

$C_1 = 1$: critically damped meaning no oscillation ✓

$C_1 < 1$: under damped meaning there is oscillation

D.) When the system reaches its ultimate value, it can be calculated by final value.

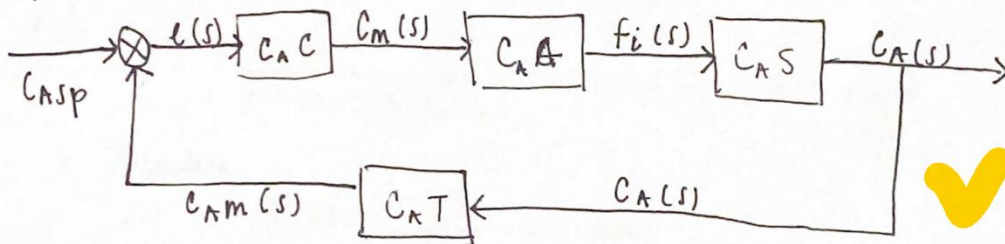
(D.) Long Term Response

$$\lim_{s \rightarrow 0} s Y(s) = \lim_{s \rightarrow 0} \frac{s \times K \times P}{\tau^2 s^2 + 2c_1 \tau s + 1} = \frac{0}{1} = 0$$

Short Term Response

$$\lim_{s \rightarrow \infty} s Y(s) = \lim_{s \rightarrow \infty} \frac{s \times K \times P}{\tau^2 s^2 + 2c_1 \tau s + 1} = \frac{K P}{\infty} = 0$$

3.)



4.) $Y(s) = \frac{K}{\tau^2 s^2 + 2c_1 \tau s + 1} u(s)$; $u(s) = \frac{\Delta u}{s}$

$$Y(s) = \frac{K}{\tau^2 s^2 + 2c_1 \tau s + 1} \frac{\Delta u}{s}$$

(A.) $Y(s) = \frac{K \times \Delta u}{s(\tau^2 s^2 + 2c_1 \tau s + 1)}$

roots:

$$s_1/s_2 = \frac{-c \pm \sqrt{c^2 - 1}}{\tau}$$

BELOW AVERAGE

Homework 4

(1) $\gamma_p d^2T/dt^2 + dT/dt + A = (U_1 - T) + B dU_1/dt$

(2) $\gamma_p s^2 T(s) + A s T = U_1(s) - T(s) + B s U_1(s)$

(2) $Y(s) = K / (\gamma^2 s^2 + 2 \zeta \gamma s + 1) U(s)$

a.

b. The behavior would be direct

c.
$$\frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \rightarrow \frac{\dot{z}^2 \pm \sqrt{2^2 - 4(1)(1)}}{2(1)} = \frac{2 \pm \sqrt{0}}{2} = 1$$
 Mal valve

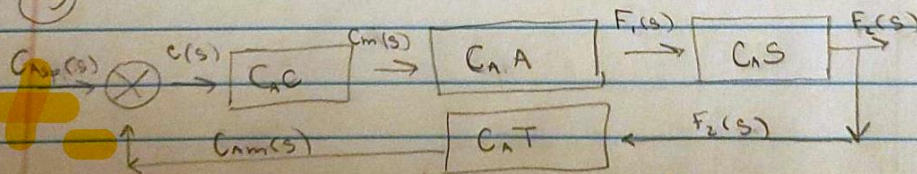
therefore, convergent (not oscillatory)

d.

long time: $t \rightarrow \infty, s \rightarrow 0; \frac{K}{(\gamma^2 s^2 + 2 \zeta \gamma s + 1)} \times \frac{\Delta U}{s} \times s = \frac{K \Delta U}{1}$

short time: $t \rightarrow 0, s \rightarrow \infty; \frac{K}{(\gamma^2 s^2 + 2 \zeta \gamma s + 1)} \times \frac{\Delta U}{s} \times s = \frac{K \Delta U}{1}$

(3)



(4)

a.

b. if γ is positive, δ is always negative. Therefore, it is stable (convergent)

c. $\delta \in \mathbb{R}$, δ the function is monotonic. There will be no oscillations

d. δ is negative, therefore convergent

**PROCESS CONTROL
FALL 2021**

Title of Assignment: Partial Exam I

TOPICS COVERED IN Partial Exam I

1. Derivation of Transient Equations

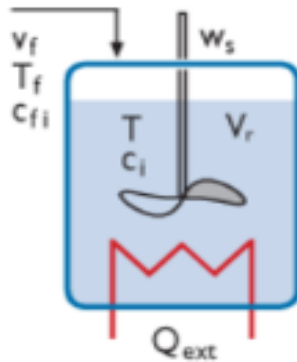
CHEG 4303

Process Control

1st Test A

- 1). Derive the transient model equations for filling a tank. Use: total mass balance (L). All parameters are constant.
- 2). Derive the transient model equations for a semi-batch reactor with a first order reaction, $A \rightarrow \text{Product}$. Use: mass balance for limiting reactant A (C_A).

Semi-batch reactor has only one input and no output. See diagram below, C_{fi} = input of the i-species, A in this case. Be careful that V_r changes with time. It is NOT constant.



ABOVE AVERAGE

the equation becomes

$$\dot{V}C_a^{in} - k C_a V_R = \frac{d(C_a \cdot V_R)}{dt} = V_R \frac{dC_a}{dt}$$

$$\dot{V}C_a^o - k C_a V_R = V_R \frac{dC_a}{dt}$$

because V_R changes with time our general equation is

$$\dot{V}C_a^o - k C_a \frac{dV_R}{dt} = \frac{d(C_a \cdot V_R)}{dt}$$



We also know that

$$P = P_{in} = P_{out}$$

then

$$\frac{dL}{dt} = \frac{A}{A_s} (\dot{V}_{in} - \dot{V}_{out})$$

2) the mass balance equation is

In - out + generation = Accumulation

For a semi-batch reactor there is one input and no output



then:

In + generation = Accumulation

$$\dot{n}_{Ain} + R_A V_R = \frac{dn_A}{dt}$$

we know that $\dot{n}_A = V C_A$

$$R_A V_R = -k C_A \cdot V_R$$

Mohamed Nabil Alkinocho

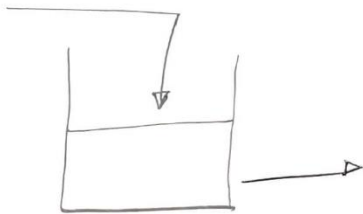
CHEG 4303

Process Control

1st Test A

10

1)



Property: mass of Water
System: the TANK
Process: Continuous

In - out + ~~generation~~⁰ = Accumulation

⇒ In - out = Accumulation

$$\Rightarrow \dot{m}_{in} - \dot{m}_{out} = \frac{dm}{dt} = \rho \frac{dV}{dt} = \rho A_s \frac{dL}{dt}$$

We know that $\rho = \frac{m}{V} \Rightarrow m = \rho \cdot V$ then the equation becomes

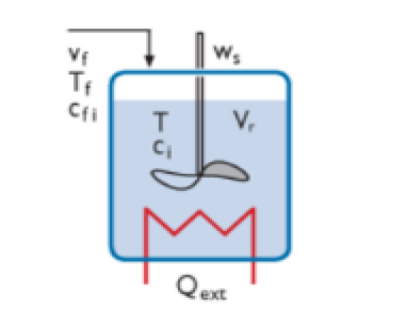
$$\rho_{in} V_{in} - \rho_{out} V_{out} = \rho A_s \frac{dL}{dt}$$

✓ 4

CHEG 4303
Process Control
1st Test A

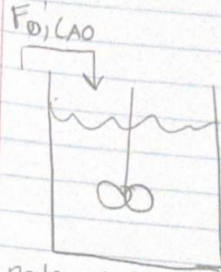
- 1). Derive the transient model equations for filling a tank. Use: total mass balance (L). All parameters are constant.

- 2). Derive the transient model equations for a semi-batch reactor with a first order reaction, $A \rightarrow \text{Product}$. Use: mass balance for limiting reactant A (C_A).
Semi-batch reactor has only one input and no output. See diagram below, C_{fi} = input of the i-species, A in this case. Be careful that V_r changes with time. It is NOT constant.



AVERAGE

2.



$n_A = \text{moles of A}$

mass in - mass out + gen = acc

$$V_0 - V = A \frac{dh}{dt}$$

rate inlet - rate outlet + rate gen = rate of accumulation

$$F_0 C_{A0} - F C_A - k C_A^2 V = \frac{d}{dt}$$

$$F_0 C_{A0} - F C_A - k C_A^2 V = V \frac{dC_A}{dt} + C_A \frac{dV}{dt}$$

$$F_0 (C_{A0} - C_A) - k C_A^2 V = V \frac{dC_A}{dt}$$

$$\frac{F_0}{V} (C_{A0} - C_A) - k C_A^2 = \frac{dC_A}{dt}$$

Alexus Lovelace

Test C

1.



energy (T)
prop: $Q(T)$, $H(U)$

general balance: in-out + gen = acc

Q_h

$$Q_{in} - Q_{out} + Q_h = \frac{du}{dt} = \rho V c_p \frac{dT}{dt}$$

V = volumetric flow rate

ρ = density

c_p = specific heat

T = Temp

$$Q_h = h(A_s)(\Delta T)$$

$$V_{out}(\rho c_p)(T_{out}) - P(V_{in})(c_p)T + Q_h = m(c_p) \frac{dT}{dt}$$

$$P(V_{in})c_p T_{in} - P(V_{out})c_p(T_{out}) + Q_h(T_{out} - T) = m(c_p) \frac{dT}{dt}$$

$$\rho(c_p)(V_{out}(T_{out}) - V_{in}(T)) + h(A_s)(\Delta T) = m(c_p) \frac{dT}{dt}$$

CHEG 4303
Process Control
1st Test C

- 1). Derive the transient energy model equation (T), for a well-mixed tank. Use: energy balance and ALL possible heat transfer mechanisms.
- 2). Derive the transient model equations for a CSTR with a second order reaction, $A \rightarrow \text{Product}$. Use: mass balance (C_A) for limiting reactant A

BELOW AVERAGE

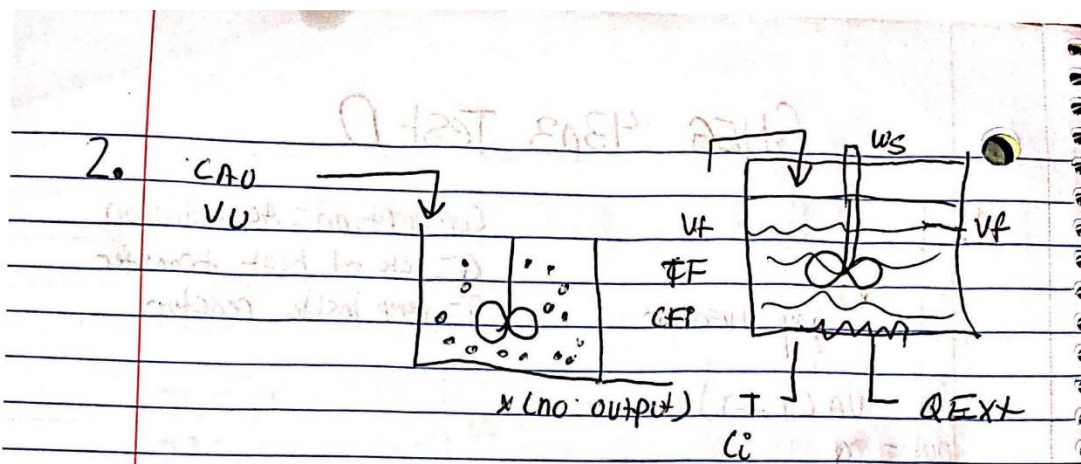
$$CA \cdot \int (k + t_1) dt = \int CA_0 e^{kt} dt + C$$

$$CA e^{kt} = \frac{CA_0}{k} e^{kt} + C$$

$$t=0; CA=0 \Rightarrow C = -CA_0/k$$

$$CA e^{kt} = \frac{CA_0}{k} e^{kt} - \frac{CA_0}{k} \neq \frac{CA_0}{k} (1 - e^{-kt})$$

$$CA = \frac{CA_0}{k} (1 - e^{-kt})$$



V = Volume of Reactor

A_0 = Initial concentration of species A

v_0 = Volumetric flow rate of A

C_A = Final

ρ = density

$$\text{Mole balance} = C_{A0} v_0 = \frac{d}{dt} (C_A \cdot V) + [(1 - r_A) \cdot V]$$

$$C_{A0} v_0 = C_A \frac{dV}{dt} + V \frac{dC_A}{dt} + k C_A \cdot V$$

Overall Mole balance

$$v_0 \rho - 0 = \frac{d}{dt} (\rho \cdot V)$$

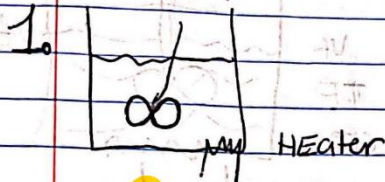
$$v_0 = \frac{dV}{dt} \quad \text{or} \quad v_0 \cdot t = V$$

$$\frac{C_{A0} \cdot v_0}{v} = \frac{C_A \cdot v_0}{v} + \frac{V}{v} \frac{dC_A}{dt} + k C_A$$

$$\frac{C_{A0}}{t} = \frac{C_A}{t} + \frac{dC_A}{dt} + k C_A$$

$$\frac{C_{A0}}{t} = \frac{dC_A}{dt} + C_A (k + 1/t)$$

CHEG 4303 Test D



Consumption = Accumulation

Q = rate of heat transfer

T = temp inside reactor

$$In - VA(T_H - T)$$

$$Out - Q$$

$$Generation = \Delta H_r C_{A0} X_A$$

$\Delta H_r \rightarrow$ heat reaction

$$Consumption = (0)$$

$$Accumulation = V c_p \frac{dT}{dt}$$

$V \rightarrow$ volume of reactor

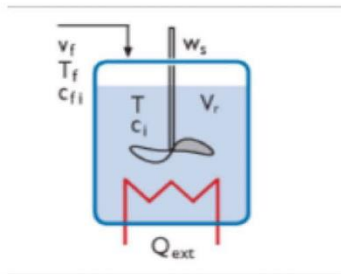
$$VA(T_H - T) + \Delta H_r C_{A0} X_A - Q = V c_p \frac{dT}{dt}$$

c_p = specific heat in reactor

$$V c_p \frac{dT}{dt} = VA(T_H - T) + \Delta H_r C_{A0} X_A - Q$$

CHEG 4303
Process Control
1st Test D

- 1). Derive the model energy equation (T), for a batch reactor with a first order reaction, $A \rightarrow \text{Product}$. Use: energy generated by, a chemical reaction, a heater, and heat transfer to the outside.
- 2). Derive the transient model equations for a semi-batch reactor with a first order reaction, $A \rightarrow \text{Product}$. Use: mass balance for limiting reactant A (C_A).
Semi-batch reactor has only one input and no output. See diagram below, C_{fi} = input of the i-species, A in this case. Be careful that V_r changes with time. It is NOT constant.



PROCESS CONTROL
FALL 2021

Title of Assignment: Partial Exam II

TOPICS COVERED IN Partial Exam II

- 1. Laplace Transform**
- 2. System Transient Behavior**

CHEG 4303
2nd Test A

1). Calculate the Laplace equivalent of the following equation:

$$\tau_p \frac{d^2 T}{dt^2} = (u_1 - T) + A \frac{du_1}{dt},$$

where T is the output variable, A, B, and τ_p are constants and u_1 is the deviation variable.

2). In a previous problem the following system transfer function has been obtained:

$Y(s) = 2 / (4 s^2 + 4 s + 1) U(s)$. The system responds to a positive pulse disturbance ($U(s) = 1$).

a). Comment on short time behavior.

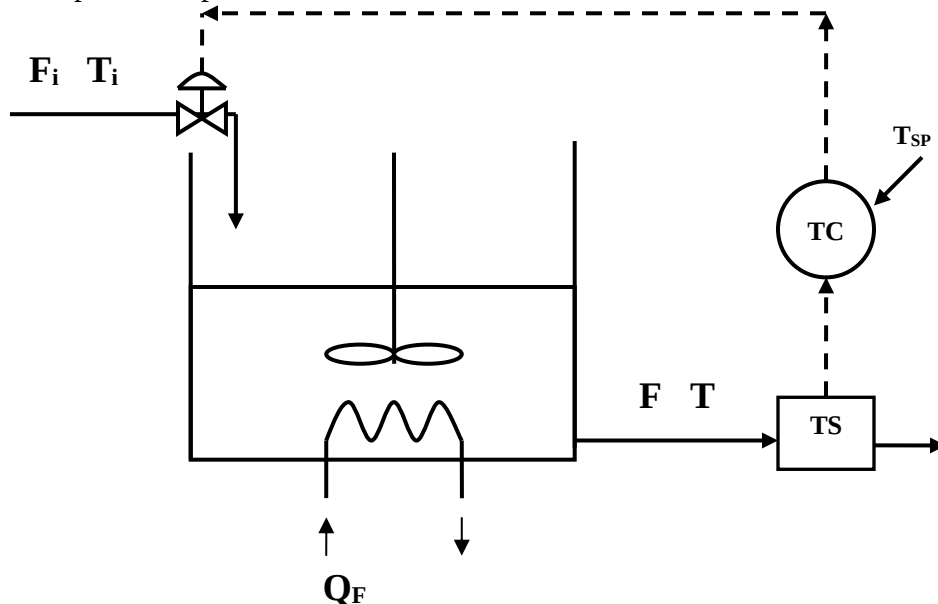
b). Will the system oscillate?

c). Will the system response be stable?

d). Which is the value of the system long time response? Same for short time.

Justify all your answers.

3). Derive the appropriate control block flow diagram using the attached P&I D. F_i is the manipulated input.



ABOVE AVERAGE

$$1) \quad \tau_p \frac{d^2 T}{dt^2} = (u_1 - T) + A \frac{du_1}{dt}$$

$$\Rightarrow \mathcal{L}\left[\tau_p \frac{d^2 T}{dt^2}\right] = \mathcal{L}[u_1 - T] + \mathcal{L}\left[A \frac{du_1}{dt}\right]$$

$$\Rightarrow \tau_p s^2 T(s) = u_1(s) - T(s) + A s u_1(s)$$

$$\Rightarrow T(s) = \frac{As + 1}{\tau_p s^2 + 1} u_1(s)$$

$$2) \quad Y(s) = \frac{2}{4s^2 + 4s + 1} U(s) \quad U(s) = 1$$

a, short time behavior: direct because the numerator 270.

b, The denominator function $4s^2 + 4s + 1 = (2s + 1)^2$ has a root $s = -\frac{1}{2}$

$\Rightarrow$ The system will NOT oscillate because s is real number

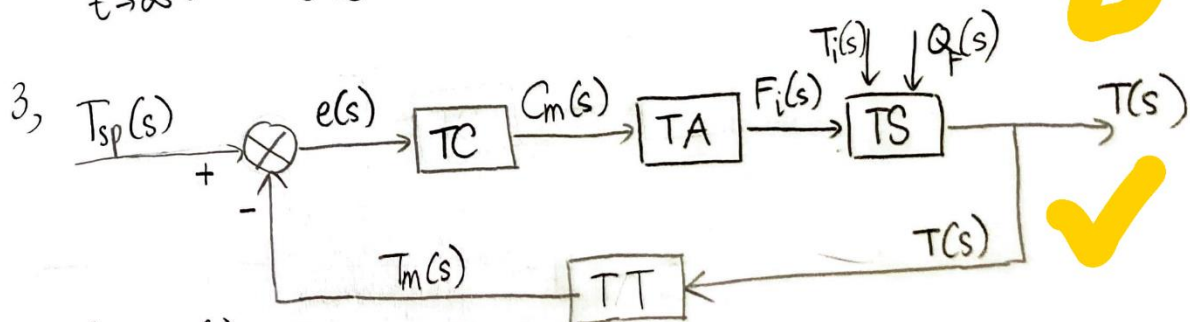
c, The system is stable because $s = -\frac{1}{2} < 0 \rightarrow$ convergent

d, short time respond

$$\lim_{t \rightarrow 0} f(t) = \lim_{s \rightarrow \infty} s Y(s) = \lim_{s \rightarrow \infty} \frac{2s}{4s^2 + 4s + 1} = \lim_{s \rightarrow \infty} \frac{2}{8s + 4} = 0$$

Long time respond

$$\lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} s Y(s) = \lim_{s \rightarrow 0} \frac{2s}{4s^2 + 4s + 1} = \lim_{s \rightarrow 0} \frac{2}{8s + 4} = \frac{1}{2}$$



$$\text{where } e(s) = T_{sp}(s) - T_m(s)$$

AVERAGE

2nd Test E

① Calculate the Laplace:

$$\gamma_p d^2T/dt^2 + A dT/dt = (U_1 - T) \cdot B du/dt$$

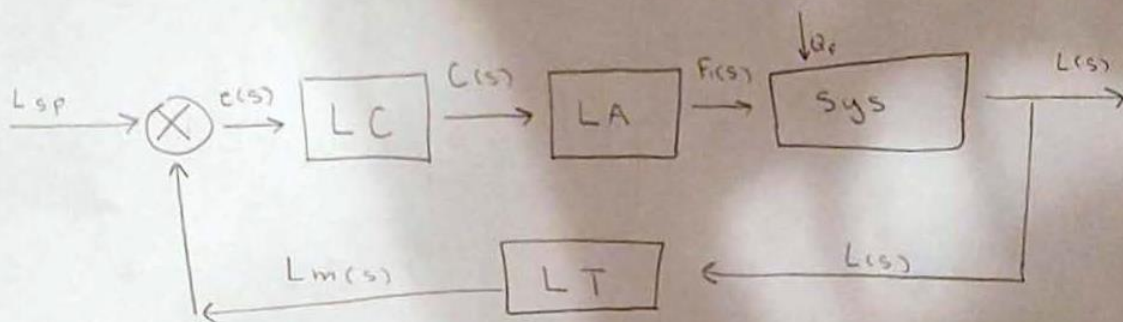
$$\mathcal{L}\{\gamma_p d^2T/dt^2\} + \mathcal{L}\{A dT/dt\} = \mathcal{L}\{U_1 - T\} + \mathcal{L}\{B du/dt\}; \text{factor out constants:}$$

$$\gamma_p \mathcal{L}\{d^2T/dt^2\} + A \mathcal{L}\{dT/dt\} = \mathcal{L}\{U_1\} - \mathcal{L}\{T\} + B \mathcal{L}\{du/dt\}; \text{solve Laplace}$$

$$\gamma_p s^2 T(s) + A s T(s) = U_1(s) - T(s) + B s U(s)$$

$$T(s) + \gamma_p s^2 T(s) + A s T(s) = U_1(s) + B s U(s) \rightarrow \boxed{T(s) = (1 + \gamma_p s^2 + A s) \cdot U(s) / (1 + B s)}$$

②



③ $Y(s) = (2s+1)/(2s^2+4s+1)U(s)$, Positive step disturbance ($U(s) = 1/s$)

a. short term behavior

- the short term behavior is direct ($s > 0$ when $\lim_{s \rightarrow 0} sY(s) \neq 0$)

b. will the system oscillate

$$- \frac{B \pm \sqrt{B^2 - 4AC}}{2A}; \frac{-4 \pm \sqrt{4^2 - 4(2)(1)}}{2(2)} = \frac{-4 \pm \sqrt{9}}{4} = \frac{-4 \pm 2\sqrt{2}}{4} \text{ ER}$$

monotonic, non oscillatory

c. stable?

The system response will be stable. All values of s ER

cl. long time value? long time: ($\lim_{s \rightarrow 0} sY(s)$)

$$2(0) + 1 = 1$$

long time value = 1

BELOW AVERAGE

6

$$1. \quad \mathcal{L}_p \left[\frac{d^2 T}{dt^2} \right] = (u_1 - T) + A \frac{du_1}{dt}$$

$$\mathcal{L}_p \left[\frac{d^2 T}{dt^2} \right] = \mathcal{L}(u_1 - T) + A \mathcal{L} \left[\frac{du_1}{dt} \right]$$

$$\mathcal{L} \left[\frac{d^2 T}{dt^2} \right] = s^2 T(s) - sT(0) - T'(0)$$

$$\mathcal{L} \left[\frac{d^2 f(t)}{dt^2} \right] = s^2 f(s) - sf'(0) - f'(0)$$

$$\mathcal{L} \left(\frac{du_1}{dt} \right) = su_1(s) - u_1(0)$$

$$\mathcal{L} \left[\frac{df(t)}{dt} \right] = sf'(s) - f(0)$$

$$\Rightarrow \mathcal{L}_p \left[\frac{d^2 T}{dt^2} \right] = \mathcal{L}(u_1 - T) + A \mathcal{L} \left[\frac{du_1}{dt} \right]$$

$$\mathcal{L}_p [s^2 T(s)] = u_1(s) - T(s) + A [su_1(s)]$$

$$\mathcal{L}_p s^2 T(s) + T(s) = u_1(s) + A s u_1(s)$$

$$T(s) [\mathcal{L}_p s^2 + 1] = u_1(s) [1 + A s]$$

$$\frac{T(s)}{u_1(s)} \rightarrow \boxed{\frac{1 + A s}{1 + \mathcal{L}_p s^2}}$$

$$2. \quad y(s) = \frac{2}{(4s^2 + 4s + 1)} \quad u(s) = 1$$

$$u(s) = 1$$

$$y(s) = \frac{2}{4s^2 + 4s + 1} \rightarrow \frac{1}{2} \cdot \frac{1}{(s + \frac{1}{2})^2}$$

$$L^{-1} \left(\frac{1}{2} \cdot \frac{1}{(s + \frac{1}{2})^2} \right)$$

$$\frac{1}{2} L^{-1} \left(\frac{1}{(s + \frac{1}{2})^2} \right) \rightarrow L^{-1} \left[\frac{1}{(s + \frac{1}{2})^2} \right] \rightarrow \frac{1}{2} e^{-\frac{1}{2}t} +$$

A. Short term behavior
initial value theorem

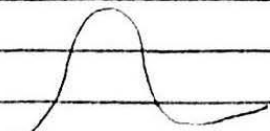
Direct

$$\lim_{t \rightarrow 0} y(t) = \lim_{s \rightarrow \infty} s f(s)$$

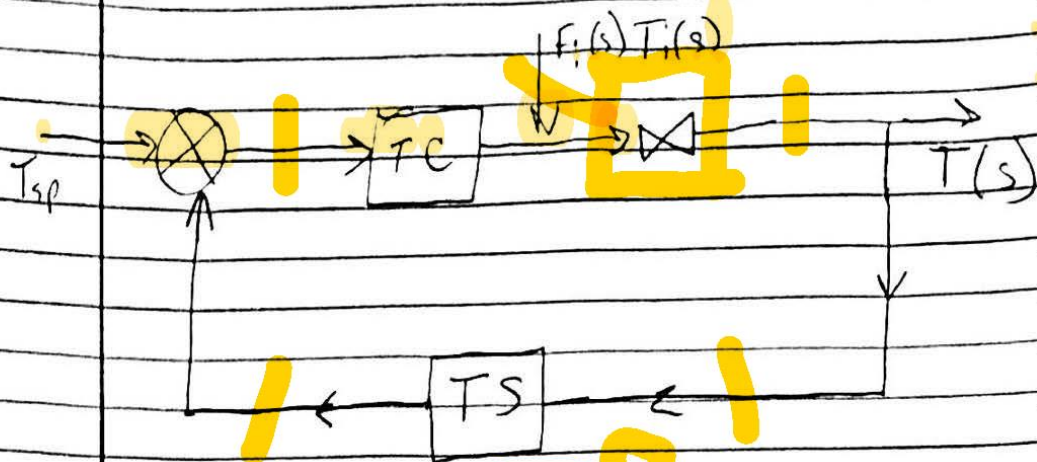
$$y(0) = \lim_{s \rightarrow \infty} \frac{s(2)}{s(4s^2 + 4s + 1)}$$

$$= 0$$

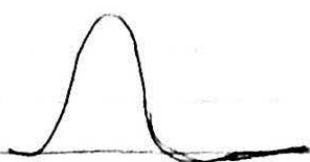
B. No it will not oscillate
it will increase and then decrease



3. Deriving control block flow diagram



C. Yes it will be stable as it goes to a point



D. Long time response
use final value theorem

$$\lim_{t \rightarrow \infty} y(t) = \lim_{s \rightarrow 0} s f(s)$$

$$y(\infty) = \lim_{s \rightarrow 0} \frac{s(2)}{s(4s^2 + 4s + 1)} = 0$$

Short time response
use initial value theorem

$$\lim_{t \rightarrow 0} y(t) = \lim_{s \rightarrow \infty} s f(s)$$

$$y(0) = \lim_{s \rightarrow \infty} \frac{s(2)}{s(4s^2 + 4s + 1)} = 0$$

**PROCESS CONTROL
FALL 2021**

Title of Assignment: Partial Exam III

TOPICS COVERED IN Partial Exam III

- 1. PID Controllers**
- 2. Closed Feedback Loops**

PROCESS CONTROL
FALL 2021

Problem Statement for Partial Exam III

CHEG 4303
Process Control
3rd Exam A

1). Calculate for the simplified two block (process and controller) block diagram the response to a negative step change ($-2/s$) if the controller is a PI. Calculate the long term value. Plot the response.

Use: $G_{ca}(s) = (0.5/s + 1)$, $G_{sys}(s) = 2 / (5s + 1)$.

2). Calculate the qualitative behavior of a closed control loop that has the following roots:

Zeroths (top): $z_1 = -0.5$, $z_2 = -0.2$,

Poles (bottom): $p_1 = -1$, p_2 and p_3 are complex numbers with **real part** = -2 and imaginary parts = 3 and -3 , respectively. Justify and plot the response.

ABOVE AVERAGE

Dynamic behavior

Top: $s = -\frac{1}{0.5} = -2 < 0 \rightarrow \text{direct}$ ✓

Bottom: $s = -\frac{2}{2.5} = -0.8 \in \mathbb{R} \rightarrow \text{monotonic}$ ✓
 $-0.8 < 0 \rightarrow \text{convergent}$ ✓

Response to step $= -\frac{1}{s}$, long-term

$$\begin{aligned}\lim_{t \rightarrow \infty} f(t) &= \lim_{s \rightarrow 0} sY(s) = \lim_{s \rightarrow 0} s \cdot \left(\frac{1+0.5s}{2+2.5s} \right) \left(-\frac{1}{s} \right) \\ &= \lim_{s \rightarrow 0} - \left(\frac{1+0.5s}{2+2.5s} \right) \\ &= -\frac{1}{2}\end{aligned}$$
 ✓

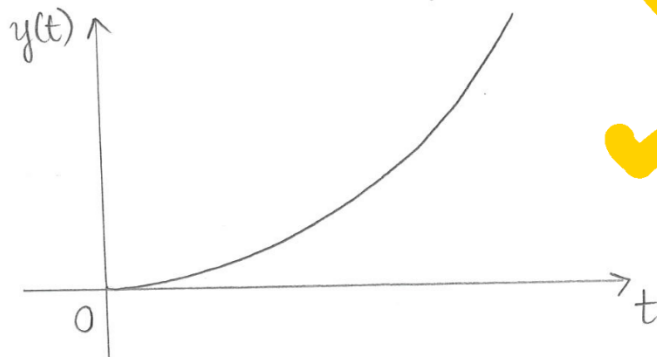
① Top : $z_1 = -0.5$, $z_2 = -0.2$ ✓

$z_1, z_2 < 0 \rightarrow$ direct

Bottom : $p_1 = -1$, $p_2 = -0.5$, $p_3 = 0.5$

$p_1, p_2, p_3 \in \mathbb{R} \rightarrow$ monotonic ✓

$p_3 > 0 \rightarrow$ divergent ✓



② $G_{sys}(s) = \frac{1}{2s+1}$

a, PD controller , $G_{CA}(s) = 1+0.5s$

$G_{sys}(s) G_{CA}(s) = \frac{1+0.5s}{1+2s}$ ✓

$$G_{total} = \frac{G_{CA}(s) G_{sys}(s)}{1 + G_{CA}(s) G_{sys}(s)} = \frac{\frac{1+0.5s}{1+2s}}{1 + \frac{1+0.5s}{1+2s}} = \frac{1+0.5s}{1+2s+1+0.5s}$$

$G_{total} = \frac{1+0.5s}{2+2.5s}$ ✓

CHEG 4303
Process Control
3rd Exam D

10

- 1). Calculate the qualitative behavior of a closed control loop that has the following roots:
Zeroths (top): $z1 = -0.5$, $z2 = -0.2$, Poles (bottom): $p1 = -1$, $p2 = -0.5$, $p3 = 0.5$.
Justify and plot the response.
- 2). A system is described by the following transfer function, $G_{sys}(s) = 1 / (2s + 1)$.
 - a). Describe the dynamic behavior of the system for a PD controller, $G_{CA}(s) = 1 + 0.5s$.
 - b). Calculate the long-term behavior for a step $= -1/s$.

AVERAGE

Jarred Essisima

Exam 3-E

2 Calculate the qualitative behavior of closed loop:

(a) short-term Behavior

Top: $z_1 = -0.5$, $z_2 = 0.2$

bottom: $p_1 = -1$

Reverse

$p_2 = (-2, 3)$

$p_3 = (-2, -3)$

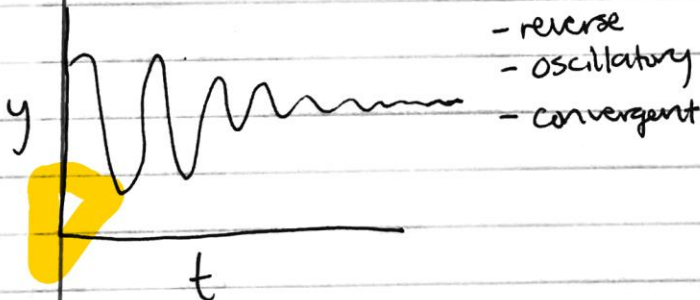
real
imaginary

(b) Oscillatory $\begin{pmatrix} -2 \\ -2 \end{pmatrix}, 3$ Functional Behavior of the
 $\begin{pmatrix} -2 \\ -2 \end{pmatrix}, -3$ output response.

(c) $-2 < 0 \Rightarrow$ Convergent

Long-term
Behavior

Plot



values? Long term + Short Term

$$U(s) = \frac{1}{s} \text{ Step of value}$$

$$= s \times G_{\text{total}} \times \overline{U}(s) =$$

$$= \cancel{s} \times \left[\frac{\frac{2}{\cancel{s}} + \cancel{1}s + 2}{6s + \frac{2}{\cancel{s}} + 3} \right] \times \frac{1}{\cancel{s}} = \boxed{\frac{\frac{2}{s} + 1s + 2}{6s + \frac{2}{s} + 3}}$$

$$\text{long term lim} \quad s \rightarrow 0 \quad \frac{\frac{2}{\cancel{s}} + \cancel{1}s + 2}{6s + \frac{2}{\cancel{s}} + 3} = \boxed{\frac{2}{3}} \quad \text{long term value} \quad \checkmark$$

$s=0$

a) Direct / Reverse

Dynamic response

$$G_{CA} = (1/s + 0.5s + 1) \rightarrow \text{Direct}$$

- Constant; no root
- positive

b) real root

$$\text{Denominator} = s + 1 = 0$$

$$\frac{s}{s} = \frac{-1}{-1}$$

$$s = -1$$

real root

= monotonic
or
Non-oscillatory

c) convergent + Divergent

$s < 0$ (All) $\Rightarrow$ convergent (Stable)

Plot

Direct, monotonic, convergence



$$(1) G_{total} = \frac{G_{CA} G_{sys}}{1 + G_{CA} G_{sys}}$$

Calculate for simple
2 block diagram
- response
- long term value

$$G_{CA} = (1/s + 0.5s + 1) \quad \text{--- } (K_P) \quad (K_{sys})$$

$$G_{sys} = 2 / (s + 1) \quad \text{or} \quad \frac{2}{(s + 1)} \quad (T_{sys})$$

a) Dynamic Behavior
- closed control loop
- use G_{total}

$$1) G_{CA} \times G_{sys} = (1/s + 0.5s + 1) \times \left(\frac{2}{(s + 1)} \right)$$

$$= \frac{\frac{2}{s} + 1s + 2}{(s + 1)}$$

$$G_{Total} = \frac{\frac{2}{s} + 1s + 2}{s + 1}$$

$$\frac{(s + 1)}{(s + 1)} \times 1 + \frac{\frac{2}{s} + 1s + 2}{s + 1}$$

$$\frac{\frac{2}{s} + 1s + 2}{s + 1}$$

$$\frac{s + 1 + \frac{2}{s} + 1s + 2}{s + 1} \quad [G_{Total}]$$

$$= \frac{\frac{2}{s} + 1s + 2}{s + 1 + \frac{2}{s} + 1s + 2} = \left[\frac{\frac{2}{s} + 1s + 2}{6s + \frac{2}{s} + 3} \right]$$

BELOW AVERAGE

Alexus Lovelace

Test 3 C

① $G_{sys}(s) = \frac{1}{(2s+1)}$ PI controller $G_{ref}(s) = \frac{(s+1)}{s}$

a) dynamic behavior of two-box loop

$$G_{total} = \frac{G_{ref} G_{sys}}{1 + G_{ref} G_{sys}} \quad G_{ref}(s) = \frac{(s+1)}{s} \left(\frac{1}{2s+1} \right)$$
$$= \frac{\frac{s+1}{s} \cdot \frac{1}{2s+1}}{1 + \frac{s+1}{s} \cdot \frac{1}{2s+1}} = \frac{\frac{s+1}{s(2s+1)}}{\frac{s(2s+1) + (s+1)}{s(2s+1)}} = \frac{s+1}{2s^2 + s + 1}$$

$$= \frac{s+1}{2s^2 + s + 1} = \frac{1}{2s+1} = G_{total} @ \text{direct / noise} = 1 = \text{constant}$$

170 Direct

② convergent $s < 0$ stable ③ mono / ocs.

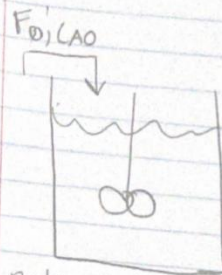
divergent if $s > 0$ unstable $2s+1 = 0 \quad s = -1/2$
monotonic

b) long term value for pulse = 1

$$\lim_{s \rightarrow 0} \left| \lim_{s \rightarrow 0} \frac{sY(s)}{\text{output}} = s G_{total}(U(s)) = \frac{1}{s} \right|$$

$$\lim_{s \rightarrow 0} = s \left(\frac{1}{2s+1} \right) \times \left(\frac{1}{s} \right) = \frac{1}{2s+1} = \frac{1}{2(0)+1} = 1$$
$$= s \left(\frac{1}{2s+1} \right) (1) = s \left(\frac{1}{2s+1} \right) = \frac{s}{2s+1} = 0$$

2.



$n_A = \text{moles of A}$

mass in - mass out + gen = acc

$$\begin{aligned} r_A &= -K C_A^2 \\ (-r_A) &= K C_A^2 \\ -(-r_A) &= -K C_A^2 \end{aligned}$$

$$V_0 - V = A \frac{dh}{dt}$$

Rate inlet - rate outlet + rate gen = rate of accumulation

$$F_0 C_{A0} - F C_A - K C_A^2 V = \frac{d}{dt}$$

$$F_0 C_{A0} - F C_A - K C_A^2 V = V \frac{dC_A}{dt} + C_A \frac{dV}{dt}$$

$$F_0 (C_{A0} - C_A) - K C_A^2 V = V \frac{dC_A}{dt}$$

$$\frac{F_0}{V} (C_{A0} - C_A) - K C_A^2 = \frac{dC_A}{dt}$$

Alexus Lovecare

Test 3 c

② Qualitative behavior closed control loop

$z_1 = -0.5$ } Direct
 $z_2 = -0.2$ }

poles: $p_1 = -1$ $p_2 = -0.5$ $p_3 = 0.2$

$$Y(s) = T.F(s) U(s)$$

monotonic

osc = complex roots

$K_p > 0$ Direct

Real #s

$s_1 = -1$

$s_2 = -0.5$

$s_3 = 0.2$

2 real parts are negative (divergent)

$$\begin{aligned} TF(s) &= \frac{K_p}{\tau s + 1} = \frac{(s - z_1)(s - z_2)}{(s - p_1)(s - p_2)(s - p_3)} \\ &= \frac{s - (-0.5)(s - (-0.2))}{(s - (-1))(s - (-0.5))(s - 0.2)} \\ &= \frac{1.5s + 0.1}{s^2 + 1.3s - 0.1} \end{aligned}$$

**PROCESS CONTROL
FALL 2021**

Title of Assignment: Final Exam

TOPICS COVERED IN Final Exam

- 1. Transient Equations Derivation**
- 2. Laplace Transform**
- 3. Dynamic Behavior**
- 4. Feedback Closed-Loop**
- 5. Dynamic Behavior**

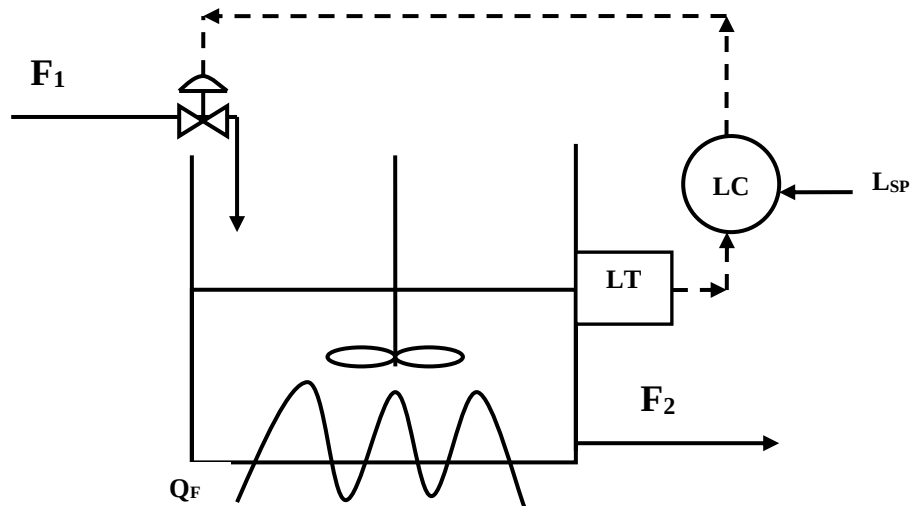
PROCESS CONTROL FALL 2021

Final Exam Sample Questions

CHEG 4303 Process Control

Final A

- 1). Derive the transient model equations for a CSTR with a first order reaction, $A \rightarrow \text{Product}$. Use: mass balance for limiting reactant A (C_A).
- 2). Derive the appropriate control block flow diagram using the attached P&ID.



- 3). Calculate for the simplified two block (process and controller) block diagram the response to a negative step change ($-2/s$) if the controller is a PI. Calculate the long-term value. Plot the response. Use: $G_{ca}(s) = (1/s + 1)$, $G_{sys}(s) = 2/(4s + 1)$.
- 4). Calculate the qualitative behavior to a positive step ($1/s$) of a closed control loop that has the following transfer function: $G_{total}(s) = (s + 1)/(s^2 + s + 1)$. Justify and plot the response in a y vs t graph.

ABOVE AVERAGE

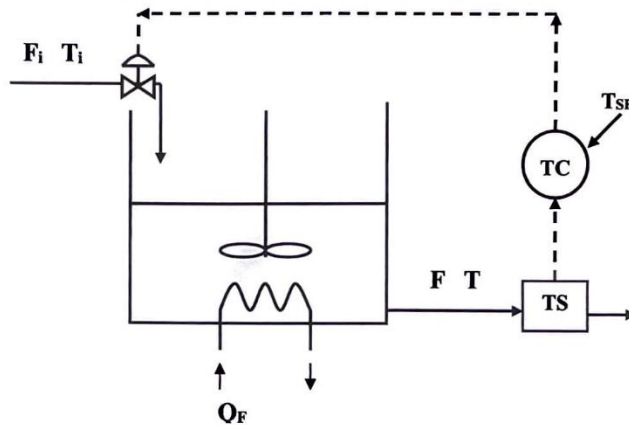
Mohamed NABIL AKINOTCHU

CHEG 4303
Process Control
Final B

- 1). Derive the model energy equation (T), for a CSTR reactor with a first order reaction, $A \rightarrow \text{Product}$.

Use: energy balance, energy generated by reaction, a heater, and heat transfer to the outside.

- 2). Derive the appropriate control block flow diagram using the attached P&ID.



- 3). Calculate the qualitative behavior to a positive step ($1/s$) of a closed control loop that has the following transfer function: $G_{\text{total}}(s) = (s - 1) / (s^2 + s + 1)$. Justify and plot the response in a y vs t graph.

- 4). A system is described by the following transfer function, $G_{\text{sys}}(s) = 2 / (3s + 1)$.
- Describe the dynamic behavior of the system.
 - Calculate the long-term value of the response to a step $= 1/s$.

3)

$$G_{\text{total}}(s) = \frac{s-1}{s^2+s+1}$$

a) Numerator

$s-1=0 \Rightarrow s=1$, because $s > 0$ the behavior is
Reverse ✓

b) Denominator polynomial

$$s^2+s+1=0$$

$$\Rightarrow s_1/s_2 = \frac{-1 \pm \sqrt{1-4}}{2} = \frac{-1 \pm \sqrt{-3}}{2}$$

$-3 < 0$ then the roots are complex numbers so the
 behavior is oscillatory ✓

c) the real part of both complex numbers solutions is $-\frac{1}{2} < 0$
 then the behavior is Convergent ✓

d) the short-term value is

$$\lim_{s \rightarrow \infty} s Y(s) = \lim_{s \rightarrow \infty} s \cdot G_{\text{total}}(s) \cdot U(s)$$

4) $G_{sys}(s) = \frac{2}{3s+1}$

a)

1) Numerator

$2 > 0$ (positive) then the behavior is Direct

2) Denominator

$$3s+1=0 \Rightarrow 3s=-1 \Rightarrow s=-\frac{1}{3}$$

$s = -\frac{1}{3} \in \mathbb{R}$ then the behavior is Monotonic

3) $s = -\frac{1}{3} < 0$, then the behavior is Convergent

b) the long-term value is with $u(s) = \frac{1}{s}$

$$\lim_{s \rightarrow 0} s \cdot Y(s) = \lim_{s \rightarrow 0} s \cdot G_{sys} \cdot u(s)$$

$$= \lim_{s \rightarrow 0} s \cdot \frac{2}{3s+1} \cdot \frac{1}{s} = \lim_{s \rightarrow 0} \frac{2}{3s+1}$$

$$\lim_{s \rightarrow \infty} s \cdot \frac{(s-1)}{s^2+s+1} \cdot \frac{1}{s} = \lim_{s \rightarrow \infty} \frac{s-1}{s^2+s+1} = \infty$$

e) long term value

$$\lim_{s \rightarrow 0} \frac{s-1}{s^2+s+1} = \boxed{-1}$$



3)

$$G_{\text{total}}(s) = \frac{s-1}{s^2+s+1}$$

a) Numerator

$s-1=0 \Rightarrow s=1$, because $s > 0$ the behavior is
Reverse ✓

b) Denominator polynomial

$$s^2+s+1=0$$

$$\Rightarrow s_1/s_2 = \frac{-1 \pm \sqrt{1-4}}{2} = \frac{-1 \pm \sqrt{-3}}{2}$$

$-3 < 0$ then the roots are complex numbers so the
 behavior is oscillatory ✓

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a)

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$s = -\frac{1}{3} \in \mathbb{R}$ then the behavior is Monotonic

3) $s = -\frac{1}{3} < 0$, then the behavior is Convergent

b) the long-term value is with $u(s) = \frac{1}{s}$

$$\lim_{s \rightarrow 0} s \cdot Y(s) = \lim_{s \rightarrow 0} s \cdot G_{sys} \cdot u(s)$$

$$= \lim_{s \rightarrow 0} s \cdot \frac{2}{3s+1} \cdot \frac{1}{s} = \lim_{s \rightarrow 0} \frac{2}{3s+1}$$

$$\lim_{s \rightarrow 0} \frac{2}{3s+1} = \lim_{s \rightarrow 0} \frac{2}{3(0)+1} = \boxed{2}$$

i) The model equations, energy, for a CSTR reactor with a first order reaction, $A \rightarrow \text{product}$

$$\text{In} - \text{out} + \text{generation} = \text{Accumulation}$$

$$\dot{H}_{in} - \dot{H}_{out} + \text{generation} = \text{Accumulation} = \frac{dU}{dt} = m \frac{du}{dt}$$

$$\Rightarrow \dot{m}_{in} h_{in} - \dot{m}_{out} h_{out} + \text{generation} = m \frac{du}{dt}$$

$$\Rightarrow \dot{m}_{in} C_p T_{in} - \dot{m}_{out} C_p T_{out} + \text{generation} = m C_p \frac{dT}{dt}$$

Generation = Enthalpy generation by chemical reaction + enthalpy generation by heat input + Enthalpy generation by heat exchange

chemical Reaction generation = $V_R R_A \Delta H_{\text{reaction}}$

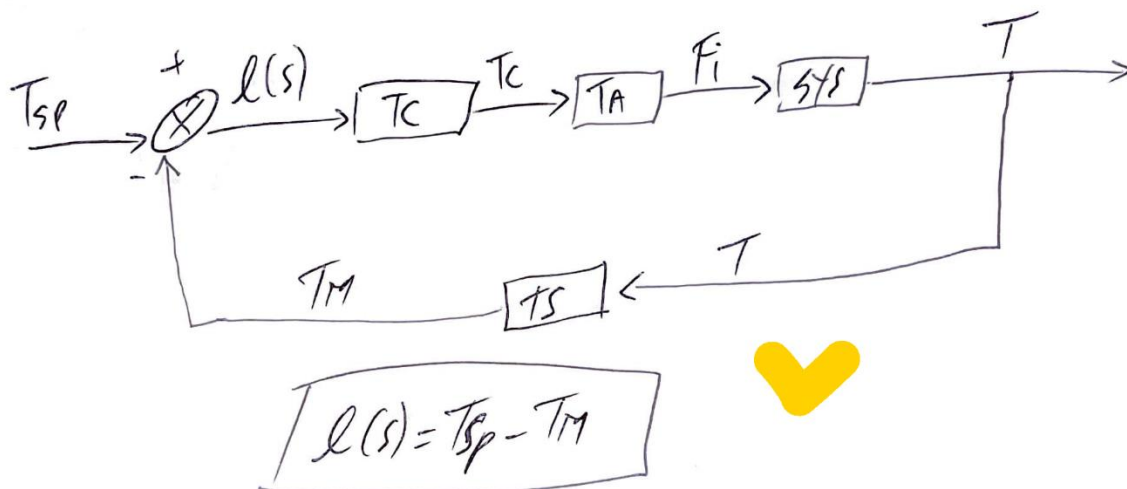
Generation by heat input = Q

Generation by heat Transfer with The Environment = $K_{HT} \cdot A_{HT} (T_{out} - T)$

* The Final equation is

$$\dot{m}_{in} C_{pin} T_{in} - \dot{m}_{out} C_{pout} \cdot T_{out} + V_R R_A \Delta H_{reaction} + Q + K_{HT} A_{HT} (T_{out} - T) = m C_w \frac{dT}{dt}$$

3)



AVERAGE

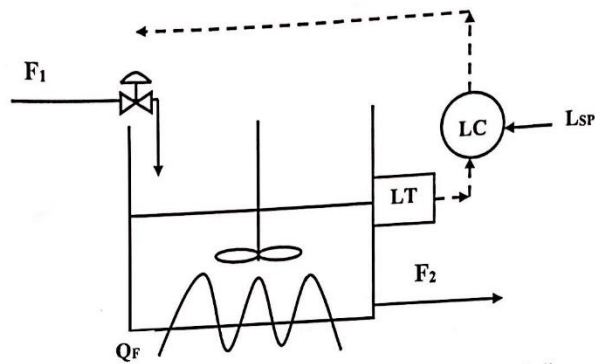
CHEG 4303 Process Control

Final D

1). Derive the model energy equation (T), for a CSTR reactor with a first order reaction, $A \rightarrow \text{Product}$.

Use: energy balance, energy generated by reaction, a heater, and heat transfer to the outside.

2). Derive the appropriate control block flow diagram using the attached PI&CD.



3). Calculate for the simplified two block (process and controller) block diagram the response to a positive step change (2/s) if the controller is a PI. Calculate the long-term value. Plot the response.
Use: $G_{ca}(s) = (2/s + 1)$, $G_{sys}(s) = 2/(3s + 1)$.

4). Calculate the qualitative behavior to a positive step (1/s) of a closed control loop that has the following transfer function: $G_{total}(s) = (s + 1)/(s^2 + 3s + 1)$. Justify and plot the response in a y vs t graph.

12/06 Final Exam

3) $G_{ca}(s) = (2/s + 1)$, $G_{sys}(s) = 2/(3s + 1)$

$$G_{ca} \cdot G_{sys} = \frac{2 \cdot 2}{(s+1)(3s+1)}$$

$$G_{ca} \cdot G_{sys} = \frac{4}{3s^2 + s + 3s + 1} = \frac{4}{3s^2 + 4s + 1}$$

$$G_{tot} = \frac{G_{ca} \cdot G_{sys}}{1 + G_{ca} \cdot G_{sys}}$$

$$= \frac{\frac{4}{3s^2 + 4s + 1}}{1 + \frac{4}{3s^2 + 4s + 1}}$$

$$= \frac{4}{3s^2 + 4s + 1 + 4}$$

$$G_{tot} = \frac{4}{3s^2 + 4s + 5}$$

a) Num: $4 > 0 \rightarrow$ Direct

b) Den: $s_1, s_2 = \frac{-4 \pm \sqrt{4^2 - 4(3)(5)}}{2(3)} = \frac{-4 \pm \sqrt{16 - 60}}{6}$ This would give a complex #

This is oscillatory since $b^2 < 4ac$; $16 < 60$

c) Both $< 0 \therefore$ convergence

Now we apply our positive step to find the long term value...

$$Y(s) = S \cdot G_{tot} \cdot U(s); U(s) = \frac{2}{s}$$

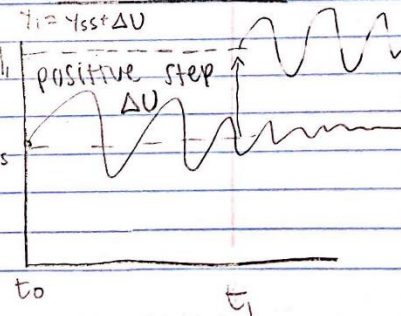
$$= S \cdot \frac{4}{3s^2 + 4s + 5} \cdot \frac{2}{s}$$

$$Y(s) = \frac{8}{3s^2 + 4s + 5}$$

Long term

$$\lim_{s \rightarrow 0} Y(s) = \frac{8}{3s^2 + 4s + 5} = \frac{8}{5}$$

Plotted response



$$4) G_{tot} = \frac{s+1}{(s^2+3s+1)}$$

$$Y(s) = S G_{tot} \cdot U(s)$$

$$= s \cdot \frac{s+1}{s^2+3s+1} \cdot \frac{1}{s}$$

$$Y(s) = \frac{s+1}{s^2+3s+1}$$

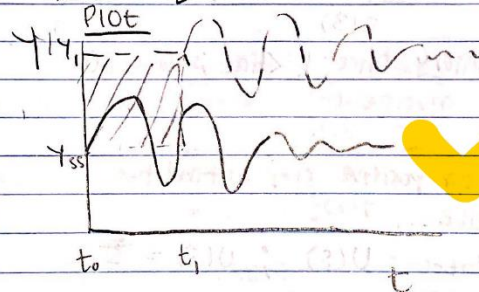
a) TOP: $s = 1 \rightarrow$ Direct

$$b) \text{Bottom: } s_{1,2} = \frac{-3 \pm \sqrt{9-4}}{2}$$

$$s_{1,2} = \frac{-3 \pm \sqrt{5}}{2} < 0$$

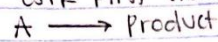
$\therefore$ oscillatory

$$c) s_{1,2} R = \frac{3}{2} < 0 \rightarrow \text{convergence}$$

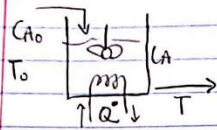


$$y_1 = y_{ss} + \Delta U$$

1) CSTR First order Reaction



Model Energy Equation



Property: H (Enthalpy)

Accountable term:

U (Internal Energy)

Process: Transient

General Equation

$$\text{In} - \text{Out} + \text{Gen.} = \text{Acc.} \quad \text{All terms remain}$$

- We can write the Enthalpy flows as mass flows times enthalpy per unit mass

$$\dot{m}_{in} h_{in} - \dot{m}_{out} h_{out} + \text{Gen.} = \text{Acc.} - \frac{dU}{dt} = m \frac{dU}{dt}$$

$$\dot{m}_{in} h_{in} - \dot{m}_{out} h_{out} + \text{Gen.} = m \frac{dU}{dt}$$

- Now we can plug in $h = C_p T$ & $U = C_v T$

$$\dot{m}_{in} C_p T_{in} - \dot{m}_{out} C_p T_{out} + \text{Gen.} = m C_v \frac{dT}{dt}$$

- We know in this case there will be three cases of generation

$$\text{Gen.} = \text{Gen. from Chem. rxn.} + \text{Gen. from Enthalpy}$$

Gen. by heat ex. w/ environment

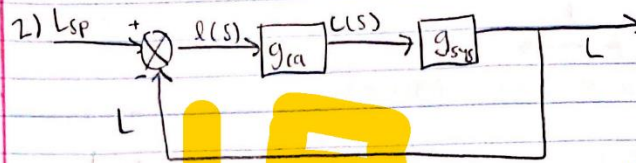
$$\therefore \text{Gen.} = (V r_p \Delta H_{rxn}) + \dot{Q} + K_{eff} A_{eff} (T_{out} - T)$$

And the final equation comes out to...

$$(\dot{m}_{in} - \dot{m}_{out}) + V r_p \Delta H_{rxn} + \dot{Q} + K_{eff} A_{eff} (T_{out} - T) = m C_v \frac{dT}{dt}$$

If the rate equation is known we can introduce

$$r_A = -k C_A$$



$$C(s) = G_{ca} e(s) \quad (1)$$

$$L = G_{sys} C(s) \quad (2)$$

$$e(s) = L_{sp} - L \quad (3)$$

Now we can manipulate these functions algebraically to find our transfer function

From Eq. 1

$$e(s) = \frac{C(s)}{G_{ca}} \quad \text{If we make substitutions using Eq. 2 we get ...}$$

$$e(s) = \frac{L}{G_{sys} \cdot G_{ca}} \Rightarrow L_{sp} = L + \frac{L}{G_{sys} \cdot G_{ca}} \quad \text{From Eq. 3}$$

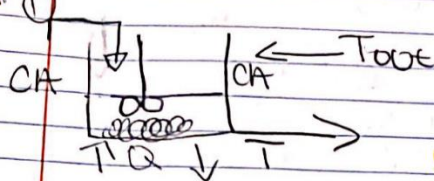
$$L_{sp} = L \left(1 + \frac{1}{G_{sys} G_{ca}} \right) \text{ or } = \frac{1 + G_{sys} \cdot G_{ca}}{G_{sys} \cdot G_{ca}}$$

$$\underbrace{L}_{\text{output}} = \frac{G_{sys} \cdot G_{ca}}{1 + G_{sys} G_{ca}} \cdot \underbrace{L_{sp}}_{\text{input}}$$

$\uparrow$
 T.F
 G_{tot}

BELOW AVERAGE

EXAM



Property: H energy terms should be U (internal energy)

Equation: $\dot{m} \dot{U} = \dot{Q} - \dot{W}$

$$\dot{m}_{in} \dot{U}_{in} - \dot{m}_{out} \dot{U}_{out} + \dot{Q} + \dot{W} = \frac{dU}{dt}$$

$$\frac{dU}{dt} = \dot{m} \dot{U} = \dot{m} \left(\frac{1}{2} v^2 + \frac{1}{2} \omega^2 + \frac{1}{2} \kappa^2 \right) + \dot{Q} + \dot{W}$$

- ② A: Solid = Direct, monotonic, Divergent
- B: Broken = Inverse, monotonic, Divergent
- C: Solid = Direct, Oscillatory, Convergent
- Broken = Reverse, Oscillatory, Convergent
- BUT Arg: Convergent (Oscillations Reduce)
- Inverse will die down eventually
- D: Solid = Reverse, monotonic, convergent
- Broken & Reverse, monotonic, convergent

$$\dot{Q}_{total} = \dot{Q}_{CA} \text{ (sys)}$$

$$\dot{Q}_{CA} = 0.5 \text{ STI KP}$$

$$\dot{Q}_{sys} = \frac{2}{s+1} \text{ 1st order}$$

$$\frac{0.5s+1(-\frac{2}{2s+1})}{1+0.5s+1(-\frac{2}{2s+1})}$$

$$\frac{0.5s+1 \cdot \frac{2}{2s+1}}{1+0.5s+1 \cdot \frac{2}{2s+1}}$$

$$u(s) = \frac{s+2}{2s+1+s+2} = \frac{s+2}{3s+3} = \frac{0.5s+2}{0.5s+2s+3}$$

$$\frac{s+2}{3(s+1)} \times \frac{1}{3} = \frac{1}{3} \left(\frac{s}{s+1} + \frac{2}{s+1} \right)$$

$$u(s) = \frac{1}{3} \left(\frac{1}{s+1} + 2 \cdot \frac{1}{s+1} - \frac{1}{s+1} \right) = \frac{2}{2s+3}$$

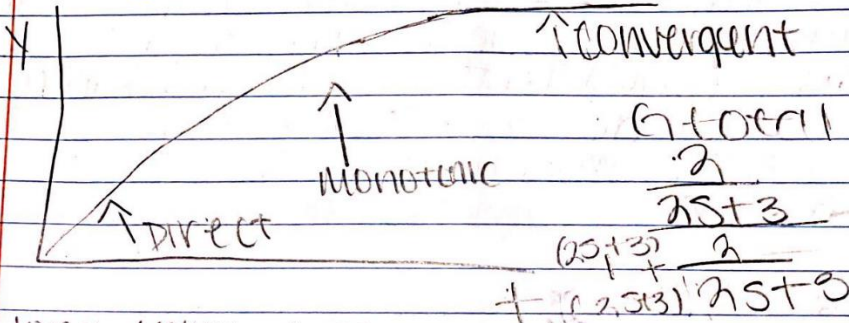
$$2s+3=0 \quad 2s=-3 \quad s=-\frac{3}{2}$$

NUMERATOR = 2

(B) The root is 'Real' (R) (monotonic) =

'constant value' which makes it Direct Because it's positive

(C) divergent



long term $\lim_{s \rightarrow 0}$

$$= \frac{2}{2s+3}$$

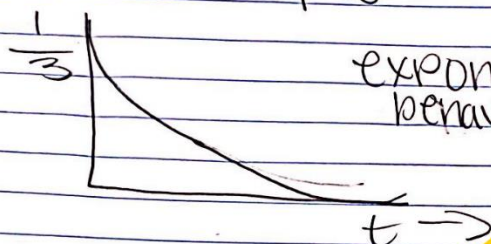
$$\frac{2}{2s+5}$$

(4) Equations used:

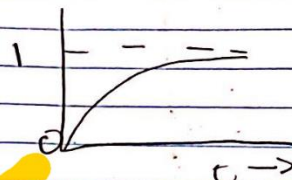
$$sX(s) + 1 \times U(s) = \frac{1}{3} \quad \text{1st order system}$$

$$G(s) = \frac{1}{3s+1}$$

$$U(s) = \frac{1}{3s+1} \quad \frac{1}{3} e^{-t/3}$$



exponential dynamic behavior

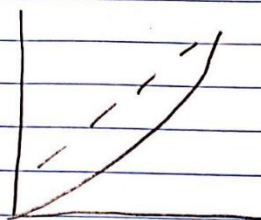


$$X(s) = \frac{1}{s^2}$$

$$Y(s) = \frac{1}{s^2(3s+1)}$$

$$y(t) = \mathcal{L}^{-1}(Y(s)) = t - 3 + 3e^{-t/3}$$

-2.5



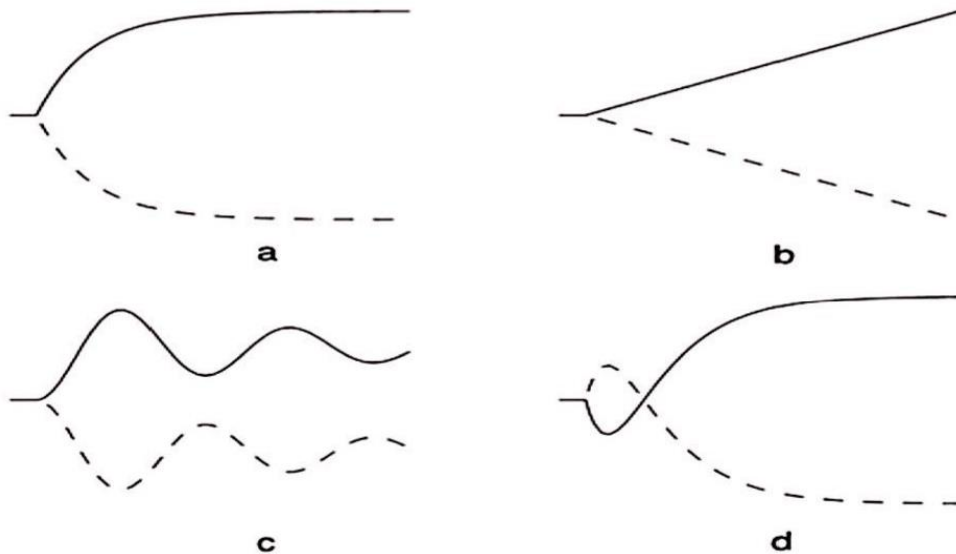
CHEG 4303

Process Control

Final C

- 1). Derive the model energy equation (T), for a CSTR reactor with a first order reaction, $A \rightarrow \text{Product}$. Use: energy balance, energy generated by reaction, a heater, and heat transfer to the outside.

- 2). Describe qualitatively the following dynamic responses to a step in the input variable:



Hint: Analyze response at short times, functional description, and convergence of the eight systems shown above, 4 given by solid lines (positive step) and 4 given by broken lines (negative steps).

- 3). Calculate for the simplified two block (process and controller) block diagram the dynamic response to a positive step change (1/s) if the controller is a PD. Calculate the long-term response. Plot the response.
Use: $G_{ca}(s) = (0.5s + 1)$, $G_{sys}(s) = 2 / (2s + 1)$

- 4). A system is described by the following transfer function, $G_{sys}(s) = 1 / (3s + 1)$.
 - a). Describe the dynamic behavior of the system.
 - b) Calculate the long-term value to a positive step (1/s).

